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Integrated Geophysical Surveying for Landslides on the Slopes of the Kyiv-Pechersk Lavra Using Electrical Resistivity Tomography and Self-Potential Methods

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SUMMARY

Slopes in urban agglomerations are increasingly vulnerable to gravity-driven geohazards, which pose significant risks to historical infrastructure and cultural heritage sites. At the UNESCO-protected Kyiv-Pechersk Lavra, continuous slope instability threatens structural integrity, demanding advanced, non-destructive monitoring techniques. This study assesses soil characteristics and slope instability risks within the Blyzhnepecherskyi Garden through an integrated, non-invasive electrical prospecting. Subsurface features were mapped across a multi-profile grid using two complementary geophysical techniques: Electrical Resistivity Tomography (ERT) with a Schlumberger array to measure electrical resistivity down to a depth of 20 meters, and the Self-Potential (SP) method to track hydrogeological variations between 2024 and 2026. The ERT 2D inversion models revealed strong structural heterogeneity, transitioning from a dense, high-resistivity undisturbed block in the west to an extensive low-resistivity zone in the east. The SP surveys demonstrated a pronounced negative potential minimum spatially aligning with the low-resistivity ERT zone. These converging geophysical surveys delineate an active hydrogeological filtration zone where groundwater infiltration and high moisture saturation drive structural decompaction within the slope mass.

Keywords: Kyiv-Pechersk Lavra; landslide monitoring; Electrical Resistivity Tomography; Self-Potential method; Non-destructive geophysical survey.

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Introduction

The Kyiv city area is characterized by a dissected relief with significant elevation drops and steep slopes, creating conditions for strong gravitational forces and triggering landslide events. Landslides are among the most widespread geohazards in urban agglomerations. In Ukraine, unstable soil formations are common; when subjected to mechanical loads and water saturation, they undergo vertical deformation, accelerating slope instability.

At the Kyiv-Pechersk Lavra National Reserve (Pecherskyi District, Kyiv), a UNESCO-protected architectural site of major historical significance, landslide activity occurs continuously and is closely monitored by specialists to preserve its archaeological and cultural heritage while ensuring engineering stability. Given the protected status of such sites, their investigation requires specialized non-destructive methods, including geophysical techniques such as Electrical Resistivity Tomography (ERT) and the Self-Potential (SP) method (Cherevko et al., 2024).

The main purpose of this study is to investigate the electrical characteristics of the soils within the Blyzhnepecherskyi Garden and to analyze the risk of landslides in the Kyiv-Pechersk Lavra National Reserve through the comprehensive application of electrical prospecting methods. The object of the study was the near-surface soil layer located within the Garden of the Reserve. The subject of the research is the electrical properties of soils and changes in their spatial distribution.

Method and Theory

The study area is located in the central part of the city of Kyiv, in Pecherskyi district on the right bank of the Dnipro. In geomorphological terms, the site is situated in the middle section of the right-hand slope of the Lavra Ravine, which forms part of the Spaska Ravine system. (Smoliy et al., 2007).

Landslide drivers encompass three primary mechanisms: morphological alterations of the slope, degradation of rock physical-mechanical properties, and supplementary hydrodynamic or mechanical pressures (Shostak, 2010). Among these triggers, groundwater dynamics play a decisive role, as infiltration and seepage along displacement surfaces generate distinct natural electric potentials.

To investigate the subsurface geological structure and slope stability, Electrical Resistivity Tomography (ERT) and Self-Potential (SP) methods were applied. Fieldwork was performed using a modern ABEM Terrameter LS2 (Sweden). The equipment allows an electric current to be passed into the ground and automatically calculates the apparent resistivity of the soils. (Bondar et al., 2023). The multi-channel system automatically managed electrode combinations, recorded electrical parameters, and stored apparent resistivity datasets for subsequent computer processing and 2D inversion modeling to evaluate the structural integrity of the slope down to a depth of 20 meters.

During the survey, the Schlumberger array was used. It is a symmetrical four-electrode system optimal for deep electrical prospecting(Koliushko et al., 2021). It consists of two source electrodes (A, B) and two measuring electrodes (M, N), arranged in a straight line with a common center.

To complement ERT, the Self-Potential (SP) method was applied. The method relies on measuring naturally occurring electric potentials arising from natural physical, chemical, and hydrogeological subsurface processes. Key sources of the natural electric field include groundwater filtration through rocks, electrochemical processes at mineral contacts, solute diffusion, and stress-strain state variations in rocks, with groundwater movement being the most dominant factor. (Vyzhva et al., 2013).

Overall, the observation grid comprised five survey profiles oriented west-to-east across the study area, with a 5-metre spacing between measurement points (Fig. 1b). The study area coincides with the zone previously investigated in 2024 (marked by a red triangle) (Fig. 1a) by students from the Institute of Geology in collaboration with GEOFIZTEKS LLC.

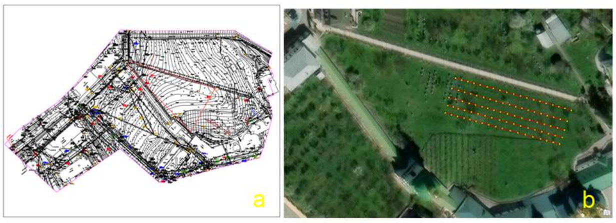

Figure 1. *A grid of profiles within the Kyiv-Pechersk Lavra Nature Reserve in 2024(a) and 2026 (b)*

Measurements of potential differences were conducted between a single fixed reference electrode and all observation points across the study grid, moving a second electrode sequentially along the profiles to evaluate geological structures, fracturing, groundwater pathways, and active landslide processes. Testing the electrodes in pairs using a multimeter in damp soil made it possible to identify the pairs with the lowest intrinsic polarisation, which should not exceed ±1-2 mV. For earthing during fieldwork, holes up to 10 cm deep were dug. It should also be noted that the measurements were taken at roughly the same time in June, which is an important aspect of monitoring.

Results

Field measurements executed across the study grid using the Self-Potential (SP) method allowed for the construction of a natural electric field isoline map in Surfer software, revealing the spatial distribution of potential anomalies. The average measurement error was 1.8 mV, which meets the requirements. An analysis of the 2024 natural electric field isoline map (Fig. 2a) reveals spatial heterogeneity in the distribution of potentials within the study area. Potential values range from –20 to +30 mV, representing a total range of 50 mV.

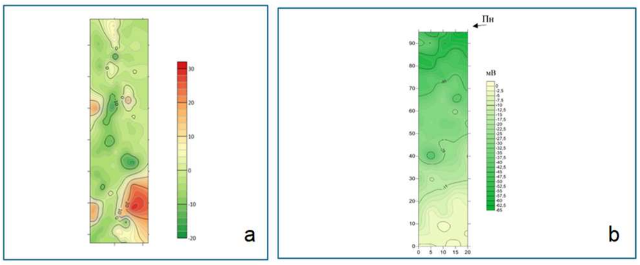

Figure 2. *Map of potentials in 2024(a) and in 2026(b) in the Blyzhnepechersky Garden (mV)*

A clearly defined local positive anomaly (red-orange tones, above +30 mV) is observed, concentrated in the eastern part of the study area. This anomaly has an isometric shape, which may indicate the presence of a localised source of elevated potential. The occurrence of positive anomalies in the natural field is traditionally associated with the upward movement of groundwater, redox processes at the interfaces between rocks of different lithological composition, or with the presence of dense, low-permeability inclusions (construction debris, compacted man-made soil).

Against a background of relatively stable, near-zero values in the central and western parts of the site, several smaller negative anomalies (down to –20 mV) stand out, most notably in the central part of the profile. Rather than a continuous gradient, these localized zones indicate a heterogeneous near-surface structure and spatially align with topographic depressions and natural runoff pathways activated during precipitation and seasonal snowmelt.

The potential values for 2026 (Fig. 2b), vary within a range from 0 to –65 mV. A gradual change in potential values can be observed from west to east (from survey point 0 to 90). In the western part of the site, the least negative values are recorded (0-10 mV, light yellow tones), which gradually transition through intermediate average values in the central part of the profile to a pronounced potential minimum (down to –65 mV, dark green tones) in the eastern part of the site. Within the overall gradient, local negative anomalies can also be observed at survey points 40-45 and 65-70 on the profile. Their presence against the general background indicates additional sources of increased filtration activity – likely areas of concentrated runoff or localised moisture accumulation.

The resulting image of the natural electric field indicates the heterogeneous nature of near-surface processes in the study area, accompanied by significant temporal dynamics in the hydrogeological regime from 2024 to 2026. The combination of intensive groundwater infiltration and heightened soil water saturation exerts a complex destructive effect on slope stability. Prolonged hydrogeological activity, coupled with static loads from surface structures and periodic dynamic impacts, promotes structural decompaction, weakening the overall integrity of the rock mass.

Using the ERT method, calculated values of apparent resistivity were obtained along the I-I profile for the Schlumberger array (Fig. 3). This array enabled the soil structure to be probed to a depth of 20 metres to confirm the anomalies.

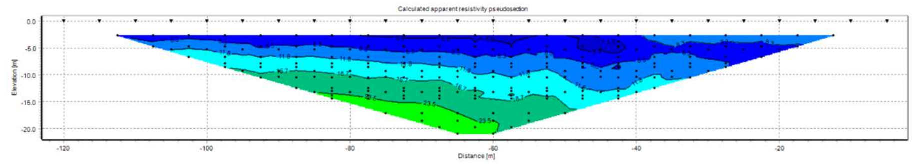

Figure 3. *Map of calculated values of apparent resistivity at section I-I*

Having analysed this cross-section, we can clearly identify a significant area of excessive moisture in the eastern part of the site, which correlates with the natural field potential values. A relatively conductive layer, observed from a depth of 5 m in the western part of the profile, gradually extends to a depth of over 10 m in the eastern part, forming a distinct low-resistance zone. The minimum apparent resistivity values (23.5 Ohm·m) were recorded in the deepest central part of the section. Also visible on this image, at a distance of 80-100 m, is a zone with relatively higher resistivity values, differing from the local background. This local high-resistance section, situated amidst a predominantly conductive medium, most likely corresponds to a denser, slightly moist inclusion that disrupts the overall homogeneity of the filtration zone.

Based on the inversion of the electrical tomography data, a 115 m geoelectric section was obtained (Fig. 4), with resistivity values ranging from approximately 3–4 to 570 Ohm·m and pronounced lateral and vertical heterogeneity reflecting variations in lithological composition and moisture content. The inversion showed a satisfactory fit to the input data, with a mean absolute error of approximately 2.07%.

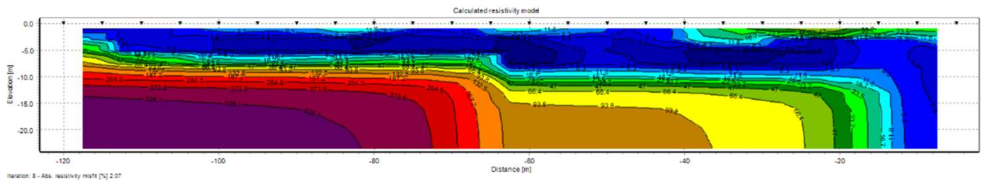

Figure 4. *Inversion model of specific electrical resistivity at section I-I*

The eastern part of the section, from approximately 80 to 115 m, is most characteristic for assessing the landslide process. Here, the upper and middle parts exhibit extensive low- to medium-resistivity zones (approximately 4-30 Ohm·m), with locally increasing thickness and complex, stepped boundaries between them, suggesting non-uniform moisture distribution and localised overmoistening within the landslide body. A local anomaly within the near-surface section, at approximately 85-105 m, deserves particular attention, showing relatively high resistivity values compared with the surrounding low-resistivity strata. At a depth of 4-5 m, small chamber-like structures were identified, possibly associated with historical cave branches of the Kyiv-Pechersk Lavra; similar features recorded during the 2023 investigation of the Metropolitan's Cellar coincided precisely with its underground passages, though this correlation requires further investigation.

At the same time, a system of low-resistivity zones can be observed below this section, which may indicate a possible accumulation and redistribution of moisture in the lower part of the soil mass. The western part of the profile is characterised by the predominance of a thick, high-resistivity layer, whilst towards the eastern part, the role of low-resistivity soils-presumably more saturated-increases. The most potentially hazardous section is the transition zone from the high-resistance mass to the low-resistance layer.

Although a precise correlation between the 2024 ERT results and the natural field potential measurements cannot be established because the ERT survey was conducted in a higher-elevation area that only partially overlaps the SP grid, the detected anomalies remain consistent, with the natural field behaviour indicating intense subsidence processes. The low-resistivity landslide mass observed to the east of the ERT section corresponds to a highly conductive area, as further confirmed by the natural field values, indicating pronounced processes within a relatively small survey zone.

Conclusions

The integrated application of Electrical Resistivity Tomography and Self-Potential methods within the Blyzhnepecherskyi Garden of the Kyiv-Pechersk Lavra National Reserve has confirmed the presence of an actively developing landslide body in the eastern part of the studied slope. The ERT model revealed pronounced lateral and vertical heterogeneity in resistivity, with a well-defined transition from a high-resistivity, undisturbed western mass to an extensive low-resistivity, moisture-saturated zone in the east, identified as the most hazardous section of the profile. The SP surveys, conducted in 2024 and 2026, consistently detected pronounced anomalies concentrated at the same eastern edge of the grid in both years. Spatial agreement between the low-resistivity zones identified by ERT and the negative SP anomalies confirms that intensive groundwater infiltration, combined with additional structural and dynamic loading, is driving progressive decompaction and weakening of the slope mass. Consequently, an integrated geophysical approach using ERT and SP methods is an effective tool for long-term landslide monitoring at heritage sites such as the Kyiv-Pechersk Lavra.

References

Bondar, K., Khomenko, R., & Bobrovskyi, T. (2023). Electrical resistivity tomography – an effective geophysical method for searching and mapping cave structures in the Sofia Kyivska Sanctuary. Kyivski zbirnyky istorii, arkheolohii, mystetstva ta pobutu, 1(4), 16-26. https://doi.org/10.55389/2786-5797.2023.01.02

Cherevko, A., Kril, T. V., & Bezrodnyi, D. A. (2024). Non-destructive methods of establishing a cause-and-effect relationship between water supply network accidents and the conditions for preserving architectural heritage. Geological Journal, (3), 11-30. https://doi.org/10.30836/igs.1025-6814.2024.3.307769

Koliushko, D. G., Rudenko, S. S., & Saliba, A. N. (2021). Method of integro-differential equations for interpreting the results of vertical electrical sounding of the soil. Electrical Engineering & Electromechanics, (5), 67-70. https://doi.org/10.20998/2074-272X.2021.5.09

Shostak, A. V. (2010). Engineering geology: A textbook. Taras Shevchenko National University of Kyiv Internet Resource. https://lnk.ua/3uStxQMxc

Smolii, V. A. (Ed.). (2007). Encyclopedia of History of Ukraine (Vol. 4: Ka-Kom). Naukova Dumka.

Vyzhva, S. A., Reva, M. V., Onyshchuk, I. I., Onyshchuk V. I. (2013). Elektrometriia. Posibnyk iz navchalnoi heofizychnoi praktyky : navch.-metod. vydannia. Kyiv : Vydavnycho-polihrafichnyi tsentr «Kyivskyi universytet» https://geophys.knu.ua/education/library