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The use of the open-source software QGIS for the assessment of the risk caused by mining the longwall face to buildings on the ground surface

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Abstract. The aim of our work is to present a variant analysis of the threat to buildings in the event of mining the underground coal seam using longwall face. QGIS, the currently open-source spatial information system, was used to assess the threat to buildings. The assessment consisted of comparing the hazard category of the mining area with the resistance category of the building. In the case of mines, an inventory of the resistance of buildings is carried out during the development of mining plans. The second important aspect of our work is the transition from traditional CAD technology to the use of GIS technology. The new technology makes it easier and quicker to carry out analyses such as the threat posed by mining to listed buildings. It helps to produce annexes to the mining plan, such as hazard maps for buildings and a table listing buildings at risk.

1 Introduction

Underground mining, particularly in coal deposits, has been found to cause significant damage to building infrastructure on the surface. This damage caused is mainly by the deformation of the rock mass disturbed by mining, which can lead to additional forces acting on the foundations of buildings [1, 2].

QGIS, which stands for Quantum GIS, is a powerful open-source Geographic Information System (GIS) software used for spatial analysis, mapping, and data visualization [3]. One of its significant applications is in risk assessment, where it provides a versatile platform for evaluating various types of risks, such as natural disasters, environmental hazards, and socio-economic vulnerabilities [4, 5]. QGIS enables users to perform complex spatial analysis by integrating diverse datasets, including satellite imagery, aerial photographs, demographic data, and environmental parameters [6]. This capability allows for the identification of areas prone to specific risks and the analysis of their potential impact [7].

QGIS offers a wide range of tools and plugins that can be tailored to specific risk assessment needs [8, 9]. With its help it is possible to develop custom workflows and integrate third-party plugins to enhance functionality, making it adaptable to different risk scenarios [10]. The software provides advanced mapping and visualization features, allowing

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users to create detailed maps and visual representations of risk factors, vulnerability, and exposure [11]. This aids in communicating complex risk information to stakeholders and decision-makers effectively [12]. QGIS supports various modelling and simulation techniques for predicting and assessing risks. The spatial modelling algorithms to simulate the propagation of hazards, assess their potential impact on the environment or infrastructure, and evaluate different mitigation strategies could be used in its framework [11, 13].

As an open-source platform, QGIS promotes collaboration and data sharing among researchers, practitioners, and communities involved in risk assessment [12, 14]. It facilitates the integration of open data sources and promotes transparency and reproducibility in risk analysis processes. Being open-source, this software is freely available for download and usage, making it an attractive option for organizations with limited budgets or those operating in resource-constrained environments [5, 12, 15]. This accessibility enhances the democratization of risk assessment tools and promotes wider adoption across diverse sectors and regions. So, it offers a robust and flexible platform for conducting risk assessments by leveraging spatial analysis, visualization, modelling, and collaboration capabilities.

The threat to structures from underground mining is a complex issue influenced by many different factors. The main ones are the thickness and depth of the excavation, the properties of the rock mass and the deformation resistance of the building structure [16]. The occurrence of damage to buildings in a region where the terrain has been disturbed by coal mining indicates the need for improved preventive methods.

As a result of mining operations, damage is caused to building structures. Polish law requires from mining companies to cover the cost of repairs, which affects their financial conditions [17, 18]. This motivates mining companies to take measures to reduce mining damage to surface infrastructure located in the mining area.

The protection of buildings in areas affected by mining activities must include forecasting, design, and monitoring [19, 20]. The stage of forecasting the effects of mining exploitation consists of 2 parts: calculations of the deformation indicators in the mining area and the assessment of the threat to buildings.

Due to the complexity of calculations of the deformation indicators performed and the labour intensity needed for graphical presentation of the threatened structures in mining plants, the aim is to calculate and visualise the final mining variant. Graphical presentation of deformation is laborious if done using CAD (Computer Aided Design) software in mining. Within the scope of the present study, the use of geo-information type software such as QGIS is proposed for the preparation of the visualisation of the hazards of the buildings. This type of software is increasingly and widely used to process spatial data in mining. These technologies are generally referred to as geomatics and are used in both the open pit and underground mines [21]. The primary tool used in geomatics to process spatial data is GIS (Geographic Information Systems). This type of system is increasingly popular in assessing the threat to buildings coming from mining exploitation [22].

The second element of this work is to identify the issue of increasing the level of computerisation on the prediction of deformation effects in buildings. This will enable not only to calculate deformations in variants, but also to assess the impact of these deformations on building structures. The possibility to consider many variants of the exploitation makes it possible to better adapt the criteria for evaluating a given exploitation [23]. The determination of a specific value of the angle of influence ($tg\beta$ – range in the rock mass) is a rather difficult task. However, it is possible to carry out calculations for 2 different values of the angle of influence and to compare the change in the degree of hazard on the ground surface under the influence of mining exploitation.

2 Materials and methods

The studies were conducted based on the mining project for the G-32 longwall in the 359/1 lg+ld[1] seam, for which a forecast of ground deformation was prepared in the form of contours of mining area categories. The calculated values of the deformation indicators: strain (compression and tension of the ground, resulting in cracks in buildings), slope (resulting in tilting of buildings) and radius of curvature (distribution of stresses in the structure) together form the category of terrain hazard. Category 0 is the absence of mining impacts, while category V is very severe ground deformation. Table 1 describes the different mining area hazard categories [24].

Table 1. Description of individual terrain categories.

Terrain category of mining area	Degree of suitability of mining area for development
I The zone is indicated on the map by the yellow colour	Areas with some protection for existing facilities
II The zone is indicated on the map by the orange colour	Areas where partial protection of all facilities is uneconomic
III The zone is indicated on the map by the purple colour	Areas requiring partial safeguarding of existing facilities
IV The zone is indicated on the map by the violet colour	Sites requiring more extensive safeguarding of existing facilities
V The zone is indicated on the map by the brown colour	Areas generally unsuitable for development

Contours of the mining terrain category were made using the EDNOPN computer program by Prof. J. Białek based on the assumptions of the Knothe-Budryk theory [25].

The following parameter values were accepted for the calculations:

- exploitation coefficient $a = 0.8$;
- rock mass parameter I variant: $tg\beta = 2.0$;
  II variant: $tg\beta = 1.5$;
- proportionality factor $B = 0.32 \cdot r$.

As a result of the calculations carried out, two variants of the isolines of the category of mining area were obtained for the longwall G-32 in seam 359/1 łg+łd. The generated mining terrain category contours were exported to GeoLISP software. A map containing the contour of longwall G-31, seam 359/1-2 łg+łd, contours of the mining area category, boundary of the "Szeroka I" mining area, layout of streets in the area of the planned exploitation of longwall G-32 in seam 359/1-2 łg+łd, administrative borders, buildings, numbers of buildings and colour-coded categories of resistance of buildings was prepared in the AutoCAD GeoLISP environment. The map was prepared using the 2000 map grid. The prepared fragment of the map is shown in Fig. 1 below.

The CAD data presented this way was then prepared for printing by manually changing the colours of the buildings. For buildings that were not at risk from mining operations, the CAD operator removed the infill. The maps prepared this way were then printed.

[1] łg – upper split coal, łd – lower split coal

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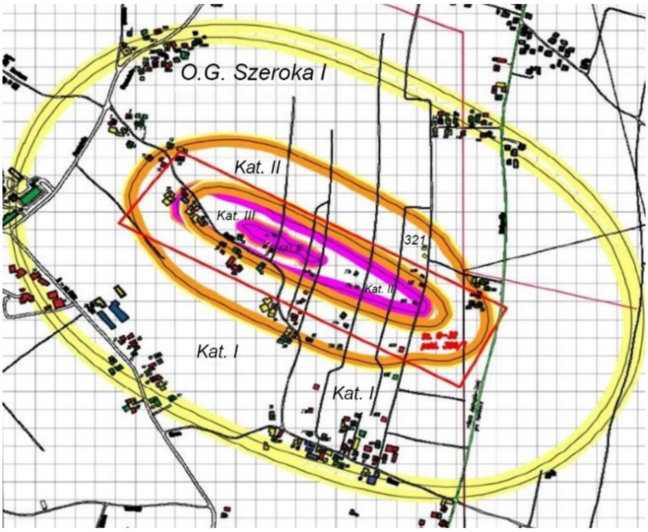

Fig. 1. Map of the terrain category contours for the two calculation variants in the CAD environment.

For planned research, these data are the starting point for further processing in the spatial information system.

3 Results and discussions

To be able to carry out the analysis of damage risk to the buildings, the corresponding layers were created in QGIS [26]. A vector layer buildings.shp was created to draw the buildings layer. Before drawing the buildings, the appropriate building resistance categories were assigned to the buildings. The colours assigned to the individual categories are in accordance with the colours established by the Polish Mining Map Standard (the four categories are described with Arabic numerals from 1 – not resistant, to 4 – very resistant). The buildings were then mapped in the QGIS environment with their attributes added, the most important of which is the resistance category of the building.

A total of 211 buildings were vectorised in influence zone of the designed G-32 wall. Each vectorised building was assigned the following attributes: resistance category, street, building number, municipality. In addition, the resistance categories of the building objects were described with the corresponding id value. Category 1 is id = 186, category 2 is id = 284, category 3 is id = 202, category 4 is id = 173. The following number of buildings were vectorised in the various resistance categories:

– 13 buildings of resistance category 1;
– 63 buildings of resistance category 2;
– 74 buildings of resistance category 3;
– 71 buildings of resistance category 4.

For each object placed on the “buildings” layer, a resistance category identifier was inserted, based on which a color code for the layer display was assigned. (Fig. 2).

The contours of terrain categories were imported into QGIS with the command “Import layers from DWG”, which allowed them to be loaded into QGIS. The coordinate system was selected to be the same in which the mining map was prepared, i.e. coordinate system 2000 (EPSG 2177). After importing the data a new project and a map layer was created.

The next layers created are the zone1 and zone2 vector layers. These layers contain the contours of the mining site hazard categories. For the first variant associated with the applied rock mass parameter *tgβ* = 2.0, the vector layer zone1.shp was created. This layer was also assigned a 2000 system (EPSG:2177).

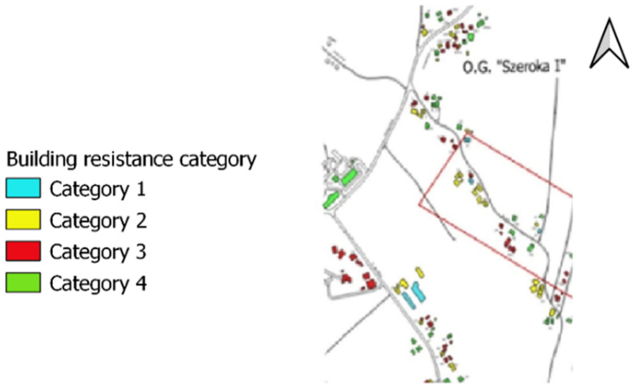

Fig. 2. Fragment of the map of building resistance category, with colour code.

The colours from Table 1 were used to style the zone1 layer. When vectorising the hazard zones, the drawing order was important. The zones were drawn from innermost (category 3) to outermost (category 1). This was due to the need to preserve the topology of these zones. The inward zones carved out an area from the outward zone, so that each piece of land belonged to only one zone.

For the second variant associated with the applied rock mass parameter *tgβ* = 1.5, a vector layer zone2.shp was created. This layer was created using the same properties as the zone1.shp layer.

In this way, a spatial database was created with 3 spatial data layers that will enable to perform spatial analysis. This type of data organisation forms the core of a more efficient spatial data management in mining [27].

3.1 Hazard analysis of buildings

In order to link and compare the site category information with the building resistance category, i.e. to make a query, geo-attribute for the two layers (buildings and zones), the tool for “Join Attributes by Location” was used (Fig. 3). This created a new layer containing the buildings supplemented with the attributes of the mining terrain category. With both attributes assigned to each building (terrain category and resistance category) it was possible to analyse them together.

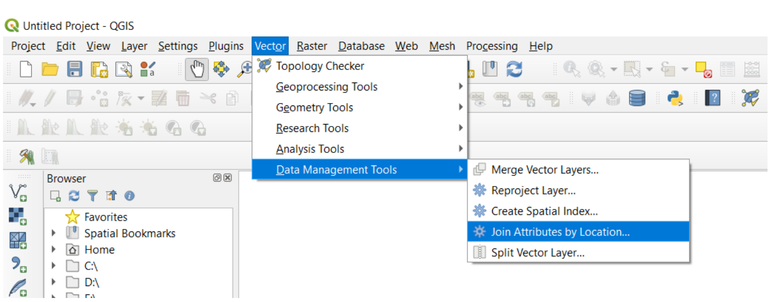

Fig. 3. QGIS tool for combining layer attributes used in analyses.

After the merge, the content of the attribute table and the number of objects on the temporary result layer were checked. There are 221 building objects in the Attribute Table. The temporary result layer was saved as result1 layer. The result1 layer attribute table can be opened in an Excel spreadsheet. There are 187 objects created on the result layer. This table contains building objects that have been assigned an id, a building resistance category, a street, a building number, a municipality, and attributes resulting from the merging of zone1-id and zone1-category. 34 buildings were outside the zone 1 of the mining area terrain category.

The result of the analysis of the extent of the threat to buildings was the creation of maps of buildings at risk and a list of these buildings in two variants. For the 1st variant, the categories of mining area were recalculated for the rock mass parameter $tg\beta = 2.0$. The range of influence of the exploitation of longwall G-32 seam 359/1 łg+łd covered 187 buildings. The hazard assessments for this mining variant are as follows:

– 152 buildings have a resistance greater than the terrain category (and are fully safe);
– 22 buildings have a resistance equal to the terrain category (low probability of damage);
– 10 buildings have a resistance one category lower than the terrain category;
– 3 buildings have resistance two categories lower than the terrain category.

A total of 13 buildings are at risk and these require safety works to be carried out prior to mining.

For the 2nd variant, the mining terrain categories were recalculated for the rock mass parameter $tg\beta = 1.5$. The range of influence of the exploitation of longwall G-32 p. 359/1 łg+łd covered 201 buildings. The hazard analysis showed that:

– 182 buildings have a resistance greater than the terrain category;
– 15 buildings have resistance equal to the terrain category;
– 4 buildings are at risk because they have resistance one category lower than the terrain category;
– there are no buildings for which the resistance category will be exceeded by two or more terrain categories.

The extent of the influence of mining exploitation in variant 2 covered a larger number of buildings compared to variant 1. However, the qualitative analysis indicates that the scale of the threat to buildings in the second variant is smaller. Very importantly, the number of buildings for which the terrain category exceeds twice and three times their resistance category is also zero in the second variant.

4 Conclusions

In conclusion, it can and should be stated that the presence of a lower value for the rock mass parameter $tg\beta$ gives more favourable results regarding the degree of risk to buildings. Carrying out such an analysis highlights how crucial and important it is to determine the $tg\beta$ parameter correctly. The acceptance of this value should always be preceded by an appropriate analysis of data on the historical impacts of mining exploitation.

The QGIS program used allows for viewing, displaying, editing, and creating vector and raster data in various formats. Once built, the spatial database of buildings can be updated at a later stage and used repeatedly for many analyses. This type of database reduces the manual work performed by the mine worker and speeds up the process of assessing the threat to buildings coming from mining. It requires a lot of work to create the project, but the possibilities to perform various analyses is a great value in working with a GIS project. QGIS allows raster and vector data to be displayed and various analyses to be performed and is an effective tool for working with different types of geodata [28], many of which can be used to observe land deformation caused by mining.

QGIS offers extensive and constantly expanding tools for automating and visualising the analyses performed during the design of mining works. To facilitate and speed up the work, it is advantageous to use event interpretation from a spatial information systems point of view, e.g. the use of "feature area/attribute value" instead of "isolines" (representing only boundary value lines) or "boundaries" (without specifying the feature inside the object). In the project presented here, the most labour-intensive part was the transfer of data from the CAD record to the GIS features. QGIS's extensive functions for attribute linking, spatial analysis and selection of objects based on rules composed of attributes enable rapid visualisation of results and analysis of different scenarios (e.g., in the case above, comparison of two assumptions on the *tgβ* coefficient). The analyses performed confirm the suitability of QGIS for coal mining applications previously indicated by the authors [29]. The analysis performed should be classified in the field of geomatics as defined in the article [30].

References

1. Can, E., Mekik, C., Kuscu, S., & Akçin, H. (2011). Subsidence occurring in mining regions and a case study of Zonguldak-Kozlu Basin. *Scientific Research and Essays*, *6*(6), 1317-1327.
2. Can, E., Kuşcu, Ş., & Mekik, C. (2012). Determination of underground mining induced displacements using GPS observations in Zonguldak-Kozlu Hard Coal Basin. *International Journal of Coal Geology*, (89), 62-69. https://doi.org/10.1016/j.coal.2011.08.006
3. Flenniken, J.M., Stuglik, S., & Iannone, B.V. (2020). Quantum GIS (QGIS): An introduction to a free alternative to more costly GIS platforms. *EDIS*, *2020*(2), 7. https://doi.org/10.32473/edis-fr428-2020
4. Polyanska, A., Pazynich, Y., Sabyrova, M., & Verbovska, L. (2023). Directions and prospects of the development of educational services in conditions of energy transformation: the aspect of the coal industry. *Polityka Energetyczna – Energy Policy Journal*, *26*(2), 195-216. https://doi.org/10.33223/epj/162054
5. Dudek, M. (2017). The analysis of the low-cost flexibility corridors. In *2017 IEEE International Conference on Innovations in Intelligent Systems and Applications* (pp. 478-483). Gdynia, Poland: Gdynia Maritime University. https://doi.org/10.1109/inista.2017.8001207
6. Passy, P., & Théry, S. (2018). The Use of SAGA GIS Modules in QGIS. *QGIS and Generic Tools*, 107-149. Portico. https://doi.org/10.1002/9781119457091.ch4
7. Polyanska, A., Pazynich, Y., Mykhailyshyn, K., & Buketov, V. (2023). Energy transition: the future of energy on the base of smart specialization. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 89-95. https://doi.org/10.33271/nvngu/2023-4/089
8. Sobczyk, E.J., & Kopacz, M. (2023). Assessing Geological and Mining Condition Nuisance and its Impact on the Cost of Exploitation in Hard Coal Mines with the Use of a Multi-Criterion Method. *Archives of Mining Sciences*, *63*(3), 665-686. https://doi.org/10.24425/123690
9. Lacaze, B., Dudek, J., & Picard, J. (2018). GRASS GIS Software with QGIS. *QGIS and Generic Tools*, 67-106. Portico. https://doi.org/10.1002/9781119457091.ch3
10. Polyanska, A., Pazynich, Y., Poplavska, Z., Kashchenko, Y., Psiuk, V., & Martynets, V. (2024). Conditions of Remote Work to Ensure Mobility in Project Activity. *Lecture Notes in Mechanical Engineering*, 151-166. https://doi.org/10.1007/978-3-031-56474-1_12
11. Holloway, P. (2023). Getting Started with QGIS. *Understanding GIS through Sustainable Development Goals*, 9-17. https://doi.org/10.1201/9781003220510-3
12. Richert, M., & Dudek, M. (2023). Risk Mapping: Ranking and Analysis of Selected, Key Risk in Supply Chains. *Journal of Risk and Financial Management*, *16*(2), 71. https://doi.org/10.3390/jrfm16020071
13. Shekhar, S., & Xiong, H. (2008). QGIS. *Encyclopedia of GIS*, 931-931. https://doi.org/10.1007/978-0-387-35973-1_1052

14. Sala, D., & Bieda, B. (2022). Stochastic approach based on Monte Carlo (MC) simulation used for Life Cycle Inventory (LCI) uncertainty analysis in Rare Earth Elements (REEs) recovery. *E3S Web of Conferences*, (349), 01013. https://doi.org/10.1051/e3sconf/202234901013
15. Kouda, R. (2017). GIS and Satellite Image Analysis Using QGIS（No.1 Introduction）. Geoinformatics, *28*(3), 111-137. https://doi.org/10.6010/geoinformatics.28.3_111
16. Ostrowski, J. (2015). *Deformacja powierzchni obszaru górniczego*. Krakow, Poland: Wydawnictwo AGH, 117 s.
17. Sobczyk, J., & Kopacz, M. (2020). Efficiency and financial standing of coal mining enterprises in Poland in terms of restructuring course and effects. *Gospodarka Surowcami Mineralnymi – Mineral Resources Management. 36*(2), 127-152. https://doi.org/10.24425/GSM.2020.132565
18. Dychkovskyi, R.O., Avdiushchenko, A.S., Falshtynskyi, V.S., & Saik, P.B. (2013) On the issue of estimation of the coal mine extraction area economic efficiency. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 107-114.
19. Florkowska, L. (2013). Example building damage caused by mining exploitation in disturbed rock mass. *Studia Geotechnica et Mechanica*, *35*(2), 19-37. https://doi.org/10.2478/sgem-2013-0021
20. Bazaluk, O., Kuchyn, O., Saik, P., Soltabayeva, S., Brui, H., Lozynskyi, V., & Cherniaiev, O. (2023). Impact of ground surface subsidence caused by underground coal mining on natural gas pipeline. *Scientific Reports*, (13), 19327. https://doi.org/10.1038/s41598-023-46814-5
21. Krawczyk, A. (2023). Mining Geomatics. *ISPRS International Journal of Geo-Information*, *12*(7), 278. https://doi.org/10.3390/ijgi12070278
22. Sokoła-Szewioła, V., & Żogała, M. (2019). Forecast and assessment of the effects of the impact of mining tremors, induced by exploitation, on building objects with the use of GIS system. *IOP Conference Series: Earth and Environmental Science*, (261), 012048. https://doi.org/10.1088/1755-1315/261/1/012048
23. Sobczyk, E. J., Kicki, J., Sobczyk, W., & Szuwarzyński, M. (2017). Support of mining investment choice decisions with the use of multi-criteria method. *Resources Policy*, (51), 94-99. https://doi.org/10.1016/j.resourpol.2016.11.012
24. ISAP – Internetowy System Aktów Prawnych. (2011). *Ustawa z dnia 9 czerwca 2011 r. – Prawo geologiczne i górnicze. Dziennik Ustaw*, (163), 981.
25. Orwat, J. (2016). The forecast effectiveness of mining exploitation effects on the exploited area conducted with the use of Bialek's formulas. *AIP Conference Proceedings*, (1), 1738. https://doi.org/10.1063/1.4951848
26. Orłowski, K. (2015). Usage of geographical information systems in automotive transportation managem. *Systemy Logistyczne Wojsk*, *43*(2), 65-84. https://doi.org/10.5604/01.3001.0012.7172
27. Krawczyk, A. (2018). A concept for the modernization of underground mining master maps based on the enrichment of data definitions and spatial database technology. *E3S Web of Conferences*, (26), 00010. https://doi.org/10.1051/e3sconf/20182600010
28. Apollo, M., Jakubiak, M., Nistor, S., Lewińska, P., Krawczyk, A., Borowski, Ł., Specht, M., Krzykowska-Piotrowska, K., Marchel, Ł., Pęska-Siwik, A., & Maciuk, K. (2023). Geodata in science-a review of selected scientific fields. *Acta Scientiarum Polonorum Formatio Circumiectus*, *22*(2), 17-40. https://doi.org/10.15576/ASP.FC/2023.22.2.02
29. Duarte, L., Teodoro, A., Fernandes, J., Santos, P., & Flores, D. (2020). An Integrated Environmental Monitoring Approach through the Development of Coal Mine, a GIS Open Source Application. In *Proceedings of the 6th International Conference on Geographical Information Systems Theory, Applications and Management* (pp. 286-293). https://doi.org/10.5220/0009578402860293
30. Krawczyk, A. (2022). Proposal of Redefinition of the Terms Geomatics and Geoinformatics on the Basis of Terminological Postulates. *ISPRS International Journal of Geo-Information*, *11*(11), 557. https://doi.org/10.3390/ijgi11110557