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Local forecast of landslide hazards: case study from Kyiv region

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SUMMARY

Landslide processes occur on slopes of different structure and morphology. One of the regions of active development of landslides in Ukraine is the Kyiv, where the mass movement processes have significant impact on the infrastructure. The determining factors of these processes are lithologic and stratigraphic conditions; hydrogeological regime; structural and textural features of rocks; geomorphology of slopes. The second category of factors includes dynamic processes that change the state of slopes, erosion, tectonic regime of the area, and anthropogenic impact. During the long-term experience of observations many landslides and landslide-prone areas were described. The database of landslides within the Kyiv region has been developed. It includes more than 120 landslides. The landslides within this region are examples of the structural landslides forming in a quasi-homogeneous environment with a layered structure. Monitoring of landslide activity for the local predictions using geological and geophysical methods has been carried out within the Glynka site in Pecherskyi district of Kyiv. The data obtained by Electrical Resistivity Tomography, Self-potential method and Infrared Thermography has been applied in order to investigate the lithostratigraphic sequences, the geometry of landslide body and potential mass movement. These methods allow to allocate the fracture zones and places with a high water saturation. It has been confirmed the potential development of new displacement within this site. It helps to plan the mitigation activities and interventions.

Introduction

Landslide processes occur on slopes of different structure and morphology. The main causes of these processes are lithologic and stratigraphic conditions; hydrogeological regime; structural and textural features of rocks; geomorphology of slopes. The second category of factors includes hydrometeorological factors, dynamic processes that change the state of slopes, erosion, weathering, tectonic regime of the area, seismicity and anthropogenic effects. Each of the processes of mass movement requires special approaches to their modeling and forecasting, determined by geological models, relevant mathematical models and algorithms (Ivanik et al., 2019).
One of the regions of active development of landslides in Ukraine is the Kyiv, where the mass movement processes have significant impact on the infrastructure. During the long-term experience of observations many landslides and landslide-prone areas were described. Accordingly, inventories of these objects have been created. The database of landslides within the Kyiv region has been developed. It includes more than 120 landslides (Figure 1). This database contains parameters of landslides (depth of surface of rupture, lithology of the rocks, etc.), description of their causes and impact on the infrastructure.

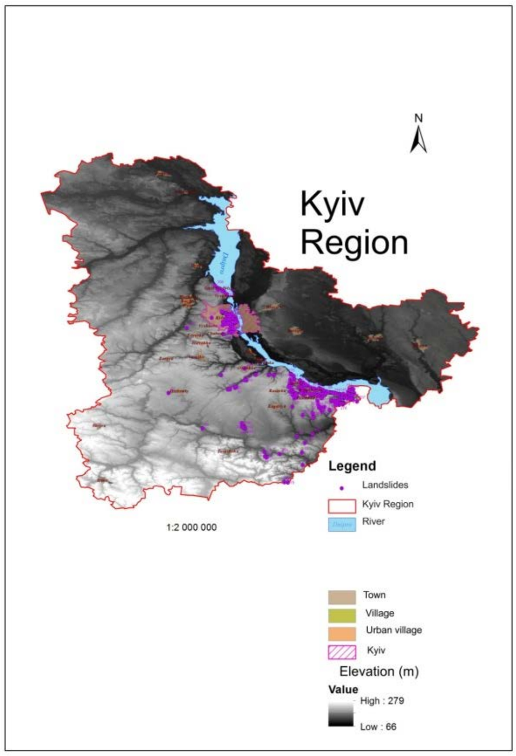

Figure 1 *Distribution of landslides within Kyiv and Middle Dnieper area*

Method and Case study

Tectonically, the territory of the Kyiv area is located within the the Bila Tserkva (Fastovsky) block on the northern slope of the Ukrainian shield. The crystalline basement has a series of faults of the submeridional, sub-latitudinal, northeast, and north-west direction. The most active are regional structures with a difference in the indicators of total amplitudes of movements up to 60 m. The largest zone is a zone of the Kyiv fault - corresponds to significant indicators of average velocity gradient of neotectonic movements - more than 0.01 (cm/km)/ths. years. The area belongs to the glacial area of the northeastern periglacial subregion. There are deposits of the Paleogene, Neogene and Quaternary systems. The hydrogeological conditions of the slopes are associated with aquifers in the upper, middle Neopleistocene alluvial sediments, in the Middle-Lower Neopleistocene and Eopleistocene alluvial and lake sediments, in the Middle Neopleistocene aquatic-glacial, lacustrine-glacial loams, Lower Neopleistocene Eolian-Deluvial loams, in Mezhigirsky-Bereksky and Novopetrivsky sediments, Eocene sediments. Lithological, stratigraphic, geomorphological and hydrogeological conditions in conjunction with the hydrometeorological factor determine the intensive development of landslide processes.

Monitoring of landslide activity for the local predictions using geological and geophysical methods has been carried out within the landslide site Glynka in Pecherskyi district of Kyiv (Figure 2). Here the Paleogene rocks are represented by Eocene-Oligocene sediments of the Kharkivska series ($P_{2\text{-}3}$ *hr*). The Neogene system is represented by sediments of Poltavska series (P_3 -N_1 *pl*), Quaternary rocks are represented by sandy loamy rocks. Lake Glynka is a flooded quarry, in the right side of which deposits of the Kharkivska series are exposed, represented by blue-green clay silts (Obukhiv Formation), in which a weak-water horizon is formed, and green striped sand with interlayers of clay (Mezhigirska Formation). Upper we can observe the sand silts of the Berek (Oligocene) Formation of Paleogene. These formations are covered by Neogene deposits represented by quartz sand, siltstones and white loose fine sands of the Novopetrivska Formation (Lower-Middle Miocene).

The causes of landslides are big height of the slope, a suffosion phenomenon - a consequence of groundwater outflow to the surface of the slope, washout of the coast by increasing the water level in the lake. There is a real threat of destruction of the heating system and water supply system, as landslide processes are constantly spreading towards Akademika Filatova Street and Mendeleeva Street. There are new cracks along the slope flank closer to Mendeleev St., which indicates the possibility of a new displacement in the near future, which is confirmed by data from Electrical Resistivity Tomography, Self-potential method and Infrared Thermography.

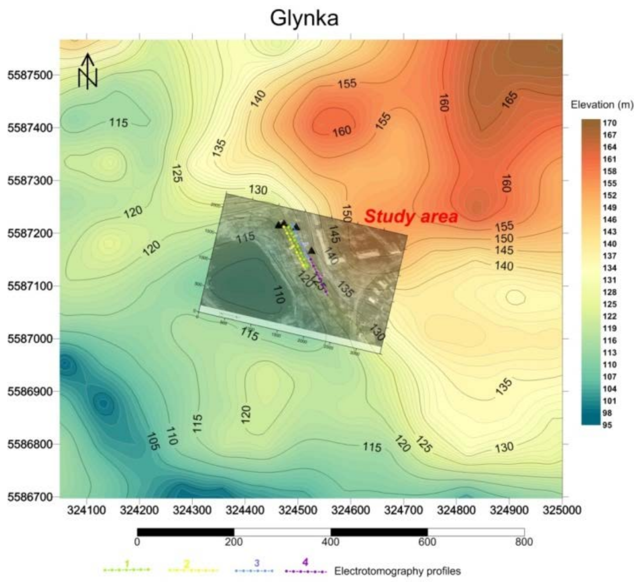

Figure 2 *Location map of the Glynka Site (Kyiv)*

Self – Potential method is used for imaging water level and water flows within the subsurface at a large scale, as well as their fluctuations over time (Patella, 1997). Surveys are conducted by measuring natural electrical potential difference between pairs of electrodes connected to a high impedance voltmeter. *The electrical resistivity method* is one of the most used geophysical methods in shallow investigation (Telford et al., 1990; Reynolds, 1997; Marescot et al., 2008). The Vertical Electrical Sounding (VES) and 2D Electrical resistivity Tomography technique, based on the measurement of the electrical resistivity values and their spatial distribution in the subsoil, has been applied to landslides in order to investigate both the lithostratigraphic sequences and the geometry of landslide body (lateral extension and thickness). Resistivity changes due to varying moisture conditions, as well as differences between geological units have been recognized from 2D-sections. Indeed, during the pre-event phase, it is very important to gather information both on the geological setting of the potentially unstable area and the presence of water tables that could trigger off the phenomenon. After the event, it is important to know the geometry of the landslide body and estimate the volume of the slide material, in order to plan the mitigation activities and interventions (stabilization structures, etc). (Perrone & Lapenna & Piscitelli, 2014).

Investigations within the Glynka site demonstrate the high potential of Electrical resistivity Tomography, Self-potential method and Infrared Thermography. The zones of the potential activity of landslides have been allocated due to combination of these techniques. The application of Electrical Resistivity Tomography and Self potential Method at the Glynka site (Figure 3) allows to allocate the lithostratigraphy units, fracture zones and places with the high water saturation.

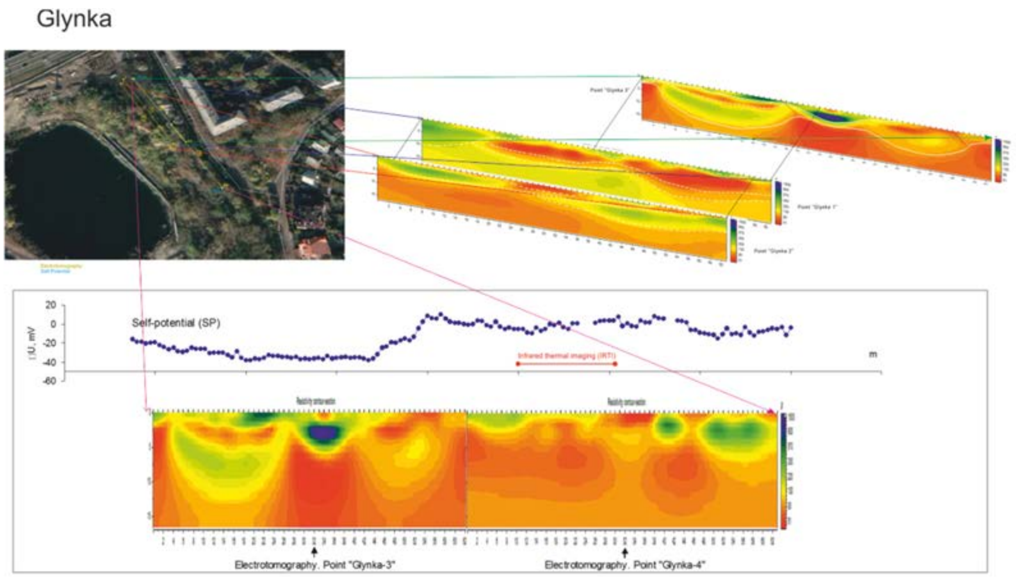

Figure 3 *Intergrated Self-potential (SP) and resistivity data, Glynka site*

For processing and interpretation of Electrical Resistivity Tomography data the following software packages were used: ZondRes2d (Dahlin, 1996) and R2dmodwin (Loke, 1995-2013). Electrical Resistivity tomogram with high differentiation of specific electrical resistivity was constructed (Figure 4).

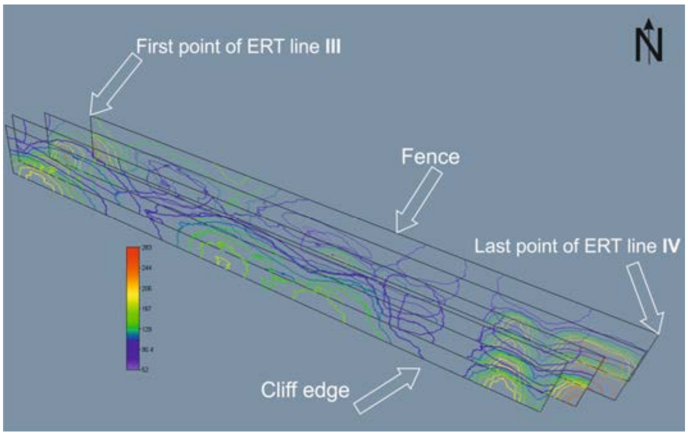

Figure 4 *Electrical Resistivity tomogram*

As a result of comparison of the rock lithology with the geoelectric section, it becomes clear that it is very difficult to rely only on the distribution of electrical resistivity of the rocks, to carry out a detailed distribution of sedimentary thickness in the lithological composition. This is explained by the fact that the value of specific resistance is influenced not only by the composition of the sedimentary rocks, but also by a large number of factors of different nature: porosity and fracture, humidity, mineralization of groundwater, rock structure and texture. Having analyzed the geological and engineering-geological information, it is possible to note that low values of specific resistance, the zones of cracking and new cracks of lawns are well distinguished on the geoelectric section. The increase in sand graining is marked by increased values of specific electrical resistance. The specific resistance of rocks located below the ground water level is much lower than that of rocks located above the ground water level, caused by increased water saturation of the pore space. Obviously the most changing of properties is observed in coarse sands and strongly cracked rocks. Thus, dry sands can have a resistance of up to tens of thousands of ohmmeters, while in conditions of full water saturation it drops to tens of ohmmeters, and in highly mineralized waters to units of ohmmeters. The lack of such dependencies in clays is due to the high (20-40% or more) content of firmly and loosely bound water. In spite of the fact that the geological medium has a horizontally layered structure, it should be considered as a three-dimensional one, taking into account the lenses of mixed sand as heterogeneity, and further measurements should be made of both parallel and intersecting profiles in order to make a more detailed three-dimensional inversion.

Conclusions

Landslides within the Kyiv region have different factors of the formation and structure of landslides due to different lithological, stratigraphic, tectonic and hydrogeological conditions. The landslides within this region are examples of the structural landslides forming in a quasi-homogeneous environment with a layered structure. The development of models was based on in-depth geological analysis of the geological environment and the determination of the parameters and characteristics of processes that differ depending on the rheological state of the geological environment and the corresponding geological structure of the slopes. Monitoring of landslide activity for the local predictions using geological and geophysical methods has been carried out within the Glynka site in Pecherskyi district of Kyiv. The data obtained by Electrical Resistivity Tomography, Self-potential method and Infrared Thermography has been applied in order to investigate the lithostratigraphic sequences, the geometry of landslide body and potential mass movement. These methods allow to allocate the fracture zones and places with the high water saturation. It has been confirmed the potential development of new displacement within this site. It helps to plan the mitigation activities and interventions.

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