

## Landslide25\_25

### Factors of the ground surface subsidence above the flooded coal mines in the Donetsk region: new dangers and risks

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#### **SUMMARY**

This study investigates the complex processes leading to ground surface subsidence above flooded coal mines in the Donetsk region, where military activities have intensified geological and hydrodynamic instability. Based on long-term monitoring data and expert analysis, ten primary factors influencing subsidence were identified. Depending on their origin, all factors were divided into 4 groups: geomechanical factors, water and hydrogeological factors, influence of the surface and other factors (including anthropogenic and military impacts). Particular attention is given to the compounding effect of military impacts, such as missile strikes and air bombings, which generate dynamic wave loads, amplify rock fracturing, and destabilize already weakened mine structures. Aggressive groundwater composition, high temperatures and structural loads further enhance subsidence mechanisms. The synergistic action of chemical corrosion and explosive dynamic loading leads to rapid collapse of mine roofs and asymmetrical ground settlement. The modeling results demonstrate an increase in the rate of surface subsidence by 1.5–2 times, while the depth of local failures reaches 1.5 meters.

## Introduction

Recently, as a result of military actions in the Donetsk region, there has been an uncontrolled mass closure and flooding of coal mines. Almost all of the mining equipment remained in the flooded mines. At the same time, geological, hydrogeological, hydrodynamic and geomechanical conditions in the mines change (*Bagheri-Gavkosh et al., 2021*). Stopping the mines without prior preparation for flooding accelerates the destruction of mine supports and the collapse of rocks, which leads to accelerated subsidence of the ground surface above the flooded mines. Rock massifs above mine workings are subject to additional influence of new factors. One of the most critical is the high-energy external impact associated with missile attacks and bombing of the surface in areas located above underground mine structures. The military impact factor in the mining region increases the influence of other negative factors and accelerates the subsidence of the ground surface, destabilizing the ecosystem (*Celauro et al., 2023*).

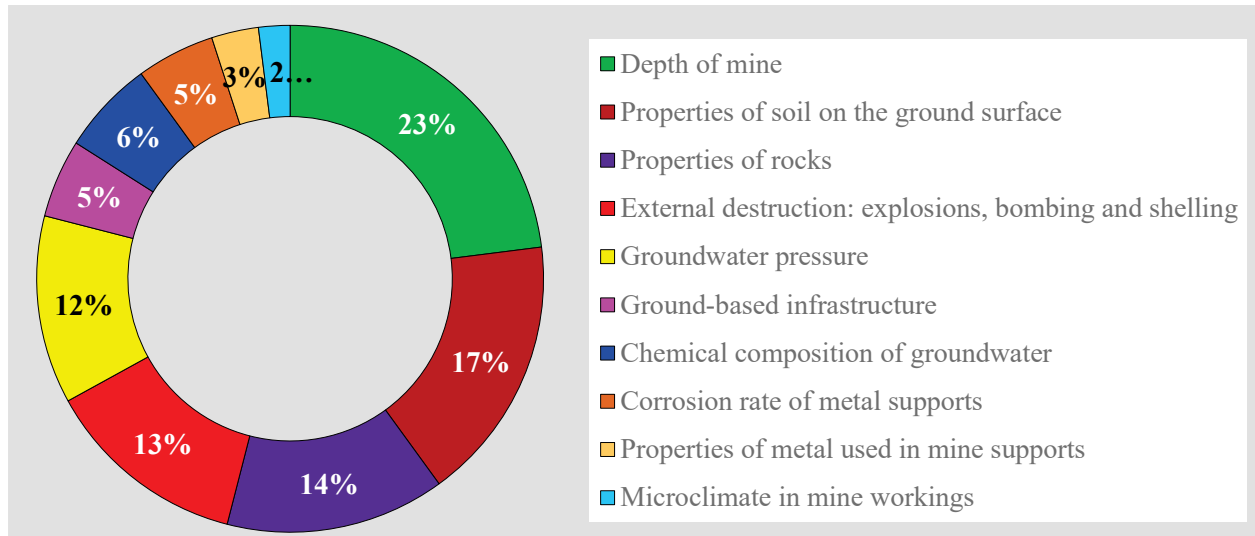
## Results

The depth of a coal mine is a key factor determining the size of the subsidence zone, the nature of rock and structure destruction, and the role of groundwater and filtration. With increasing depth of the mine, the total geomechanical stress, the volume of rock involved in the destruction, as well as the time and amplitude of surface deformations increase (*Peng, 2019; Yan et al., 2021*). With increasing depth of mine workings, the intensity of groundwater inflow rises, particularly in zones composed of fractured rocks. At the same time, both water temperature and the concentrations of dissolved gases and ions increase significantly (*Shvets et al., 2025a*). This creates an aggressive environment, increasing the rate of corrosion of metal support elements (*Shvets et al., 2025b*). The second factor in terms of significance in influencing the subsidence of the ground surface is the properties of the soil on the surface. Clay soils are structurally unstable and degrade integrity of the soil in combination with underground water flows (*Wang et al., 2022*). The mechanical properties and geological structure of the rocks above a mine working influence the spatial distribution and dynamics of subsidence of the ground surface (*Cao et al., 2021; Li et al., 2024*). Low-strength rocks are subject to intense deformation after the workings lose stability. Stronger rocks such as sandstones and limestones are less resistant to vertical movements, but subsidence in them may be more extensive in area and develop slowly over time. At high pressure, the flow of groundwater washes away small particles of rock and soil (*Yoon et al., 2011*). As a result, the stability of the rocks decreases, which increases the subsidence of the soil.

Groundwater with an aggressive chemical composition (high acidity, presence of dissolved salts) accelerates the corrosion of metal supports and the destruction of rocks, which leads to weakening of the mine supports (*Zbykovskyy et al., 2025*). The microclimate in the mine, especially the temperature regime, affects the rate of chemical reactions, including the corrosion of supports and the processes of rock weathering. Higher temperatures accelerate corrosion processes and the destruction of structures. Metals with low corrosion resistance are destroyed faster in aggressive conditions, which reduces the durability of supports and increases the likelihood of mine workings collapsing. Ground infrastructure is an additional load, increasing the pressure on the ground surface and contributing to ground subsidence when underground workings are destroyed (*Strozik et al., 2016*). Currently, coal mines in Donetsk region are located in the zone of active military actions, which is an additional risk factor for subsidence of the ground surface. Explosions and bombings create impulse loads. Dynamic waves increase rock fracturing. Rock vibrations activate existing geomechanical processes that cause deformation and destruction of supports.

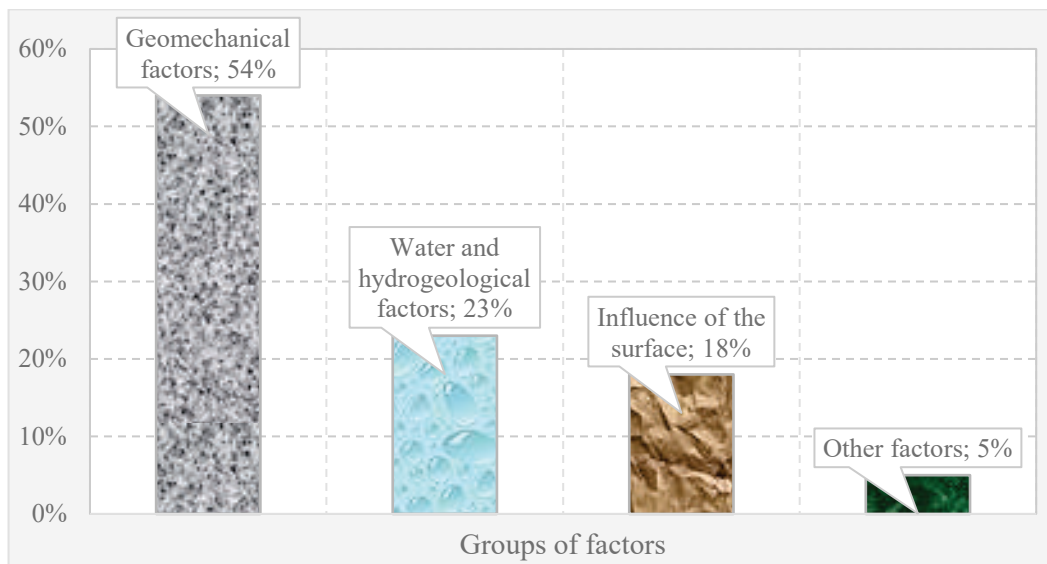
As a result of the analysis of factors influencing the subsidence of the ground surface above the flooded coal mines, 10 main factors were identified for subsequent expert assessment of the degree of their influence. The work is based on the results of an analysis of actual data on the subsidence of the ground surface above flooded mine workings in the Donetsk region over the past 20 years. The expert assessment was carried out on the basis of information on monitoring the territories above abandoned and operating mines. The factors

affecting the process and the degree of their influence on the subsidence of the ground surface above the flooded coal mines are shown in Figure 1.



**Figure 1** Diagram of the degree of influence of factors on ground subsidence above the flooded coal mines.

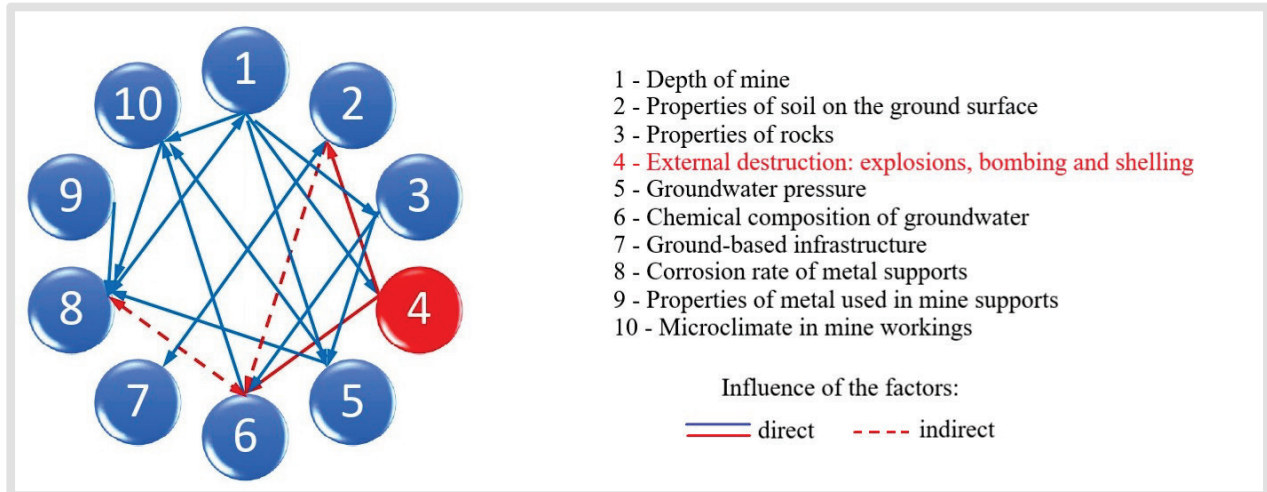
Depending on their origin, all factors were divided into 4 groups: geomechanical factors, water and hydrogeological factors, influence of the surface and other factors. A summary assessment of the degree of their influence on the subsidence of the ground surface was made and these factors were ranked (Fig. 2).



**Figure 2** Groups of factors influencing ground subsidence above flooded mine workings.

Experience shows that in real conditions it is impossible to give a quantitative characteristic of factors and assess the degree of influence of each of them. However, some factors may act at different rates and with different strengths. There is also a mutual influence of factors and an indirect impact on processes. The grouping of factors allows us to structure the diversity of factors and their impacts on the subsidence of the ground surface.

In the Donetsk region, artillery shelling, air bombing, and missile strikes are an additional factor of external anthropogenic impact. At the same time, physical processes that intensify subsidence-related deformations are activated and accelerated. As a result of explosions, seismic waves propagate through the rock mass, repeatedly amplifying shock resonance and vibration amplitude. The rock mass loses stability, and interlayer contacts are disrupted. As a result, permeability of the rocks increases due to the formation of new fractures. This causes a redistribution of pressures and groundwater flows within the saturated horizons, as well as hydrodynamic erosion of the clay roof strata. A breakthrough of the water-bearing horizon may induce roof collapses. Thus, the external factor has not only a direct but also an indirect influence on the action of other factors, enhancing them (Fig. 3).



**Figure 3** Mutual influence of factors on subsidence of the ground surface above the mine workings.

In flooded mines, under conditions of highly mineralized water with elevated temperature and high concentrations of aggressive chlorides and sulfates, accelerated corrosion of all support elements occurs. As their load-bearing capacity deteriorates under dynamic effects (blast waves), the support structures fail instantaneously, leading to roof collapse. The combination of dynamic excitation of the rock mass, increased hydraulic pressure in the saturated horizons, and corrosion-induced deterioration of the supports produces a synergistic effect, accelerating the rate of subsidence deformations. Calculations show that the rate of vertical subsidence increases by 1.5 to 2 times, while the depth of local collapses with an asymmetric profile reaches from 1 to 1.5 meters.

## Conclusions

In the territory of Donetsk region, under conditions of uncontrolled mine flooding and ongoing military actions, an intensification of ground subsidence processes is predicted. The main causes include support failure, rock mass collapse, changes in hydrogeological conditions, and external dynamic impact. Based on expert analysis, ten key factors influencing the development of subsidence deformations have been identified. All factors were grouped into four categories: geomechanical, hydrogeological, surface influence factors, and others (including anthropogenic and military impacts). Geomechanical processes have the greatest influence, accounting for 54% of the total impact. Military actions accompanied by missile, artillery and air strikes enhance the effect of all other factors, creating a cumulative effect. The combination of the mechanical impact of the blast wave, the chemical aggression of highly mineralized waters and the increase in hydraulic pressure in the horizons leads to a synergistic effect, sharply accelerating the development of subsidence of the ground surface. The presented results emphasize the need to take into account the military factor in the engineering assessment of the geodynamic stability of areas previously mined by coal mines.

Monitoring and modeling of ground surface subsidence processes must take into account multifactorial non-stationary high-energy impacts under conditions of active military operations.

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