https://doi.org/10.18485/resylab.2024.6.ch45

Landslide mapping for the regional gas pipeline construction near Priboj (Serbia)

Katarina Andrejev(1), Miloš Marjanović(2)*, Rastko Petrović(1)

1) Taš Grupa, Kraljice Marije 9, Belgrade, Serbia

2) University of Belgrade, Faculty of Mining and Geology, Belgrade, Djusina 7, milos.marjanovic@rgf.bg.ac.rs

Abstract The on-going gas pipeline design in Serbia is currently reaching its apex, and therein, extensive investigation and planning had to be undertaken to ensure its safe execution and long-term exploitation. Therein, engineering-geological conditions play important role and at the stage of preliminary design directly imply the alinement of the future pipeline route. This paper is focused on Zlatibor-Prijepolje pipeline branch in SW Serbia, which is further split into Priboj and Prijepolje sections. The former, Priboj section, is the subject of this work. The mapping methodology included: preparation of the base maps, field mapping, and data interpretation. Preparation stage was extensive and included acquisition of earlier investigations and maps at larger scale, primarily Engineering-geological map of Prijepolje at 1:300,000 scale, which was digitized in GIS environment, and converted into mobile GIS formats for field work. The entire route was scanned using airborne LiDAR, which resulted in a dense point cloud and Digital Terrain Model of 25 cm resolution. It was used for delineating landslides, proluvial fans, riverbeds, gullies, and other relevant morphological phenomena that indicate poor stability. This interpretation was also digitized in the GIS environment and prepared for mobile GIS application. After compiling all engineering-geological data, mobile base maps were created for field work, where additional forms were digitized on-spot. General characteristics of the area can be deducted as follows. The ophiolitic mélange is dominant and hosts most instabilities, due to its high weathering grade and unfavourable hydrological conditions. All landslides are predominantly deep-seated, and mostly of earth slide type. In total, 37 landslides are identified in the area, 12 of which along the current route. Based on their spatial extents further recommendations are given regarding particular locations and segments of the Priboj section in order to optimize its rout. It has been demonstrated how integrative approach is essential to gather relevant data and characterize the terrain appropriately, for further, more detailed design stages.

Keywords landslides, LiDAR, DTM, pipeline, Priboj

Introduction

A new gas pipeline route has been included in the Spatial plan of Serbia, and its western branch Zlatibor-Prijepolje, contains several sections, one of which connects Priboj and Nova Varoš, i.e., Pribojska Banja – Rutoši, to be more specific (Fig. 1). The target pipeline segment is at its preliminary design stage, and its route totals 13.6 km. It will service installation with working pressure of 16-50 bars and will be installed at 1.5 to 2.0 m depth, depending on the terrain conditions. The primary objective was to compile engineering-geological map with focus on current and potential instabilities along the corridor that encloses 500 m left and right along the pipeline route (approximately 14 km^2).

Study area

Seated in the SW Serbia, the wider area of interest belongs to a hilly-mountainous region with continental to sub-alpine climate. It has a distinct river system subdued to the Lim River watershed. The centreline is the Rutoška River valley, tightened in the W-E direction between the foothills of the Zlatibor Mt. to the north and Zlatar Mt. to the south. High relative elevations (840 m) and large variation in slope angles ranging from very gentle along the riverbed to subvertical in the gorge part of the valley, suggest a terrain which is very discontinuous and drastically different conditions. It is sparsely populated, mainly rural area, but industrially important with numerous objects of the hydro energetic Lim River system, and regional level roads. Geologically, it belongs to a highly complex and intensively tectonized zone on the contact of two major formations, Mesozoic limestones and Jurassic ophiolitic mélange, suggesting complex geological conditions during the closure of the Thetis ocean, delineated along transform SW-NE trending faults. Its continental development is seized during Miocene, when a basin was form, comprising of typical lacustrine sedimentation, which transited into the current fluvial development, and associated quaternary deposits (Dimitrijević et al., 1980). The entire area is in neo-tectonic uplift along the SW-NE trending faults, although seismic activity is not particularly pronounced. The most distinct geological feature is the ophiolitic mélange itself, as it comprises of various rock types with significantly different characteristics (Jevremović and Sunarić, 2009). It includes clastic, volcanic and metamorphic constituents, but diabase predominates, covering 46% of the area of interest, while serpentinites. cherts and sandstones are subordinate as isolated masses, totalling about 14% altogether.

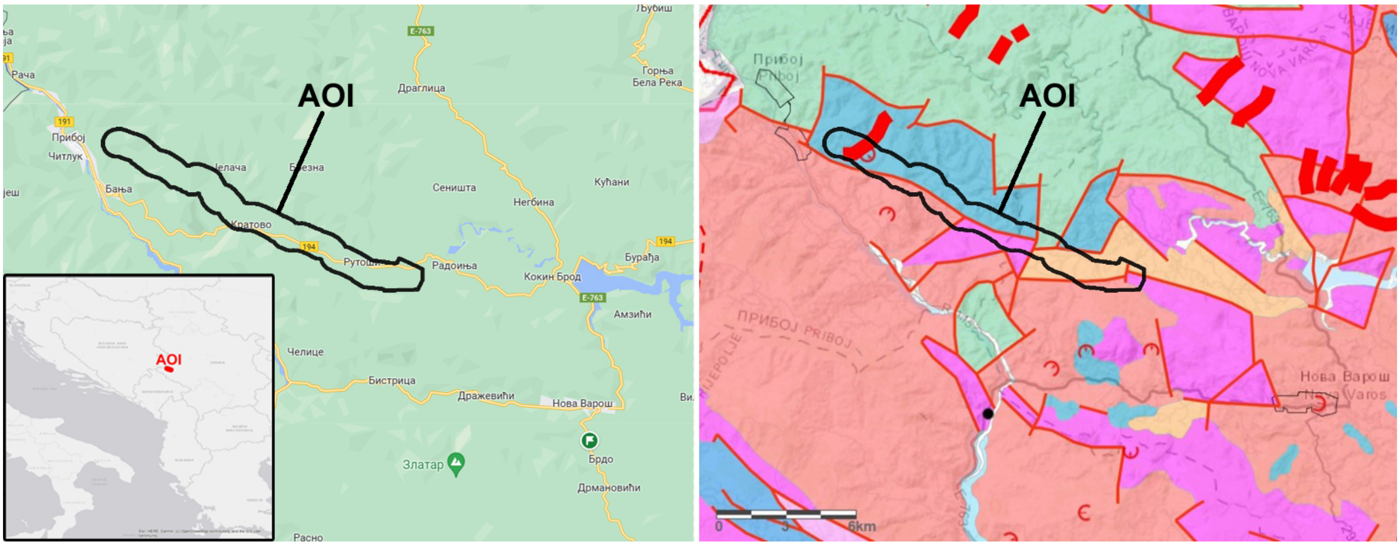

Figure 1 Location of the study area (to the left) and engineering-geological map (to the right).

Such lithological variability and tectonic distress suggest that this complex is highly susceptible to weathering, with very thick crust of frail and loose material. The main counterpart of this unit is represented by Miocene clastic sequence, covering about 25% of the area. Remaining 15% is covered by isolated limestone masses, and alluvial and proluvial deposits enclosed in the area of interest.

Different types of instabilities are rather frequent in this area, ranging from earth slides to rockfalls (Hungr et al., 2014). They are traditionally interpreted as deep seated rotational slides hosted in the thick weathered crust of the ophiolitic mélange unit, but also as shallow translational slides in the Miocene clayey deposits. As limestone masses are locally thrusted over ophiolitic mélange, the groundwater conditions are also unfavourable, and traditionally considered as one of the principal factors of deteriorating rock and soil strength at expense of pore pressure. The draw-down effect is also a possibility, given the close allocation of several artificial lakes within the hydro-energetic powerplant system. The natural trigger is the intensive rainfall and snow thaw in the highlands, which is customary in spring and autumn season.

Materials and methods

The task required compiling all valuable data together and delivering an up-to-date interpretation of the ground conditions in the area. It was conducted through several phases, preparation of the base maps, field work and their final compilation and interpretation. The footprint of the area of interest is generated as a buffer of 500 m around the pipeline route, covering approximately 14 km^2. For desktop GIS environment ArcMap 10.4 was used, with standard file formats (shp. for vector and .tiff for raster data), while MapitGIS android application (using the .mbtiles file format for raster and vector data) was used for mobile GIS environment installed on a tablet device Lenovo S5000-F with Android OS.

Preparation of the base maps

The base maps included several sources (Tab. 1) and each one of them was used to compile a master base map which was interactively used in the field (Fig. 2).

The Digital Terrain Model (DTM) was created by using the airborne RIEGL VUX-40 sensor on payload (flight conducted in 2022), with the initial point density of $50/m^2$. The last reflection points were used to generate a point cloud stripped from the vegetation. The raw point cloud was decimated to 25 cm resolution and regular spacing. It was used to interpolate the DTM by spline function with default setting, from which a *Hillshade* model was created, using default sun incidence and azimuth angle (315° and 45° respectively). Simultaneously, the terrain was imaged using a high definition photogrammetric camera and appropriate *Orthophoto* was created in .ecw format matching the DTM 25 cm resolution. The LiDAR *Hillshade* at such resolution can be considered as a powerful tool for landslide mapping (Bernat Gazibara et al., 2017). Therein, a shade effect that simulates 3D visual impression can indicate fresh footprints of the landslide elements (scars, foots, tension cracks, etc.) and imply the status of the landslide activity (Fig. 3). The *Orthophoto* base map was used to append the *GoogleEarth* historical imagery to visualize ground changes linked to landslides (Fig. 3).

Table 1 Data sources.

Base map	Data source	Scale/ resolution
Digital Terrain Model	Airborne LiDAR survey	25 cm
Orthophoto image	Airborne Photogrammetric survey	25 cm
Engineering-geologic map	https://geoliss.mre.gov.rs	1:300k
Engineering-geologic map sheet Prijepolje	https://gzs.gov.rs/	1:100k
Depth to bedrock	https://soilgrid.org	250 m
Historical Satellite Images	https://earth.google.com/	NA

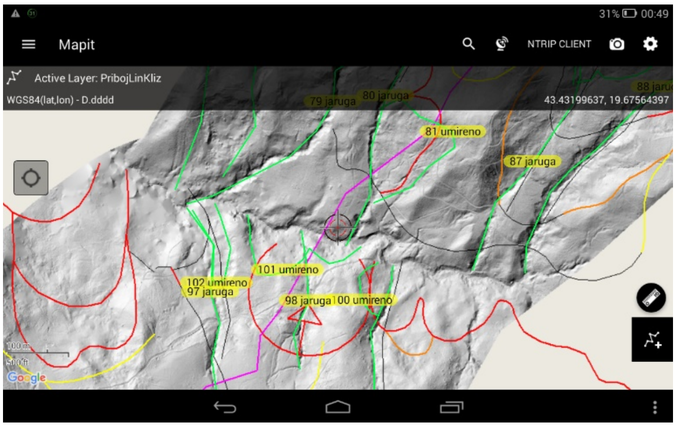

Figure 2 MapitGIS display for interactive use during the field work (*Hillshade* base map and on-spot digitized content). Red lines represent content from Engineering-geological map, while other lines are digitized on-spot while using the app.

Engineering-geological map of Prijepolje at 1:100 000 scale (Jevremović and Sunarić, 2009) was digitized in desktop GIS environment and converted to mobile format for field use (Fig. 2). All instabilities were grouped into active and dormant landslides and marginally stable slopes, while gullies and fluvial fans are also outlined.

Finally, depth to bedrock base map was created using the coarse resolution source map from *Soilgrid* portal (250 m). To make it more suitable for the application in the field it was converted from raster to the 250 x 250 m point grid. Subsequently, these points were used to interpolate depths by using spline interpolation tool (at default settings) in desktop GIS environment (Fig. 4). The interpolated raster was then converted to contour lines with 2.0 m vertical spacing.

Field work

Conventional field mapping was conducted along the route, covering about 14 km². Due to time limitation it was undertaken during the vegetated season which reduced the visibility of fresh landslide footprints. The mapping included direct classification of encountered units, mainly in accordance with the engineering-geological base map, whereas greater attention was dedicated to mapping of instabilities, and their state of activity (by direct and indirect indicators, such as morphological features, but also hydrological, damaged objects, tilted trees, etc.). Incision depths at gullies and other open scarps was also recorded and levels of groundwater table at available wells and streams. The existing (base map) instabilities were checked for their current status, whereas new instabilities were directly digitized on-spot by using the MapitGIS app, which has offline mode of geo-locating, allowing for a seamless field logistics (Fig. 2). Analogue field log was also kept and field photographs taken for relevant details.

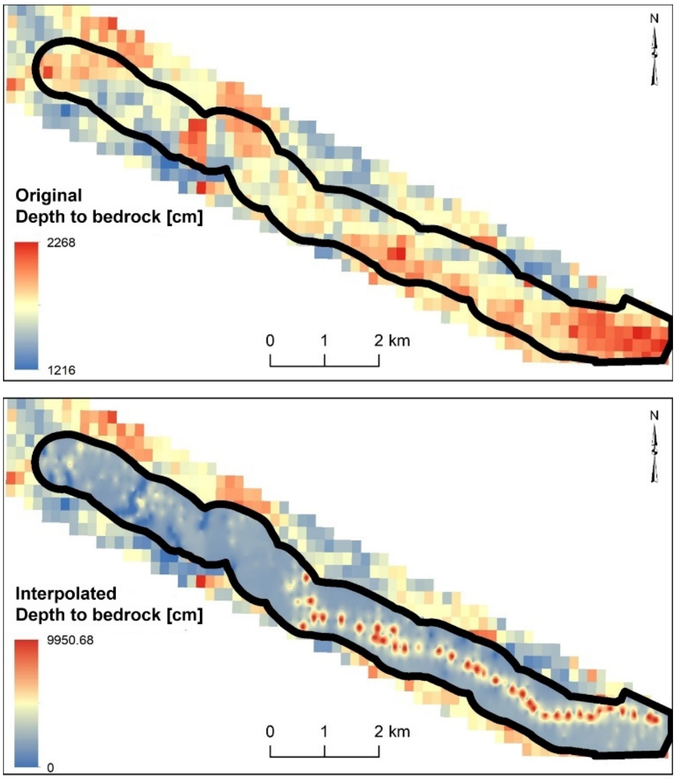

Figure 4 Depth to bedrock base map before (upper) and after (lower) spline interpolation.

Data compilation

All collected data were combined in a desktop GIS environment. Typical cross sections were traced across the main landslides, 17 in total. Due to an elongated shape, the area of interest was split into 8 frames suitable for visualizing in 1:5000 scale.

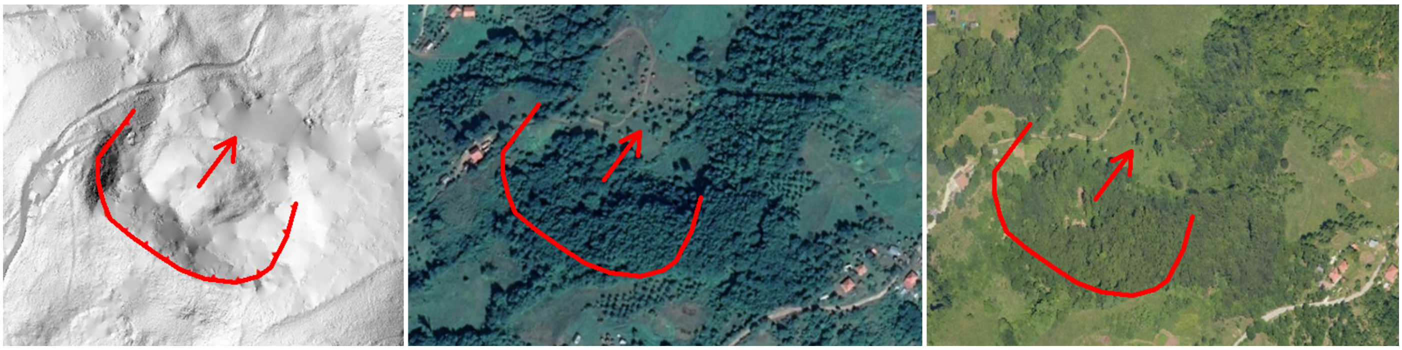

Figure 3 Detail of the *Hillshade* base map clearly delineating landslide elements (left); GoogleEarth footage of the same location from 2019 (middle); Orthophoto base map of the same site in 2022 with indicated destruction of vegetation possibly due to landslding (left).

Results

The entire area can be roughly halved into western highland and the eastern valley, which matches the hypsometric and lithological difference.

The landslides are more abundant in highland part (Fig. 5-6), composed primarily of ophiolitic mélange wherein weathered diabase (ββ) predominate. These host deeper landslides, ranging from 5 to 15 m (Fig. 6). Locally, the unit containing clastic component (PŠGA), a mixture of sandstone transiting to siltstone and claystone. The landslides within this unit, are smaller and slightly shallower. The least susceptible is the chert unit (R). The preconditions to sliding is primarily related to the groundwater table, which is in this area relatively shallow, as indicated in numerous contact springs and observed wells. Springs are arrayed around the periphery where water bearing Triassic carbonates thrusting the ophiolitic mélange below, as less conductive.

The valley stretches eastward firstly with steep slopes, and the second half of the valley, further upstream has much more gentle slopes. The steeper end is composed of ophiolitic mélange (PŠGRKββ) on the right valley side, while left slopes are made of massive carbonates (LK). The gentler upstream part is entirely made of loose clastic sediments, primarily marls and clay (LCLG), deformable and weathered, covered with thick deluvial crust. Landslides are less prominent and mainly shallow. Fluvial fans edging the valley plain and several deep gullies are present as the valley is the dominant erosion basis from highland downslope.

There are 18 distinct landslide bodies, 3 of the flow type, while 6 are rotational (deep-seated) and 9 translational (shallow) earth slides. Their size varies, especially lengths which are ranging from 100 to 500 m, but mostly are 200-300 m long. There are 6 active landslides, with fresh footprints recognized on the field or remotely, while remaining are dormant.

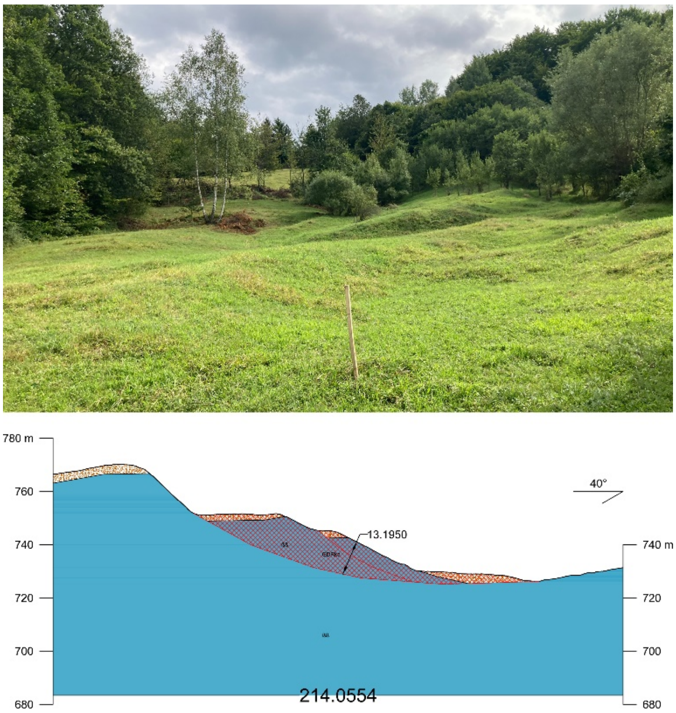

Figure 6 A field photo (above) and the cross-section No. 8 (bellow), depicting deep-seated rotational landslide (visualized also in Fig. 3) with typical hummocky ground in the foot area.

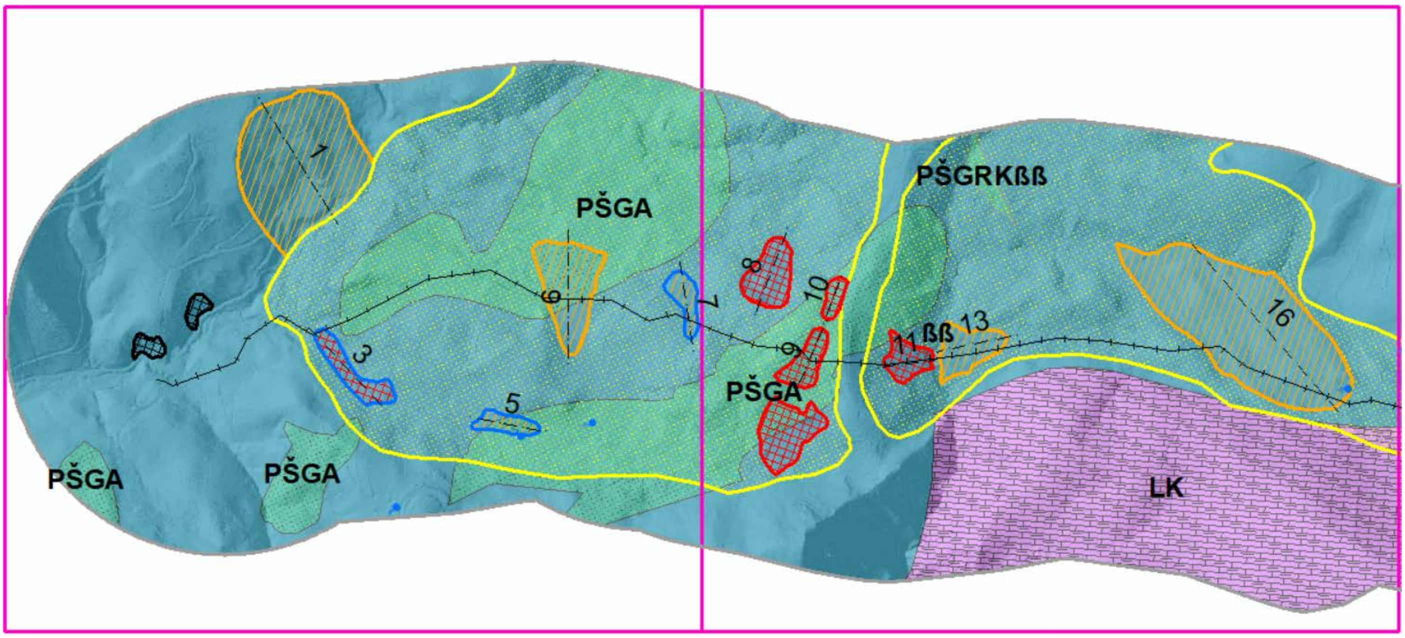

Figure 5 The two most critical and most westward frames of the engineering-geological map (crossed black line – designed pipeline; dashed line – cross section; red polygons – active landslides; orange polygons – dormant landslides; yellow polygons – marginally stable slope; ββ – diabase; PŠGA – clastic mélange; PŠGRKββ – undifferentiated mélange; LK – marly limestone;).

Table 2 Engineering geological complexes and basic properties.

Complex	Depth to bedrock [m]	Elastic moduli [GPa]
Cemented soft rock	5-10	2.0-5.5
Cemented carbonate	2-3	5.0-10.0
Cemented volcaniclastic	5-10	0.2-3.0
Cemented hard igneous	10-15	0.5-3.0
Cemented metamorphic	3-5	1.0-3.0

Earlier interpretations suggest considerable overestimation of the number of active landslides, although it is important to mention again that the field work was conducted during the vegetated season. Considerable portion of the terrain remained categorized as marginally stable slope, approximately 4 km^2, while all other instabilities combined occupy 0.7 km^2. It suggests that any type of engineering work undertaken could cause new landslides enclosed in this zone. There are also 3 larger fluvial fans which are also considered as inconvenient.

The gas pipeline is routed through 11 landslides, two of which are active, and one fluvial fan. These suggest that rerouting should be taken to account, before moving to the next design stage, or undertake the necessary remediation measures.

As for the engineering geological classification (Tab. 2), all units can be separated into: cohesionless soil complex (sand and gravel of the fluvial origin); poorly cemented complex (clayey-silty sand of deluvial and proluvial genesis); complex of cemented soft rock (marlstones, sandstones etc.); complex of well cemented carbonate rocks (limestone and marly limestones); complex of well cemented volcaniclastic rock (chert, siltstone, etc.); complex of cemented hard igneous rock (diabase); complex of cemented hard metamorphic rock (serpentinite). Each of these complexes, except for the cohesionless and poorly cemented, have their weathered and fresh counterparts (of varying depth), and in Table 2 their generalized engineering-geological properties are given.

Conclusion

This work shows a successful example of integrated approach combining various source of data and state-of-the-art field and desktop technics for combining them. Relying solely on earlier findings was deemed unjustified. Instead, a thorough LiDAR mapping and field check are to be used as standard of practice for objects of such importance and longevity since it is important for them to remain in stable grounds not as of current but for decades to come. For this reason, all earlier findings, e.g., former active landslides, should be considered dormant and susceptible to reactivation. In addition, all further engineering work might open new instabilities within the zone of marginally stable slopes, possibly during the execution of pipeline groundworks itself. Groundwater influence is predominant in weakening the topmost weathered layers and are responsible for most of the anticipated instabilities. Most landslides are occurring on the interface of saturated weathered layer and its fresh rock counterpart. The most critical are pipeline segments passing through the active landslides in the westernmost frame, where surface ground de-stripping (and other groundworks such as re-sloping) or retaining and draining structures are in order. Alternatively, the rerouting is also a viable option, if other gas pipeline standards are met (ground stability is only one of them).

Further design stages imply more detailed analysis of focused areas, including explorational drilling to proposed depths (based on estimated slip surface depths), sampling and lab testing for determining strength properties of materials in weathered and fresh zones, etc. For further project development monitoring of the site, is also in order, and it can be easily continued by further sequences of LiDAR scanning, whereas focused areas of active landslides can be further instrumentally monitored.

References

Bernat Gazibara, S., Krkač, M., Sečanj, M., & Mihalić Arbanas, S. (2017). Identification and mapping of shallow landslides in the City of Zagreb (Croatia) using the LiDAR–based terrain model. In Advancing Culture of Living with Landslides: Volume 2 Advances in Landslide Science (pp. 1093-1100). Springer International Publishing.

Jevremović D, Sunarić D (2009) Tumač za osnovnu inženjerskogeološku kartu 1:100 000, list Prijepolje K34-16. University of Belgrade, Faculty of Mining and Geology, Belgrade. 57p. (in Serbian)

Dimitrijević M, Karamata S, Petrović B, Sikošek B, Veselinović D (1980) Tumač za snovnu geološku kartu 1:100 000, list Prijepolje K34-16. National Geological Survey, Belgrade. 55 p. (in Serbian)

Hungr O, Leroueil S, Picarelli L (2014) The Varnes classification of landslide types, an update. Landslides. 11: 167-194.