Review article

An Environmental Impact Assessment of the underground operations at the designed Petrikov potash mine, Belarus

Dmitry V. Barbikov¹, Anatoly M. Grechko², Vladimir V. Savchenko^{*2}, Anzhelika E. Zlebova²,
Dmitry M. Kurlovich², Siarhei F. Sauchy²

¹JSC "Belaruskali", Korzha Str. 5, 223710, Soligorsk, Minsk oblast, Belarus

²JSC "Belgorkhimprom", Masherova av. 17, 220029 Minsk, Belarus

E-mail address (*corresponding author): savchenko@tut.by

ABSTRACT

The Petrikov deposits of potash salt is situated in Gomel oblast of Belarus in the south-east of Pripyat Trough, and have Northern and Southern prospects. Underground mining of potash salt will start at the Northern prospect with an area of 166 km². It is expected that mining will last for between 50-80 years. An Environmental Impact Assessment (EIA) was carried out at the design stage of the Petrikov mining and processing plant. The standard EIA procedure included a set of investigations, including assessments of surface subsidence, changes in groundwater level, changes in productivity of forest phytocoenoses and crops, and assessment of groundwater pollution due to production of potash fertilizers. Maximum values of possible surface subsidence (up to 2.3 m) will occur within the area, where the surface will be affected by the mining of potash layers 1, 2, and 3 of the productive horizon IV-п, using a long-pillar mining system. Surface subsidence will influence surface topography, surface and groundwater, landscape structure and land resources. The result of surface subsidence will lead to inundation and swamping of land, as well as to an increase in the areas affected by annual floods in the valleys of the Pripyat and Bobrik rivers. Surface subsidence will affect the whole area of the prospect within the limits of planned mining fields, except the areas above safety pillars. In the result of raised groundwater levels the area with groundwater depth of more than 2 m will decrease from 69.1% to 17.8%, and the areas with groundwater depth from 3 to 5 m will disappear. The area with a groundwater depth less than 1 m will increase from 0.1% to 34.0%. In 19.5% of the area the groundwater level will raise above the surface level (the area of inundation). Surface subsidence and change in groundwater level will cause certain decreases in yields of timber and crops, and 2564 ha of forest, 68 ha of arable land and 324 ha of meadows will be inundated. In order to prevent inundation within certain areas protective engineering facilities have been designed, and an arrangement of groundwater monitoring wells has been proposed.

KEY WORDS: environmental impact assessment, potash deposits, surface subsidence, environmental pollution

ARTICLE HISTORY: received 15 March 2016; received in revised form 3 May 2016; accepted 26 May 2016

1. Introduction

The development of a new Petrikov potash deposit will start in the near future in Gomel oblast, Belarus (Fig. 1). It is planned to start mining at the Northern prospect of the deposit within the area of 166 km². The main target of mining is the potash salt horizon IV-п that occurs at the depth between 516 to 1386 m. The annual production of Petrikov mining and processing facilities will be 1.5 million tons of KCl. An Environmental Impact Assessment (EIA) was carried out at the design

stage of the mining and processing facilities at the Petrikov deposit. Standard EIA procedure included a set of investigations which assessed the impact of underground mining on the environment.

2. Geographical setting

The climate in the area of the Petrikov deposit is temperate, transitional from marine to continental. The territory of the deposit is situated in the western part of Pripyat artesian basin that is the area of regional discharge of groundwater-bearing

horizons and formations. Water-bearing horizons belong to the zone of intensive water exchange, they are hydraulically connected and drained by surface hydrological networks.

The surface hydrological network within the Northern prospect of Petrikov deposit belongs to the Pripyat river drainage area, which is the largest by area and discharge tributary of the river Dnieper. The surface hydrological network

within the EIA area includes the river Bobrik and amelioration channels and ditches with regulated discharge. The feed of the river and channels is mixed (snow, rain, and groundwater) with a predominance of snow-melt feed. Groundwater occurs at a depth of 0.6 - 3.3 m that corresponds to the absolute heights of 123.66 - 125.37 m. The groundwater is mainly free. The water-bearing rock is sand with varying grain sizes.

Fig. 1. General map of the Northern prospect of Petrikov potash deposit

In terms of geomorphology, the Northern permit of Petrikov deposit is situated in the area of the Polesie Lowland in Belarusian Polesie. The main geomorphological features were formed during the Dnieper stage of Pripyat Glaciation (JAKUSHKO ET AL., 2000). The topography forms flat lowlands with a general decline towards the rivers Pripyat and Bobrik valleys. Heights ASL range from 116.7 m (shore of Pripyat river in the town of Petrikov) to 150.0 m (hills in the south and south-east) (Fig. 2). Natural landscapes at the Northern prospect belong to the sub-boreal Polesie type. At present most of the previously natural landscapes altered due to human impact (agriculture, forestry, intensive amelioration) (MARTSYNKEVICH, 2005; NATIONAL ATLAS OF BELARUS, 2002).

The most serious environmental alterations within the area of the Petrikov deposit were caused by the large-scale amelioration campaign implemented in the 1960s. Lowering of groundwater level, deforestation, and ploughing of peat-bog soils has led to wind erosion, fast depletion of peat, and water deficit in soil in summer. Reclaimed peat-bogs were turned into arable land and hay meadows, which are in the "unstable" state with features of degradation. Large-scale reclamation and deforestation also caused exhaustion of fauna.

There are no nature reserves or monuments within the Northern prospect. Pripyatsky National park is situated 2 km to the south-west from the prospect. Several nature reserves and monuments of all-country and local significance are within the 30-km zone around the prospect (Fig. 3).

Fig. 2. Topography and surface hydrology of the study area under natural priorities (A) and after (B) impact of mining

It is planned to implement underground mining of potash at Petrikov deposit, in the same way as it has been done at Starobin potash deposit since the beginning of the 1960s. Based on the experience of mining at the similar Starobin potash deposit, underground mining may cause subsidence of the surface, the intensity of which depends on technical parameters of mining, and may be quite significant.

The peculiar feature of the Northern prospect of Petrikov deposit is the high level of groundwater. This can be a reason for inundation and swamping of vast areas, and significant changes in landscapes pattern as a result of underground mining. Based on this, assessment of possible magnitude of surface subsidence becomes the main target of EIA of mining and processing project at Petrikov potash deposit.

Fig. 3. Nature reserves and monuments within Petrikov potash deposit

3. Assessment of surface subsidence

The assessment of surface subsidence due to underground mining consists in evaluating of the maximum possible values of subsidence for certain geological and technical conditions of mining. These values are being used mainly to define permissible volumes of reserves to be mined under certain objects of infrastructure, as well as to select certain measures to protect such objects. Thus, these values are referred to as maximal ones, with no possibility to exceed them in reality. It should be noted that maximum possible values of subsidence are relevant for any point on the surface within the entire Northern prospect of the deposit, taking into account possible future changes in locations and shapes of underground excavations.

Because of the lack of necessary information on the surface subsidence rates, it is not expected to calculate exact value of future subsidence on the first stage of mining at Petrikov deposit. The rates of subsidence were calculated by analogy with those at Starobin potash deposit (GUIDELINES FOR PROTECTION..., 2001), although some specific conditions of Petrikov deposit were taken into account. In accordance with TEMPORARY METHODOLOGICAL GUIDELINES... (2013), calculation of possible deformations of land surface is being made as follows:

$$\eta = q_0 \cdot m \cdot K \quad (1)$$

where:

q_0 - relative magnitude of maximum subsidence;
 m - minable thickness;
 K - extraction coefficient.

Relative magnitude of maximum subsidence for the rocks of Petrikov deposit equals to 0.9. The value of the extraction coefficient K depends on methods of mining, and equals to 0.7 for board- and pillar mining, and to 0.5 - 0.6 for room- and pillar mining (depending on the area of mining). Border angles of displacement vary from 60° in Devonian rocks to 45° in younger rocks. Calculations were made for each mineable layer separately, and then added. This approach provides an evaluation of all possible maximal risks related to surface subsidence due to underground mining at Petrikov potash deposit.

According to calculations, maximum values of possible surface subsidence (up to 2.3 m) will occur within the area, where the surface will be effected by mining of potash layers 1, 2, and 3 of the productive horizon IV-п, using the long-pillar mining system (Fig. 4). Productive potash horizon VI-п occurs within most areas of Northern prospect, excluding western and south-western areas. The depth of the roof of horizon VI-п varies from 550 to 1442 m, and its thickness ranges from 0.35 to 3.52 m. Potash horizon VI-п consists of four sylvinite layers, separated by the layers of rock salt.

Fig. 4. Amplitude of land subsidence due to mining of potash horizon IV-п

Surface subsidence will significantly influence such components of the environment as relief, surface and groundwater, land resources, soil, etc. The result of surface subsidence will be not only inundation and swamping of land, but also widening of areas affected by annual floods in the valleys of the rivers Pripyat and Bobrik (Fig. 2). In general it is expected that surface subsidence will affect the whole area of the prospect within the limits of planned mining fields, except the areas

above safety pillars (Fig. 2). The maximum values of subsidence are expected within outwash and lacustrine-alluvial lowlands, as well as within the alluvial valley in the middle and lower reaches of the river Bobrik. The process will also involve a small area ($\sim 3 \text{ km}^2$) of the left-bank floodplain of River Pripyat. River Pripyat channel and most of the floodplain will not be affected by subsidence. Surface subsidence values will be up to 2.0 m to the east of the town of Petrikov (Fig. 5).

Fig. 5. Schematic map of the areas of possible inundation and under-flooding due to underground mining

4. Assessment of changes in groundwater level

Long-term monitoring of surface subsidence and changes in groundwater level due to underground mining at Starobin potash deposit allowed us to conclude that the absolute height of the groundwater level remains stable, nevertheless, the relative height of the groundwater level with respect to the land surface rises due to land surface subsidence. The same mechanism of change in land surface absolute heights and relative heights of groundwater level with respect to the land surface is expected at Petrikov deposit after the commencement of underground mining.

Due to underground mining the area of Northern prospect of Petrikov deposit will be affected by inundation, as well as intensive, moderate and gentle under-flooding. *The area of inundation*, within which the groundwater will flood the surface, will have an area of 32.6 km^2 (within the limits of influence of underground mining on the surface). This area is situated mainly in the centre of the

Northern prospect, and is covered now by forest (78.8%) and meadows (9.9%)(Fig. 5).

The area of intensive under-flooding (expected depth of groundwater will be between 0.01 and 0.5 m from the surface) contours the area of inundation. The area of this zone is 19.3 km^2 within the limits of influence of underground mining on the surface.

The area of moderate under-flooding (expected depth of groundwater will be between 0.5 and 1.5 m from the surface) is the most spacious one (54.2 km^2).

The area of gentle under-flooding (expected depth of groundwater will be between 1.5 and 2.5 m from the surface) is situated mainly on the edges of the zone of underground mining influence on the surface; it's area is 403 km^2 . The average expected rise in groundwater level within the area affected by underground mining will be 1.68 m, and the maximum raise will be 2.3 m. The areas zones with different expected depths of groundwater are listed in Table 1.

Table 1. The areas with different expected depths of groundwater

Depth of groundwater [m]	Area [ha]	
	Before a rise in groundwater level	After a rise in groundwater level
< 0	–	3238
0 – 1	22	5643
1– 2	5119	4780
2 – 3	6534	1845
>3	4939	1108

In the result of a rise in groundwater level the area with groundwater depth of more than 2 m will decrease from 69.1% to 17.8%, and the areas with groundwater depth from 3 to 5 m will disappear. The area with a groundwater depth less than 1 m will increase from 0.1 % to 34%. The vast area (19.5%) will appear, where the groundwater level will rise above the surface level (the area of inundation). The total area of land with groundwater depths 1-2 m (slight decrease from 30.8% to 28.8%), because the pattern of this area will be re-arranged over the area influenced by underground mining.

5. Assessment of changes in productivity of forest and agricultural phytocoenoses

The assessment of changes in productivity of forest phytocoenoses and crops within the areas affected by underground mining has been done using the method of Ministry of Environmental Protection of Belarus (RUSALENKO, 1999; MEEROVSKY, 1999).

The area of pine-tree forest will be affected by underground mining, of which 2 564 ha will be inundated. It is expected that over the rest of the affected area the depth of groundwater level will rise from 2.9 m to 1.4 m. This will result in a decrease in productivity of pine-tree timber from 11.51 to 9.46 m³/ha (by 2.05 m³/ha). Gross yield of timber in the affected forest area will decrease from 48 903 to 40 187 m³ (by 8720 m³).

The yield of different crops is being affected by groundwater with layer less than 2 m. The most significant changes in yield of crops occur if groundwater level changes in the depth interval from 0.4 to 1.2 m from the surface. Fluctuations in groundwater level within the depth 1.2-2.0 m do not affect yields directly, and changes in productivity depend more on the type of soil, because the root systems of many local species do not respond to excessive moisture in the soil deeper than 1.2 m from the surface.

Both arable land and meadows will be affected by the surface subsidence. Arable lands with a

total area of 68 ha will be inundated. For the rest of the arable land area, the level of groundwater will rise from 2.0 m to 0.7 m that will result in a decrease in yields of cereal crops from 29.11 to 25.77 center/ha (by 3.34 center/ha), and that of potato from 191.89 to 179.17 center/ha (by 12.72 center/ha). As a result, over the entire affected area the yield of cereal crops will decrease from 21 803 to 19 298 centers (by 2505 centers), and that of potato from 143 726 to 134 198 centers (by 9529 centers).

The total area of completely inundated meadows will be 324 ha. For the rest of the area of affected meadows the level of groundwater will rise from 2.2 to 0.7 m that will be favorable for a growth of perennial grasses, and will result in an increase in their yields from 29.05 to 30.68 center/ha (by 1.63 center/ha). Over the whole area moderately affected by subsidence meadows the expected yield of perennial grasses will increase from 26 436 to 27 922 centers (by 1487 centers).

It should be noted that natural ecosystems in River Pripyat valley within most of the area of northern prospect are well adapted to the annual high floods. The vegetation season here lasts from April till September. Therefore higher floods due to very slowly occurring land subsidence are not expected to be critical for the plant communities of floodplain and lower terraces of River Pripyat.

7. Conclusion

Mining at the Northern prospect of Petrikov potash deposit will last for about 50-80 years. It is expected that every year land subsidence will occur within a very limited area of about 3 km². Mining of potash salt at Petrikov deposit will cause a significant increase in the area of inundated and under-flooded lands that will require changes in forestry and agricultural practices. However, an expansion of inundated and under-flooded areas will occur slowly over the period of 50-80 years (1-2% increase per year), which will enable natural ecosystems to gradually adapt to new conditions.

The EIA allowed definition of the areas that will be inundated, severely under flooded or affected by annual floods due to surface subsidence. The protective engineering facilities have been designed, and arrangement of groundwater monitoring wells has been proposed. One of the most effective ways to mitigate surface subsidence due to underground mining is to use the backfilling system.

The decisions on re-arrangement of land use practices will include gradual transition of arable lands into meadows, and of meadows (if necessary) into bush lands within the areas affected by inundation and severe under-flooding. Also, the settlements pattern existing within the future mining area will be re-arranged.

References

Guidelines for protection of infrastructure and nature objects from unfavorable effects of underground mining at Starobin potash deposit. Soligorsk-Minsk, 2001 [in Russian].

- Jakushko O.Ph., Marina L.V., Emeljanov Ju.N. 2000. *Geomorphology of Belarus*. Belarusian State Univ., Minsk [in Russian].
- Martsynkevich G.I. 2005. *Landscape Science*. Belarusian State Univ., Minsk [in Russian].
- Meerovsky A.S. 1999. Assessment of changes in productivity of soils and important crops depending on changes in groundwater level. Collection of papers: *Multifunctional automated system of groundwater modeling and assessment of groundwater extraction impact on the environment*. CRIWR, Minsk: 101-107 [in Russian].
- National Atlas of Belarus*. Miasnikov M.Ul. (ed.), Committee on Land Resources, Geodesy and Mapping under the Council of Ministers of the Republic of Belarus, Minsk, 2002 [in Russian].
- Rusalenko A.I. 1999. Calculation of productivity and tax cost of timber of main forest species in Belarus. Collection of papers: *Multifunctional automated system of groundwater modeling and assessment of groundwater extraction impact on the environment*, CRIWR, Minsk: 94-100 [in Russian].
- Temporary methodical guidelines for calculation of parameters of displacement and possible deformation of land surface at Petrikov deposit with insufficiently studied character of deformation of rocks*. Minsk, 2013 [in Russian].