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**Research paper**

# Risk assessment for underground utility damage due to spatial data quality

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**Abstract:** Spatial data are used in a variety of projects. Their quality directly contributes to the project's success. One of the risk sources for underground utility damage in construction works is the quality of spatial data. The article presents the results of research on a method for estimating underground utility damage risk. It consists in calculating the risk (both qualitative and quantitative risk) from specific risk factors and impact weights. The primary risk factors are incomplete spatial datasets and horizontal and vertical position accuracy of objects in the database. The calculated risk value is within 7.0 to 34.2 points. This means that the minimum risk of damage to underground utilities during construction works is 7.0 points and the maximum risk of 34.2 points is nearly five times higher. We also developed a risk map of underground utility damage. It is a thematic map with qualitative project risk. The proposed map is a 2D and 3D cartographic document that represents the actual risk of damage to underground utilities due to spatial data quality.

**Keywords:** spatial data quality, risk assessment, GIS, risk map

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# 1. Introduction

The notion of risk means uncertainty as to the chance of an event that may have an adverse impact on the intended goal [1]. This definition applies to qualitative methods for threat assessment based on expert knowledge and experience. The quantitative definition of risk is given by Kaplan and Garrick [2]. The risk of an event is described as a set of three elements:

$$R = \{S, P, I\} \tag{1.1}$$

where: $S$– is an event scenario, $P$ – is the probability of the event, $I$ – is the potential impact or consequences of the event.

Risk analysis can also be considered in the context of spatial data quality analysis. Spatial data are used in a variety of projects. Their quality directly contributes to the project's success. Project risk can be described with a three-element diagram [3]:

$$R - C - I \tag{1.2}$$

where: $R$ is the risk, $C$ is the cause, and $I$ is the effect (impact of the risk).

Researchers analysed the problem of risk inherent to the use of spatial data in decision-making from several angles. One of them was the presence of natural threats and anthropogenic hazards. Analytical research on risk analysis with GIS tools tends to focus on such issues as geological disasters, floods, drought, earthquakes, landslides, and fires [4].

As the economy grows, a significant number of developments in the natural environment directly and indirectly increase the chance of geological disasters. Numerous geological disasters occurring every year pose a serious threat to human life and property and significantly hinder effective economic activity [5]. Utility infrastructure (water, gas, electricity) is often located in areas at risk of land movements. Malinowska et al. [6] proposed a method based on artificial intelligence for assessing the risk of gas transmission line failure. Her other work [7] describes an innovative method for controlling the risk of sinkholes in urban areas. It contains final risk maps based on four key factors that lead to subsidence.

Research on flood risk requires knowledge of the spatial structure of vegetation, topography, climate, and anthropogenic changes in river drainage basins [8]. GIS functionality, including thematic maps and multi-criteria analysis, can help identify flood zones with predefined flood risk levels [9]. GIS tools can be used also to build multi-index spatial models for assessing flood risk. Such models are successfully employed globally in risk analysis. Flood risk maps are the primary components of flood risk management plans (mainly for risk mitigation) [10–12].

Persistent increases in water demand and climate change have directed public attention to global drought scenarios in recent years. Drought is a multidimensional situation described by multiple climatological and hydrological parameters. Drought models based on multiple climate, soil, and land-use factors are an effective approach to determining drought characteristics [13]. Today, drought risk assessment is dominated by remote sensing and GIS techniques. The fuzzy analytic hierarchy process (FAHP) is an effective and popular technique for building local drought–risk assessment models [14].

Natural earthquakes pose a grave danger to urbanised areas. They remain a substantial hazard even despite evident progress in construction techniques and constant improvement in expert knowledge and skills regarding natural disaster control. Today, the leading approach to seismic threat research and risk assessment is GIS modelling [15]. Susceptibility to earthquakes is assessed and analysed with demographic, physical, and environmental criteria. Quantitative risk is visualised with risk maps They are usually generated with the fuzzy analytic hierarchy process combined with an artificial neural network model. Validations of the risk assessment models demonstrate that it is possible to create 95% accurate earthquake probability maps [16].

Another disastrous event harmful to the public and economic well-being is the landslide. Detailed soil susceptibility maps are needed to effectively control landslide threats. Such maps are employed in targeted risk management plans [17]. Now, expert methods are particularly effective. They integrate Earth observation, GIS, and multi-criteria analysis. Analysts evaluate the impact of both natural and anthropogenic factorson landslides. The analytic hierarchy process (AHP) method is the primary technique for building landslide-risk weight matrices [18, 19].

Forest and residential fires are another serious threat to natural forest ecosystems and public and economic well-being. Fire susceptibility risk assessment is of utmost practical relevance to prevent fires, limit them, and mitigate their impact on the environment, the public, and property [20]. Some of the over a dozen fire susceptibility factors include topography, climate, vegetation, and human activity. Risk assessment models built with GIS tools can visualise threats on risk maps. Such risk maps are a useful tool for decision-making in crisis management and urban planning [4, 21].

The risk of damage to underground utilities is inherent to the construction process. One of the sources of this risk is the quality of spatial data. The literature [22] enumerates three main causes of damage to buried pipes and cables in the context of the quality of spatial data. The first cause is the presence on site of underground utilities not included on a site map. The source of this risk can be defined as an incomplete database. The second cause of the risk is the insufficient horizontal accuracy of pipe and cable positioning on the site map generated from spatial data from official databases. The third reason is the insufficient vertical accuracy of underground pipe and cable positioning [23, 24].

If the risk occurs, its impact on the construction project can be substantial and affect the health and safety of people in addition to material losses. Damage to buried pipes or cables can lead to accidents, delays, or even stoppages [25].

## 2. Score-based risk analysis

The first stage of the risk analysis is to identify the phenomenon. In this model, it is the risk of damage to underground utilities. The risk factors are incomplete data and the accuracy of horizontal and vertical positioning of the infrastructure. The standard project risk assessment involves a quantitative score based on the probability and impact of the threat on the project. The probability and consequences are evaluated with a point scale [26].

We adopted a five-point scale for the probability and impact (consequences) in the underground utility damage risk analysis (Table 1). The selected range of the scale is in line with risk analysis indicators used in the construction industry [27]. We intersected the probability and impact of the risk to build a risk matrix (Table 2) for qualitative project risk assessment [28, 29]. The assumption, in this case, is that values from 1 to 3 reflect low risk, 4–12 mean moderate risk, and 15–25 are typical of high risk.

Table 1. Risk probability and impact scores

| **Probability of risk factors (*P*)** | | | | |
|---|---|---|---|---|
| Rare | Low | Moderate | Probable | Almost certain |
| $P \leq 0.20$ | $0.20 < P \leq 0.40$ | $0.40 < P \leq 0.60$ | $0.60 < P \leq 0.80$ | $P > 0.80$ |
| **Risk impact (*I*)** | | | | |
| Very severe | Severe | Moderate | Minor | Negligible |
| 5 points | 4 points | 3 points | 2 points | 1 point |

Table 2. Risk matrix

| | | | **Probability (*P*)** | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Rare** | **Minor** | **Moderate** | **Probable** | **Almost certain** |
| Impact (*I*) | | Degree | 1 | 2 | 3 | 4 | 5 |
| | Negligible | 1 | 1 | 2 | 3 | 4 | 5 |
| | Minor | 2 | 2 | 4 | 6 | 8 | 10 |
| | Moderate | 3 | 3 | 6 | 9 | 12 | 15 |
| | Severe | 4 | 4 | 8 | 12 | 16 | 20 |
| | Very severe | 5 | 5 | 10 | 15 | 20 | 25 |

We conducted a sample score risk assessment based on our research on the probability of risk factors for underground utility damage. The research involved contractors specialising in linear structures (water systems, sewers, power lines, or gas lines) in Małopolskie Voivodeship, Poland. The parameters of the underground utility damage risk model were estimated from technical files from construction processes and survey questionnaires.

We estimated the probability of the risk factors in an original analysis for 250 cases of conflicts between planned pipes and cables with the existing underground utilities (Table 3). The impact and the acceptable score of the risk were estimated from an analysis of 40 questionnaires completed by construction site managers (Table 4). All the construction works were in urban areas. In these circumstances, building plans and specifications are usually based on a 1:500 ordnance survey site map.

Considering the data in Tables 3 and 4, we assessed the probability of unmapped underground utilities in the project area as rare (19%). We then estimated the probability of the existence of underground utilities with insufficient horizontal position accuracy in the project area as moderate (54%). The estimated probability for vertical accuracy is similar (moderate, 66%). The impact of incomplete data on underground utilities is very severe (5 points for 95% of the cases). The impact of insufficient (for building purposes) horizontal accuracy of underground utility positioning is severe (4 points for 92% of cases), and the impact of vertical accuracy is moderate (3 points for 92% of cases).

The predicted risk of damage to underground pipes and cables (*RL* – risk level) was calculated from the sum of products of the probabilities of individual risk factors (*P*) and the impact (*I*).The values are shown in Table 5.

Table 3. Probability of risk factors

| **Risk factors** | **Number of analysed cases** | **Incidence of risk factors** | |
|---|---|---|---|
| | | **Number** | **[%]** |
| Incomplete underground utility data (*ID*) | 250 | 48 | 19 |
| Horizontal accuracy of underground utilities (*HA*) | 250 | 135 | 54 |
| Vertical accuracy of underground utilities (*VA*) | 250 | 165 | 66 |

Table 4. Risk factor impact

| **Risk factors** | **Risk factor impact ($I$)** | **Incidence of impact ($I$) of risk factors** | |
|---|---|---|---|
| | | **Number** | **[%]** |
| Incomplete underground utility data (*ID*) | 5 – very severe | 38 | 95 |
| | 4 – severe | 2 | 5 |
| Horizontal accuracy of underground utilities (*HA*) | 4 – severe | 37 | 92 |
| | 3 – moderate | 3 | 8 |
| Vertical accuracy of underground utilities (*VA*) | 3 – moderate | 37 | 92 |
| | 2 – minor | 3 | 8 |
| Acceptable risk level ($R_A$) | 1 ($P = 1, I = 1$) | 38 | 95 |
| | 2 ($P = 1, I = 2$) | 2 | 5 |

Table 5. Predicted risk of damage to underground utilities

| **Item** | **Risk factors** | **Probability ($P$)** | **Impact ($I$)** | **Risk level $RL = P{\cdot}I$** |
|---|---|---|---|---|
| 1 | Incomplete underground utility data (*ID*) | 0.19 | 5 | 0.95 |
| 2 | Horizontal accuracy of underground utilities (*HA*) | 0.54 | 4 | 2.16 |
| 3 | Vertical accuracy of underground utilities (*VA*) | 0.66 | 3 | 1.98 |
| | | | Sum: | 5.09 |

The project risk score $\left(\sum RL = 5.1\right)$ classifies it as a moderate risk. The acceptable risk level in individual factors is estimated at 1.0 (Table 4). Based on this value, we plotted an acceptable risk curve (Fig. 1) with the following function:

$$S = \frac{R_A}{P} \tag{2.1}$$

where: $R_A = 1.0$ is the acceptable risk.

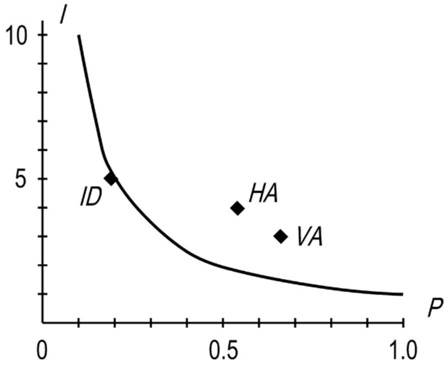

Fig. 1. Acceptable risk curve

Figure 1 demonstrates that incomplete data on underground utility (*ID*) reaches an acceptable level, while horizontal accuracy (*HA*) and vertical accuracy (*VA*) breach the acceptable level.

The calculated project risk score indicates that the construction project involves moderate risk. The risk level of 5.1 will not be exceeded only if the risk factors occur with the assumed probability. If all adverse factors coincide (which is not impossible), the risk increases to 12 points.

The project risk factors are random [2]. Thus, the most probable risk level can be estimated. In the method proposed here, values from the interval of <0; 1) are randomly selected, and impact values are conditionally assigned. The procedure is described below.

If the randomly selected value is less or equal to the probability ($P$), the risk level ($RL$) is equal to the impact ($I$). Otherwise, the $RL$ is zero. The estimated risk level from a single random selection is the sum of randomly selected impact values. With repeated random selections, one can calculate the most probable project risk. We employed the *rand()* function of MS Excel to calculate the project risk with 2000 random selections (Fig. 2). The horizontal axis shows the risk values for individual random selections, and the vertical axis depicts the aggregate probability of the risk.

Assuming a conservative confidence interval of $p = 0.90$, the risk would not exceed 6 points. The most probable calculated risk is approx. 60% higher than the predicted risk (Table 5). Even though the difference is substantial, quantitatively, the risk of damage to underground utilities estimated with the proposed method remains moderate.

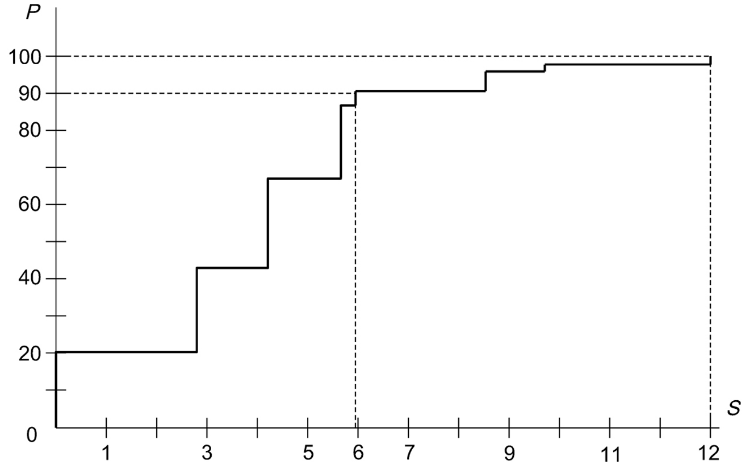

Fig. 2. Project risk plot

## 3. Risk map

The risk estimation method is founded on expert knowledge and experience, which directly contribute to the results of the evaluation. The method is capable of estimating the risk level for a project as a whole. Therefore, the proposed method for assessing the risk to underground utilities will be useful for smaller projects (an area of a cadastral parcel). However, risk assessment for large projects (be it linear or enclosed structures) calls for a different approach. The primary reason for the search for a suitable solution is the diversified quality of spatial data from official databases that affects the estimated risk.

The quality of spatial data in official databases, Land and Property Register (EGiB), Utilities Database (GESUT), and Database of Topographic Objects 500 (BDOT500) is far from uniform. Differences are clear even for small areas, such as cadastral districts because the databases are not updated regularly and data acquisition processes vary. Therefore, a reliable underground utility damage risk analysis should be presented as a risk map.

The first stage of the risk assessment is to identify all factors that contribute to the risk. Just as in the case of the point analysis described above, the decisive risk factors include incomplete data on underground utilities and insufficient horizontal and vertical positioning accuracy of underground utilities. The factors involve different sets of values, so they need to be standardised.

Risk factor standardisation is the second stage of the procedure. The standardisation involves functions with the following set of values: $\{1, 2, \ldots, 8\}$. We excluded the (0,1) interval because projects always entail risk if only a small one. The intervals of the standardisation functions' values are defined based on two characteristics of spatial data quality, data completeness and data source. The values used in the standardisation functions are defined according to construction process technical files.

The first standardisation function for *incomplete underground utility data* (*ID*) is defined based on dataset completeness. The function is defined below:

$$f(ID) = \begin{cases} 1 & \text{for} \quad ID = \mathrm{I} \\ 2 & \text{for} \quad ID = \mathrm{II} \\ 4 & \text{for} \quad ID = \mathrm{III} \end{cases} \tag{3.1}$$

where:

$ID = \mathrm{I}$ – underground utility data incomplete in 0 – 10%,

$ID = \mathrm{II}$ – underground utility data incomplete in 11 – 30%,

$ID = \mathrm{III}$ – underground utility data incomplete in >30%.

The second standardisation function for *horizontal accuracy of underground utilities* (*HA*) is defined according to the source of the data. The function is defined below:

$$f(HA) = \begin{cases} 1 & \text{for} \quad HA = \mathrm{I} \\ 3 & \text{for} \quad HA = \mathrm{II} \\ 6 & \text{for} \quad DP = \mathrm{III} \\ 8 & \text{for} \quad HA = \mathrm{IV} \end{cases} \tag{3.2}$$

where:

$HA = \mathrm{I}$ – data source: site land survey,

$HA = \mathrm{II}$ – data source: cartometric measurements on a 1:500 analogue map,

$HA = \mathrm{III}$ – data source: cartometric measurements on a 1:1,000 analogue map,

$HA = \mathrm{IV}$ – data source: cartometric measurements on a 1:2,000 analogue map,

The third standardisation function for *vertical accuracy of underground utilities (VA)* is defined based on the existence or lack of data on the vertical position of buried pipes and cables. The function is defined below:

$$f(VA) = \begin{cases} 1 & \text{for} \quad VA = \mathrm{I} \\ 2 & \text{for} \quad VA = \mathrm{II} \end{cases} \tag{3.3}$$

where:

$VA = \mathrm{I}$ – the data set contains data on the vertical position,

$VA = \mathrm{II}$ – the data set does not contain data on the vertical position.

The next stage of the proposed risk assessment method is to define the risk impact. The risk consequences are defined with an impact weight function. The interval follows from expert knowledge and experience. The risk impact severity is estimated from a survey among contractors specialising in water, sewer, power, and gas networks.

The impact function is defined below:

$$f(p) = \begin{cases} 6 & \text{for} \quad p = \mathrm{I} \\ 3 & \text{for} \quad p = \mathrm{II} \\ 2 & \text{for} \quad p = \mathrm{III} \end{cases} \tag{3.4}$$

where:

$p = \mathrm{I}$ – very severe impact of the risk factor: incomplete underground utility data (*ID*),

$p = \mathrm{II}$ – severe impact of the risk factor: horizontal accuracy of underground utilities (*HA*),

$p = \mathrm{III}$ – moderate impact of the risk factor: vertical accuracy of underground utilities (*VA*).

The last stage of the procedure is to calculate the quantitative and qualitative risk levels. Quantitative risk is defined by a value calculated with the following formula:

$$R^2 = (bk \cdot p1)^2 + (dp \cdot p2)^2 + (dv \cdot p3)^2 \tag{3.5}$$

where:

$R$ is the risk of damage to underground utilities,

*id, ha, va* are normalised values of risk factors,

$p1$, $p2$ , $p3$ are risk impact weights for factors *ID*, *HA*, and *VA*.

The calculated numeric risk level is then used to determine qualitative assessment intervals and build the risk map. The numeric intervals of risk factor normalising functions and values of impact weights narrow down the calculated project risk to 24 numbers. Table 6 shows the calculated risk values.

Table 6. Range of the risk of damage to underground utilities

| **Item** | **Risk factor numeric value** | | | **Numeric value of weights for impact on:** | | | **Risk** | |
|---|---|---|---|---|---|---|---|---|
| | **Incomplete data (*ID*)** | **Horizontal accuracy (*HA*)** | **Vertical accuracy (*VA*)** | **(*ID*) $p1$** | **(*HA*) $p2$** | **(*VA*) $p3$** | **Qualitative *R*** | **Quantitative LR/MR/HR** |
| 1 | 1 | 1 | 1 | 6 | 3 | 2 | 7.0 | LR |
| 2 | 1 | 1 | 2 | 6 | 3 | 4 | 7.8 | LR |
| 3 | 1 | 3 | 1 | 6 | 9 | 2 | 11.0 | LR |
| 4 | 1 | 3 | 2 | 6 | 9 | 4 | 11.5 | LR |
| 5 | 2 | 1 | 1 | 12 | 3 | 2 | 12.5 | MR |
| 6 | 2 | 1 | 2 | 12 | 3 | 4 | 13.0 | MR |
| 7 | 2 | 3 | 1 | 12 | 9 | 2 | 15.1 | MR |
| 8 | 2 | 3 | 2 | 12 | 9 | 4 | 15.5 | MR |
| 9 | 1 | 6 | 1 | 6 | 18 | 2 | 19.1 | HR |
| 10 | 1 | 6 | 2 | 6 | 18 | 4 | 19.4 | HR |
| 11 | 1 | 6 | 2 | 6 | 18 | 4 | 19.4 | HR |
| 12 | 2 | 6 | 1 | 12 | 18 | 2 | 21.7 | HR |
| 13 | 2 | 6 | 2 | 12 | 18 | 4 | 22.0 | HR |
| 14 | 2 | 6 | 2 | 12 | 18 | 4 | 22.0 | HR |
| 15 | 4 | 1 | 1 | 24 | 3 | 2 | 24.3 | HR |
| 16 | 4 | 1 | 2 | 24 | 3 | 4 | 24.5 | HR |
| 17 | 1 | 8 | 1 | 6 | 24 | 2 | 24.8 | HR |
| 18 | 4 | 3 | 1 | 24 | 9 | 2 | 25.7 | HR |

*Continued on next page*

Table 6 – *Continued from previous page*

| **Item** | **Risk factor numeric value** | | | **Numeric value of weights for impact on:** | | | **Risk** | |
|---|---|---|---|---|---|---|---|---|
| | **Incomplete data (*ID*)** | **Horizontal accuracy (*HA*)** | **Vertical accuracy (*VA*)** | **(*ID*) *p*1** | **(*HA*) *p*2** | **(*VA*) *p*3** | **Qualitative *R*** | **Quantitative LR/MR/HR** |
| 19 | 4 | 3 | 2 | 24 | 9 | 4 | 25.9 | HR |
| 20 | 2 | 8 | 1 | 12 | 24 | 2 | 26.9 | HR |
| 21 | 4 | 6 | 1 | 24 | 18 | 2 | 30.1 | HR |
| 22 | 4 | 6 | 2 | 24 | 18 | 4 | 30.3 | HR |
| 23 | 4 | 8 | 1 | 24 | 24 | 2 | 34.0 | HR |
| 24 | 4 | 8 | 2 | 24 | 24 | 4 | 34.2 | HR |

$R = \sqrt{(BK \cdot p1)^2 + (DP \cdot p2)^2 + (DV \cdot p3)^2}$; LR – low risk, MR – moderate risk, HR – high risk.

The calculated risk value is within 7.0 to 34.2 points. This means that the minimum risk of damage to underground utilities during construction works is 7.0 points and the maximum risk of 34.2 points is nearly five times higher.

To present the risk level qualitatively, the quantitative risk is grouped into three intervals. We assumed that low risk (LR [7.0; . . . ; 11.5]) should occur when 90% complete data are used that had been obtained from site land surveys and cartometric measurements on a 1:500 analogue map. Moderate risk (MR [12.5; . . . ; 15.5]) should occur for spatial data where the share of incomplete data on underground utilities does not exceed 30%. In the remaining cases, the risk of damage to underground utilities should be high (HR [19.1; . . . ; 34.2]). The calculated qualitative risk is the foundation for 2D and 3D risk maps.

The 2D map of underground utility damage risk is a large-scale thematic map with qualitative project risk. The risk map created under the present study covers one cadastral district. Its underpinnings are the results of the risk analysis study (as presented above) and spatial data from the Utilities Database. The map follows the principle of superimposition of layers with different qualitative risk values (lowest to highest). In the first stage, the entire study area is overlaid with a low-risk layer. Next, the moderate-risk layer is generated and superimposed on the low-risk layer. Stretches of underground utilities with moderate risk are drawn with 1.5-metre thick lines on this layer. The last stage concerns the high-risk layer. Buried pipes and cables with high risk are drawn with 2.0-metre lines. Figure 3 shows an excerpt of the 2D risk map.

A 3D qualitative risk map is another useful tool to improve construction process safety. The x-axis and y-axis of the map represent the position of underground utilities and the R-axis represents the risk value (Fig. 4).

For large projects (of linear and enclosed structures), project risk assessment requires a solution founded on predefined risk factors and impact weights. This way, quantitative and qualitative risk can be estimated reliably. A large-scale risk map is a good tool for assessing the potential qualitative risk.

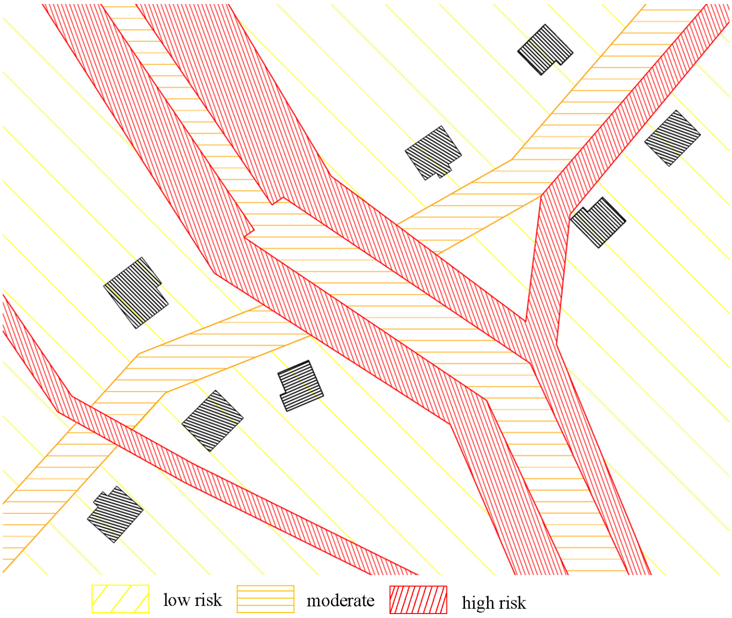

Fig. 3. Excerpt from the 2D risk map of underground utility damage

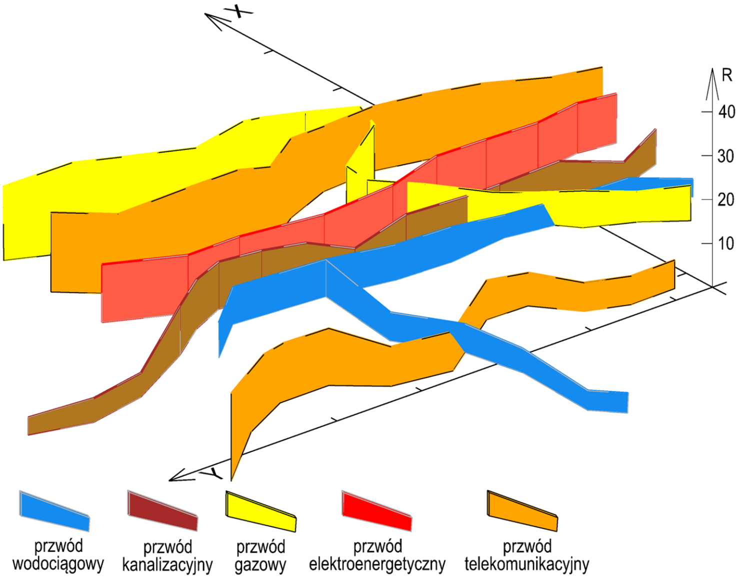

Fig. 4. Excerpt from the 3D risk map of underground utility damage

# 4. Conclusions

The risk of damage to buried pipes and cables is inherent to the construction process. One of the sources of this risk is the quality of spatial data. The literature enumerates three main reasons linked to the quality of spatial data why buried pipes and cables can be damaged. The first cause is the presence of underground utilities not recorded in a spatial database on a project site. This source is defined as an incomplete spatial data set. The second and third reasons concern the accuracy of horizontal and vertical positioning of buried pipes and cables in spatial databases, respectively.

The point risk analysis is founded on expert knowledge and experience, which directly contribute to the results of the evaluation. This method can reliably estimate the level of project risk for small projects (within a cadastral parcel). For large projects (of linear and enclosed structures), project risk assessment requires a solution founded on predefined risk factors and impact weights. This way, quantitative and qualitative risk can be estimated reliably. A large-scale risk map is a good tool for assessing the potential qualitative risk. The proposed map is a 2D and 3D cartographic document that represents the actual risk of damage to underground utilities due to spatial data quality.

# References

[1] I.N. Gleim, *CIA Review – Part I: The Internal Audit Activity's Role in Governance, Risk and Control.* Gainesville FL: Gleim Publications Inc., 2004.

[2] S. Kaplan and B.J. Garrick, “On the quantitative definition of risk”, *Risk Analysis*, vol. 1, no. 1, pp. 11–27, 1981.

[3] Y.Y. Haimes, *Risk Modeling*, *Assessment, and Management*. London: Wiley, 2015.

[4] M. Zhao and X. Liu, “Regional risk assessment for urban major hazards based on GIS geoprocessing to improve public safety”, *Safety Science*, vol. 87, pp. 18–24, 2016, doi:10.1016/j.ssci.2016.03.016.

[5] Q. Tan, M. Bai, P. Zhou, J. Hu, and X. Qin, “Geological hazard risk assessment of line landslide based on remotely sensed data and GIS”, *Measurement*, vol. 169, 2021, doi:10.1016/j.measurement.2020.108370.

[6] A. Malinowska, X. Cui, E.F. Salmi, and R. Hejmanowski, “A novel fuzzy approach to gas pipeline risk assessment under influence of ground movement”, *International Journal of Coal Science & Technology*, vol. 9, art. no. 47, 2022, doi:10.1007/s40789-022-00511-2.

[7] A. Malinowska, A. Guzy, R. Hejmanowski, and P. Ulmaniec, “Hybrid-approach for sinkhole occurrence risk mitigation in urban areas”, *IOP Conf. Series: Earth and Environmental Science*, vol. 291, 2019, doi:10.1088/1755-1315/291/1/012022.

[8] F.H. Bouzahar, L. Ouerdachi, M. Keblouti, and A. Seddiki, “The contribution of remote sensing in hydraulics and hydrology, analysis and evaluation of digital terrain model for flood risk mapping”, *Journal Of Water And Land Development*, no. 39, pp. 17–26, 2018, doi:10.2478/jwld-2018-0055.

[9] S. Cai, J. Fan, and W. Yang, “Flooding Risk Assessment and Analysis Based on GIS and the TFN-AHP Method, A Case Study of Chongqing, China”, *Atmosphere*, vol. 12, no. 5, pp. 623, 2021, doi:10.3390/atmos12050623.

[10] D. Zhang, X. Shi, H. Xu, Q. Jing, X. Pan, T. Liu, H. Wang, and H. Hou, “A GIS-based spatial multi-index model for flood risk assessment in the Yangtze River Basin, China”, *Environmental Impact Assessment Review*, vol. 83, art. no. 106397, 2020, doi:10.1016/j.eiar.2020.106397.

[11] V. Hadipour, F. Vafaie, and K. Deilami, “Coastal Flooding Risk Assessment Using a GIS-Based Spatial Multi-Criteria Decision Analysis Approach”, *Water*, vol. 12, no. 9, art. no. 2379, 2020, doi:10.3390/w12092379.

[12] P. Tomar, S.K. Singh, S. Kanga, G. Meraj, N. Kranjcic, B. Durin, and A. Pattanaik, “GIS-Based Urban Flood Risk Assessment and Management – A Case Study of Delhi National Capital Territory (NCT), India”, *Sustainability*, vol. 13, no. 22, art. no. 12850, 2021, doi:10.3390/su132212850.

[13] A.A. Belal, H.R. El-Ramady, S. Elsayed, and A.M. Saleh, "Drought risk assessment using remote sensing and GIS techniques", *Arabian Journal of Geosciences*, vol. 7, pp. 35–53, 2014, doi:10.1007/s12517-012-0707-2.

[14] S. Wijitkosum and T. Sriburi, "Fuzzy AHP Integrated with GIS Analyses for DroughtRisk Assessment: A Case Study from Upper Phetchaburi River Basin, Thailand", *Water*, vol. 11, no. 5, art. no. 939, 2019, doi:10.3390/w11050939.

[15] R. Jena, B. Pradhan, G. Beydoun, A. Al-Amri, and H. Sofyan, "Seismic hazard and risk assessment: a review of state-of-the-art traditional and GIS models", *Arabian Journal of Geosciences*, vol. 13, art. no. 50, 2020, doi:10.1007/s12517-019-5012-x.

[16] P. Yariyan, H. Zabihi, I. D. Wolf, M. Karami, and S. Amiriyan, "Earthquake risk assessment using anintegrated Fuzzy Analytic Hierarchy Process with Artificial Neural Networks based on GIS: A case study of Sanandaj in Iran", *International Journal of Disaster Risk Reduction*, vol. 50, art. no. 101705, 2020, doi:10.1016/j.ijdrr.2020.101705.

[17] E. Psomiadis, N. Charizopoulos, N. Efthimiou, K.X. Soulis, and I. Charalampopoulos, "Earth Observation and GIS-Based Analysis for Landslide Susceptibility and Risk Assessment", *ISPRS International Journal of Geo-Information*, vol. 9, no. 9, art. no. 552, 2020, doi:10.3390/ijgi9090552.

[18] A. Roccati, G. Paliaga, F. Luino, F. Faccini, and L. Turconi, "GIS-Based Landslide Susceptibility Mapping for Land Use Planning and Risk Assessment", *Land*, vol. 10, no. 2, art. no. 162, 2021, doi:10.3390/land10020162.

[19] Q. Zhenga, H. M. Lyua, A. Zhoub, and S.L. Shen, "Risk assessment of geohazards along Cheng-Kun railway using fuzzy AHP incorporated into GIS", *Geomatics, Natural Hazards And Risk*, vol. 12, no. 1, pp. 1508–1531, 2021, doi:10.1080/19475705.2021.1933614.

[20] X. Yang, X. Jin, and Y. Zhou, "Wildfire Risk Assessment and Zoning by Integrating Maxent and GIS in Hunan Province, China", *Forests*, vol. 12, no. 10, art. no. 1299, 2021, doi:10.3390/f12101299.

[21] Y. A. Hermawan, L. Warlina, and M. Mohd, "GIS-based urban village regional fire riskassessment and mapping", *International Journal of Informatics, Information System and Computer Engineering*, vol. 2, no. 2, pp. 143–155, 2021, doi:10.34010/injiiscom.v2i2.6041.

[22] P. Oort, *Spatial data quality: from description to application*. *Publications on Geodesy, no. 60*. Delft, 2005.

[23] A. Przewięźlikowska, "Right-of-way for Transmission Facilities as Regulation of Legal Relationships Regarding Real Estate between the Real Estate Owner and the Transmission Entity", in *10th International Conference: Environmental Engineering*, 2017, pp. 1–8, doi:10.3846/enviro.2017.233.

[24] A. Przewięźlikowska and R. Krzyżek, "Inwentaryzacja powykonawcza budynków w konteście zgodności usytuowania z projektem zagospodarowania terenu – As-built survey of buildings in the context of compliance of the location of the building with the site development plan for the plot", *Przegląd Geodezyjny*, no. 8, pp. 11–15, 2016.

[25] B. Tchórzewska-Cieślak, "Characterization of risk function in the analysis and assessment of water supply systems safety", *Technical Transactions*, vol. 3, pp. 187–196, 2018.

[26] Y. Kleiner, B.B. Rajani, and R. Sadiq, "Failure risk management of buried infrastructure using fuzzy-based techniques", *Journal of Water Supply Research and Technology – Aqua*, vol. 55, no. 2, pp. 81–94, 2006.

[27] B. Tchórzewska-Cieślak, "Rozmyty model ryzyka awarii sieci wodociągowej", *Ochrona Środowiska*, vol. 33, no. 1, pp. 35-40, 2012.

[28] P. Kostrzewa-Demczuk and M. Rogalska, "Planning of construction projects taking into account the design risk", *Archives of Civil Engineering*, vol. 69, no. 1, pp. 613-626, 2023, doi:10.24425/ace.2023.144191.

[29] T. Godlewski, E. Koda, M. Mitew-Czajewska, S. Łukasik, and S. Rabarijoely, "Essential georisk factors in the assessment of the influence of underground structures on neighboring facilities", *Archives of Civil Engineering*, vol. 69, no. 3, pp. 113-128, 2023, doi:10.24425/ace.2023.146070.

# Analiza ryzyka uszkodzenia sieci podziemnego uzbrojenia terenu, spowodowanego jakością danych przestrzennych

**Słowa kluczowe:** jakość danych przestrzennych, zarządzanie ryzykiem, GIS, mapa ryzyka

## Streszczenie:

Ryzyko uszkodzenia podziemnych rur i kabli jest nieodłącznym elementem procesu budowlanego, a jednym z jego źródeł jest jakość danych przestrzennych. Istnieją trzy główne przyczyny uszkadzania podziemnych rur kabli, których źródłem jest jakość zbioru danych przestrzennych. Pierwsza przyczyna wynika z obecności na obszarze inwestycji podziemnego uzbrojenia terenu, które nie istnieje w bazie danych przestrzennych. Takie źródło ryzyka jest zdefiniowane jako brak kompletności zbiorów danych przestrzennych. Druga i trzecia przyczyna ryzyka dotyczy odpowiednio dokładności położenia poziomego i pionowego rur oraz kabli gromadzonych w przestrzennych bazach danych. Punktowa analiza ryzyka bazuje na wiedzy i doświadczeniu ekspertów, które bezpośrednio wpływają na wynik oceny. Metoda ta pozwala dobrze oszacować poziom ryzyka projektowego przy realizacji małych inwestycji (obszar działki ewidencyjnej). Ocena ryzyka projektowego dla dużych inwestycji (liniowych i kubaturowych) wymaga zastosowania rozwiązania bazującego na zdefiniowanych czynnikach ryzyka i określonych wagach oddziaływania. Takie postępowania zapewnia rzetelne szacownie poziomu ryzyka ilościowego i jakościowego. Obliczona wartość ryzyka należy do przedziału od 7,0 do 34,2 punktów. Oznacza to, że minimalne ryzyko uszkodzenia podziemnych rur i kabli podczas wykonywania prac budowlach wynosi 7,0 punktu, a ryzyko maksymalne jest prawie pięciokrotnie większe: 34,2 punktów. Dobrym narzędziem oceny potencjalnego ryzyka jakościowego jest wielkoskalowa mapa ryzyka. Wykonana przez autorów pracy mapa jest dwu- i trzywymiarowym (2D i 3D) opracowaniem kartograficznym, które prezentuje rzeczywiste ryzyko uszkodzenia sieci podziemnego uzbrojenia terenu, spowodowanego jakością danych przestrzennych.

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