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Tools and criteria for regional environmental and geological monitoring of open-pit mines (Case of Volyn Polissya, NW Ukraine)

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SUMMARY

The article provides a comprehensive analysis of the potential environmental impact of open-pit mining of certain deposits of construction raw materials (on the example of the plain region of Volyn Polissya). Official project data on locations, areas and volumes of extraction are taken into account. The availability of tools and services for independent verification of mining development based on the analysis of remote sensing data is described separately. Examples of such analysis are given. A number of criteria for assessing the environmental impact of such developments on the geological environment are proposed, including the area and depth of development, production volumes, the presence or absence of groundwater disclosure and factors of their pollution, distances to the nearest vulnerable objects, etc. Based on this, a scoring scale was developed and applied to assess the relative risk of negative impact of mines on the environment in this region.

Introduction

The disturbance of natural landscapes by mining is a significant environmental problem, primarily due to the destruction of soil and vegetation cover, changes in the regime and pollution of surface and ground water, etc. To properly assess the scale of the problem and develop measures to eliminate it, high-quality environmental monitoring is necessary. However, its implementation is often complicated due to lack of material and human resources, institutional inconsistency, and difficulty of physical access. In addition, the assessment of potential impacts is highly dependent on the specific geological and landscape setting, so monitoring criteria may differ significantly in different regions.

Therefore, we decided to try to combine several assessment tools for one of the regions of Ukraine - Volyn Polissya. This territory is poorly industrialized, the largest areas are occupied by forestry and agriculture. At the same time, the most noticeable technogenic transformations of landscapes are associated with mining. On the territory of Volyn Polissya there are many deposits of various, mainly construction raw materials. There are deposits of basalt, loam, chalk, sand, clay, amber, peat. The development of such deposits is carried out in quarries, their average area ranges from 50 to 200 hectares. In addition to official deposits, significant areas were also developed illegally (most of all - for the extraction of amber).

Field studies of the dynamics of mountain landscapes are very costly and not always possible. Therefore, first of all, it is worth to conduct a low-cost analysis of statistical data and available satellite images.

Materials and methods

There are already many methods, algorithms and examples of environmental impact assessments of mining operations for different territories in the literature. In Ukraine, these are, in particular, works by H. Rudko, V. Stetsiuk, (2014), H. Rudko, Y. Ivanov, I. Kovalchuk (2019), M. Syvyj, (2005) etc. For the region of Volyn Polissya we can name the works of I. Zaleski (2005), F. Zuzuk, I. Zaleski (2013), A. Kalko (2014). Since 2015, there have been many works on monitoring illegal amber mining, for example, A. Smaliychuk, G. Ghazaryan, O. Dubovyk (2021), V. Filipovych, R. Shevchuk (2016), R. Shevchuk (2018). Most of these works are based on remote sensing methods for monitoring mining operations.

We tried to combine the methods described in these works and develop our own algorithm and scale for assessing the potential environmental impact of quarries.

The basis for the study was the reports on environmental impact assessment of planned mineral developments in the region published in 2019-2020. Data on the locations of quarries, rock conditions, area, depth and annual volumes of development, extraction technology and expected volumes of pollution from the operation of equipment were selected and analyzed from them. It should be taken into account that these data may not always be correct, since they are submitted by the interested party - the applicant, but in most cases they can serve as a basis for subsequent comparisons and monitoring.

In addition to these data, we used multi-temporal optical images of GoogleEarth and PlanetExplorer, and carried out cartometric measurements of distances from the mine boundary to residential buildings, to local erosion bases and to the nearest protected areas.

The EO-Browser and EOS LandViewer services also selected multispectral images of Sentinel-2 and Landsat-8 to assess the dynamics of changes in the quarry area.

Based on the combination of the collected data, a scoring scale for assessing the potential impact of quarries on the environment was proposed.

Results

In total, about 150 mineral deposits are accounted for in the territory, but about 30 are currently considered active. We analyzed the data of 14 deposits that were planned for development in 2019-2020 (mainly by expanding the area of existing ones).

The area of all studied quarries is 619 hectares, the largest are peat deposits ("Zakrynytsia" - 143 hectares) and sand (Turopynske - 100.7 hectares).

The total annual production volume at the studied deposits is estimated at 886 thousand m^3/year, the largest - for basalt and peat, more than 200 thousand m^3/year. Some deposits have a planned production volume of less than 15 thousand m^3/year (Kopyllivske, Pivnichnyi Berestovets).

The maximum mining depth at the quarries in the Volyn part is at the Potokivske clay deposit and is 9.3 m. The smallest depth of development at Novoukrainske sand deposit is 1.6 m. The average depth of development at the deposits is 4.6 m. In Rivne region, the maximum depth of development reaches 24.8 m at Ivano-Dolynske basalt deposit, and the average depth is about 7 m.

An important indicator in this case is also the relative height above the local erosion base, which, together with the distance to the river, indirectly shows the probability of pollution of water bodies by quarry waters. We determined this by cartometric measurements and automated construction of elevation profiles from the SRTM database in GoogleEarthPro. Since the territory is low-lying, the relative heights are often small, from 1 to 4-6 m, they are higher in several basalt deposits in the interfluve of the rivers Horyn and Styr (10-12 m), as well as in 2 sand deposits in the watershed between the rivers Vyzhivka and Turiya (up to 24-30 m).

We also used cartometric operations to determine the distance from the boundary of the development to the nearest residential buildings and protected areas. In most cases, these distances are large, more than 1 km, and are quite sufficient to offset the impact of small quarries. Only in a few cases there is a possibility of approaching the boundary of quarries up to 50-61 m to residential buildings, in case of development not on the declared area, but on neighboring plots. To avoid this, independent monitoring of the development is required.

Actually, several different services are suitable for remote monitoring purposes, many of which can be used for free.

The already mentioned GoogleEarthPro provides high-resolution imagery and accessible measurement tools. However, the availability of new imagery is not regular and coverage is very different for different areas even within the same region. Today, there are already dozens of images in the GoogleEarth database around urban areas, but in the remote northern parts of the region there are areas with only 3-4 images for the last 20 years. In addition, the database contains images from different satellites under different imaging conditions, so their joint spatial reference without specialized correction sometimes gives an error of several meters, sometimes up to 15-20 m, which makes it difficult to compare objects for different years.

Another resource PlanetExplorer provides good opportunities for periodic monitoring, as it has daily updates of images from its own satellites. Optical band images with a declared resolution of 3-5 m, but in practice for our territory the quality of images is often not better, and often inferior to the quality of Sentinel-2 images with a resolution of 10-15 m. Therefore, some large-scale developments can be tracked, but small ones are almost impossible.

Sentinel-2 and Landsat-8,9 images due to free access, relatively frequent updates and availability of different spectral bands can be the main source for quarries monitoring. Especially important is the possibility of automatic or semi-automatic classification of the selected area by different spectral indices or their combinations. Thus, it is quite easy to track changes in the ratio of exposed rocks, flooded and vegetated areas of quarries (example in Fig. 1)

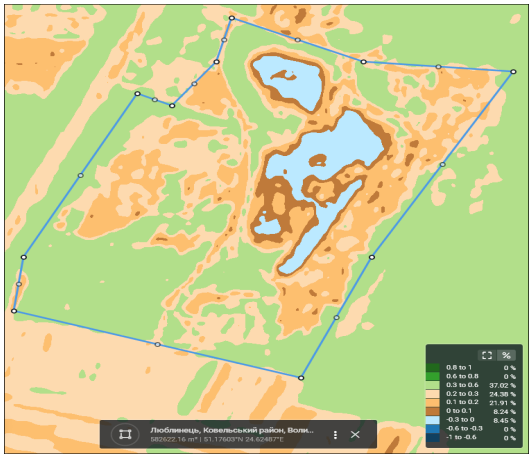

Figure 2 *An example of automatic classification of a site to identify the ratio of different types of quarry land*

At the same time, such estimates can differ significantly in different services, even with the same source data and the same selected indices, due to different image post-processing algorithms (Kovalchuk, Fedoniuk, 2020). Therefore, if possible, it is advisable to conduct parallel classification by several indices in at least 2 different services (e.g., EO-Browser and EOS LandViewer)
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After reviewing various reports on the environmental impact assessment of quarries, and conducting our own research on remote data, we identified a number of criteria that, in our opinion, are the most significant for the environment and can be at least approximately objectively assessed or verified from other sources. Based on this, a quantitative assessment of such impact was developed, based on examples of scoring for various criteria.
As a result, based on the range of values of various analyzed indicators for quarries in the region, the following scoring scale was compiled (Table 1):

Table 1 *Scoring scale of environmental impact of quarries*

Indicator/scores	0-1	2-4	5-6	7-8	9-10
Development area, hectares	Up to 1	1-5	5-25	25-100	More than 100
Depth of development, m	Up to 2	2-5	5-10	10-20	More than 20
Disclosure of groundwater	absent	probable	periodic	Constant, water inflow small	Constant, strong water inflow
Annual production volume, thousand m^3	Less than 15	15-50	50-100	100-200	More than 200
Distance to rivers, km	More than 2	1-2	0,3-1,0	0,1-0,3	Less than 0,1
Relative height above the erosion base, m	More than 20	10-20	5-10	2-5	Less than 2
On what deposits does it lie		crystal	clay	chalk	sand
Volume of annual dust emissions, t	Up to 1	1-5	5-15	15-25	More than 25
Volume of annual NO_2 emissions, t	Up to 1	1-5	5-15	15-25	More than 25
Are blasting operations used	No	Yes, periodically			Yes, always
distance to the nearest buildings, m	More than 1000	300-1000	100-300	50-100	Less than 50
Type of land to be developed	technogenic	agricultural fields	Meadows, shrubs	Forests, swamps	objects with protected status

Accordingly, the investigated 14 quarries were ranked according to this scale, the results are shown in Fig.2.
The availability of such an assessment allows to establish the priority and frequency of monitoring for different objects and, accordingly, partially optimize the environmental control over the conduct of such activities.

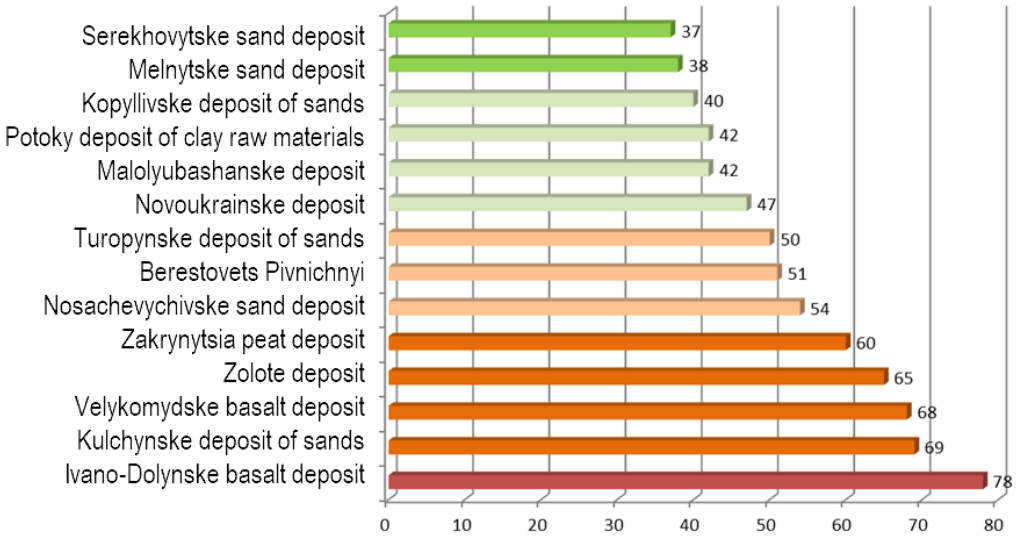

Figure 2 *Comparison of the magnitude of the likely impact of developments on a scoring scale*

Conclusions

In general, it is worth noting that different types of quarries have their own peculiarities for better detection of the dynamics of their condition. To a large extent, it is advisable to monitor the mining area using remote sensing data, combining available high-resolution optical data with multispectral images of Sentinel-2 and Landsat-8,9. This makes it possible to independently verify the declared design data. Together with the official documents, such studies help to assess the probability of environmental impact and risks of pollution. In the studied region of Volyn Polissya, it is especially important to take into account the impact on nearby groundwater, runoff to surface water bodies and infiltration to groundwater, in addition to direct quantitative indicators of extraction volumes. The scoring scale of the probable impact of quarries, developed according to the set of criteria considered, can be applied by employees of the environmental inspection, state geocadastre, state geological companies, forestry, etc.

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