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TECHNICAL NOTES

Landslide Hazard Zonation Along Milot-Kukës Motorway, Albania

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Abstract
In this paper it is briefly described the landslide hazard zonation before and after the construction of the Milot-Kukës motorway, Albania. The studied area is a mountains zone with extremely complicated morphological and geological framework, characterized by steep slopes, intensively fractured and highly to completely weathered rocks. Due to intensive excavations done during its construction, many of the slopes are destabilized and nowadays, have become unstable. During and after the rainfalls, on both sides of the motorway, several landslides such as earth slide debris flow, rock falls and rocks slides have occurred and have increased the risk due to natural hazards.
For this reason, the motorway's area is analyzed in terms of landslide hazard zonation by using the high-resolution satellite imagery and factors data in a GIS environment. During 2015-2017, a 1:10000 scale engineering geological map is compiled and was used to identify the landslides location, lithological characteristic, slope features, geotechnical conditions and land use situations.
As a result, the studied area was divided into five categories from very low to very high-risk zones. Moreover, based on the analysis results of the landslide hazard zonation before the motorway's construction, it was concluded that the excavation works had a considerable influence in increase of hazard level, particularly on the instability of the slopes.

Keywords
landslide hazard zonation, lithology, landslide, morphology, slope angle, slope aspect, landuse, GIS

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1 Introduction

Most of Milot-Kukes motorway area is built on a hilly and mountainous terrain. More than 78% of the present area is built by steep slopes consisting of various lithological units that are the soils and intensively fractured and weathered flysch, limestones, molasses, mélanges, ultrabasics, gabbros, andesites and dacites formations. The construction works, especially the slope excavations done by blasting, have caused many geotechnical problems regarding to slope instability. Since its construction, every year during rainy season, many landslides have seriously endangered human lives and their properties. Many cut slopes areas along this route are affected from mass movement's activity, which are the rock falls, debris flows, earth slides and rock slides [4]. In addition, the previous studies [15, 20] indicate that the present area is subject to landslide processes. To analyze the landslide susceptible slopes over large areas, landslide hazard zonation (LHZ) techniques can be employed [18]. For this reason, during 2015–2017, an engineering geological map at the scale 1:10000 was compiled for Milot-Kukës motorway area [16]. The main aim of this study was the evaluation of the engineering geological conditions regarding the landslide activities and location, as well as identification of unstable cut slopes areas. Based on this work, a landslide hazard zonation map of Milot-Kukes motorway area was compiled using geographic information systems (GIS) techniques, taking into consideration some factors such as landslides distribution, lithology, slope features, geotechnical conditions (weathered and fractured rocks) and land use characteristics. These factors have been considered as main cause for landslides [6, 10, 12, 18, and 22]. The landslide hazard zonation map is classified into several hazardous categories from very low to very high. The zones with varying degrees of potential landslides have been identified. This map will allow to propose the proper and mitigating engineering measures, in order to avoid any potential hazard that can be occurred in the motorway area.

2 Methodology

The studied area of 94 km long is situated in the north-western part of Albania, stretching out from Milot to the city of Kukës (Fig. 1). It represents a mountainous zone characterized

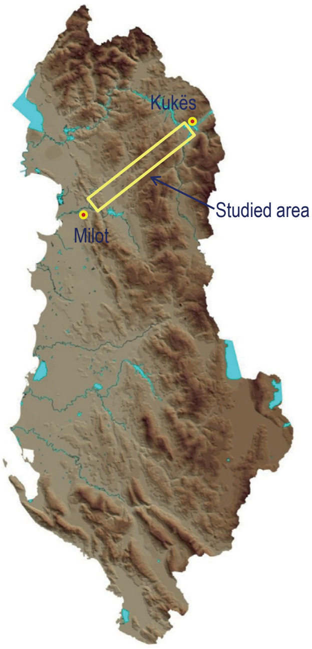


Fig. 1 Location of the studied area

by steep slopes, fractured and highly weathered rocks. Between 2004–2006 and 2016–2017, before and after construction of the four-lane motorway from Milot to Kukës, some geo-engineering studies [15, 16] were conducted. In this context, in the area there have been done many field works as geo-engineering maps on scale 1:10000, drillings (15–60 m deep), SPT and laboratory tests [15].

Due to a high amount of excavations done for the construction of the motorway, many of the hill slopes have been destabilized and slipped down into the road, whereas many others are currently unstable. During rainstorms, in the most of cut slopes areas occur the mass movements, such as earth slides, rock falls, debris flow and rock slides [4]. For that reason, in 2015–2017, a geo-engineering study [16] was performed for the following issues:

i) movement's location, type and distribution;
ii) morphologic conditions;
iii) determination of the lithological types and geotechnical characteristic and
iv) compilation of the landslide hazard zonation map by using of GIS techniques.

For the evaluation of the landslide hazard zonation, the heuristic method was applied [11, 12, 18], which is very useful regarding to the landslide hazard map compilation. This approach uses a simple ranking and rating technique for landslide hazard zonation. The first step of this method is to find the factors that affect the mass movement. In Milot-Kukës motorway area, for the evaluation of the landslide's hazard zonation map, four factors have been taken into account: the lithology, geomorphology-slope angle, slope aspect and landuse. All data layers were converted into grids with cell size 20m × 20m and each factor was considered as a parameter map and it is created as vector format in GIS. The relative

Fig. 2 Earth slide occurred before motorway construction, January 2006

importance of each parameter map for the slope instability is evaluated according to subjective expert's knowledge. Thus, every class in each factor was assigned from "1" to "5", where "1" represents the lowest influence and "5" indicates the highest impact on the landslide occurrence [2, 6, 12, and 18].

3 Landslide map

The four-lane motorway crosses the north-eastern Albania from Miloti in the northwest to the city of Kukës, in the east, traversing the Mirdita-Kukesi mountain range. There is a great variety of lithological types and geotechnical conditions, as well as various features in term of weak rock mass and potential for unstable slopes. In the case of geo-engineering studies [15], since the early stage of design, the motorway area has been subject to landslide occurrences. The first data were taken from geo-engineering studies [15], in 2004–2006, before and during the motorway construction. There have been identified 15 debris flows on the slope hills built by basalts, plagiogranites and gabbros, as well as 5 earth slides on the molassic formations (Figs. 2. 3).

The last geo-engineering studies [16] have shown that most of the cut slopes in the Milot-Kukës motorway area are in unstable state and are affected by mass movements, closely related to man-made works (blasts, excavations), cut slopes morphometry, lithological types of the geological formations, geotechnical properties of the bedrocks and soils and rainfalls. The cut slopes are built by flysch, molasses, limestones, mélanges, ultrabasics, gabbros, basalts, andesites and dacites formations, which are characterized by weak (highly-completely weathered) and fractured rocks masses.

They are 25–35m up to 70.0–100.0m high, 0.1–0.3 km to 1.0 km wide and slope angle that range 45–55° to 70°. For the protection against the mass movements, several benches have been built, from which most of them are currently damaged and have slipped down the slope. Moreover, this area is subject of heavy rainfalls with an average of 1600–2000 mm/yr [19]. Occasionally, the rainfalls exceed 100 mm in 24 hours, 1–2 up to

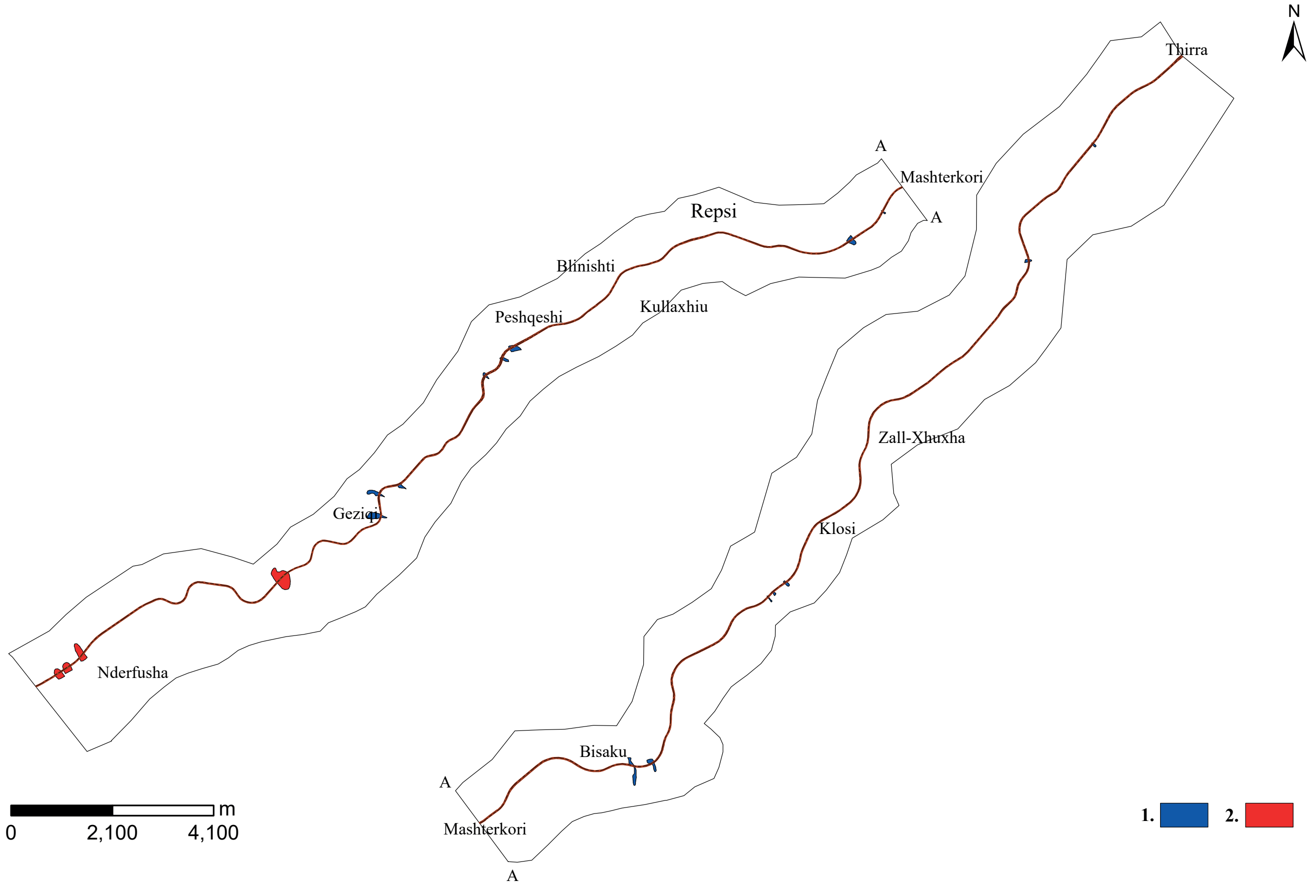


Fig. 3 Landslides map of studied area
1. Debris flow, 2. earth slide

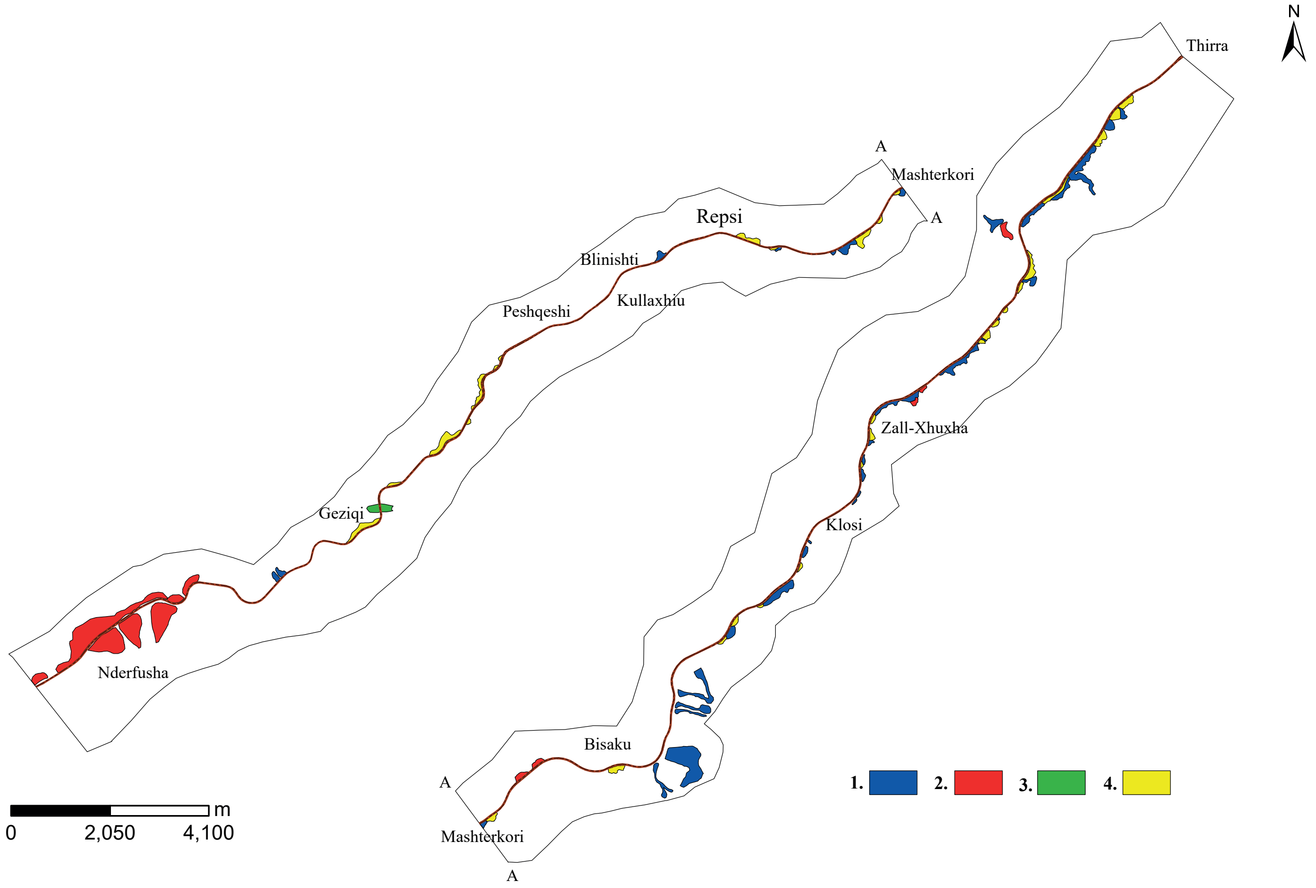


Fig. 4 Landslides map of studied area
Debris flow, 2. earth slide, 3. rock slide, 4. rock fall

3 times per year, causing serious problems in this region. The maximum rainfall was recorded on October 1970 (180.5 mm in 24h) and on January 1963 (189.6 mm in 24h) [17]. Over the years, mass movements have been occurred and others are also to be expected in the future, suddenly and in large quantities (Fig. 4). They are classified in rocks fall, debris flow, earth slides and rocks slide [4].

3.1 Rock falls

From the current geotechnical observations, it has been revealed that the rock masses (limestones, ultrabasic, basalts, gabbro, dacites, etc.) that build the cut slopes are intensively weathered, tectonized and fractured due to excavation works (i.e. blasts). Thus, during the freeze–thaw periods, many rock blocks (1.0–1.7 m^3 up to 2.0–3.0 m^3) and fragments (0. 25–0.50 m^3) are in loose and unstable state, ready to be detached and to fall (Figs. 5, 6). The rock falls with sizes of 0.25–3.0 m^3 occur on about 40 cut-slopes occasionally during heavy rainfall (Figs. 5, 6). Most of rockfalls are observed on the following cut slopes (6.6–7.1 km, 14.6–15.3 km, 18.0–19.2 km and 21.2 to 93.3 km of motorway) during the wet period (October-March) in the first 24h of rainfalls with high intensity (bigger than 90 mm/ 24 h) [17]. The authorities have reported that during the wet period, the rock blocks and stones are falling into motorway 1–3 times during year in all cut slopes. The materials consist of rock blocks and broken stones of ultrabasics, gabbros, basalts, andesites, sheeted dike and dacites.

3.2 Debris flow

Due to man-made works and weathering processes of ultrabasic, basalts and gabbro formations, as well as rainfall water erosion and transport, on the cut slopes along the motorway, there are deposited unconsolidated granular materials-soils (rubbles-cobbles-gravel mixture with no fines). These soils are in unstable state, ready to slide down in form of debris flow. Along the path of the motorway, especially from 14.0 km to 89.5 km, there are 26 locations where the debris flow has occurred. Over the past years, the biggest debris flows were observed on 24 November 2015 (54.75–54.80 km, 1950.0-2000.0 m^3 of volume) and 03 March 2018 (52+450 to 52.485 km, 2600.0 m^3 of volume) and caused a road block for several hours (Figs. 7).

3.3 Earth slides

During the last 10 years, numerous earth slides have occurred on the cut slopes of Milot-Kukës motorway. Generally, the earth slides are situated in the upper part of the molasses rocks-

Fig. 5 It shows the loose blocks on cut slopes

Fig. 7 Debris flow occurred on 03 March, 2018 (km 52.0)

Fig. 6 Rockfalls occurred on 08 March, 2018 (km 18.4)

Fig. 8 Earth slide occurred during motorway construction, 2007

Fig. 9 Earth slide occurred current time

cut slopes of highway with inclination 18°–35°. They are from 20.0–50.0 m to 70.0–100.0 m long, from 15.0–30.0 m to 50.0–75.0 m wide and 2.8–3.5 m to 5.5–7.0 m thick. The earth slides are the translational slide type with slow velocity [4].

From the geotechnical analyses carried out on this area, 49 earth slides have been mapped (Fig. 4) [16]. They are located to the north of Rresheni town, Ndërfusha, Mashtekori-Bisaku and ZallXhuxha villages (Fig. 4). The landslides body consists of inorganic silts and very fine sands [1] (Figs. 8, 9).

3.4 Rocks slides

The rock slides on the studied area has occurred on hills slopes-cut slopes which are built by ultrabasic rocks along the segment 36.44–36.58 km of the motorway (Fig. 4). The ultrabasic rocks in this site are intensively fractured and weathered. They are separated from joints in blocks with different sizes. Due to man-made works (blasts) during the road construction, on the slopes cutting, a large fault on ultrabasic rocks was observed. It lies from top to bottom of the slope with a dip angle of 55°–68°, almost parallel to the hill slope and below the motorway. In this situation, the slope stability was in a critical condition because a large ultrabasic mass in unstable state threatening the motorway's stability. It is 350.0 m long, 140.0 m wide and the failure's plane lies from 15.0–20.0 m up to 35.0–40.0 m in depth.

Furthermore, from the geo-engineering studies [16] were recognized the main factors that played the most important role in causing the landslides are the lithology, slope angle, slope aspect and land use.

4 Litholgy

Among the factors, the lithology plays the main role in the landslide occurrences. It can affect the likelihood of landslides to a large extent [23]. The geotechnical conditions of the landslide depend on lithological types. Thus, the different lithological types specify the different geotechnical characterization of the hill slopes concerning to slope stability conditions. Based on this conclusion, the studied area is classified into several lithological units that are described as follows (Fig. 10):

Soils: Represent the dilluvial and alluvial deposits. The dilluvial deposits building the hills slopes have a thickness which varies from 0.8–1.5 m up to 4.5–6.0 m. They consist of inorganic silts and very fine sands with rubbles contents [1], stiff consistency. The alluvial build the river bed and terrace of Fani River. They are composed by gravel-sand mixtures with little fines [1], loose to medium conditions and are 1.0–2.0 m up to 5.0–8.0 m thick.

Molasses: These have been deposited in the molassic basins of Rrëshen and Kukës and are composed of conglomerates, sandstones layers intercalated with siltstones-claystone layers, reddish, brownish and yellowish in color, constituting a very weak to weak rock mass. In upper part of lithological profile (7.0–10.0 m) these formations are highly to completely weathered. These formations are weatherable, forming a clayey horizon of residual soil, as well as very susceptible to erosion and landslide activities. Such a geological environment hosts large-scale old rotational and translational landslides and earth flow. In this type of environment, the potential for a re-activation of these landslides or the development of new ones is relatively high.

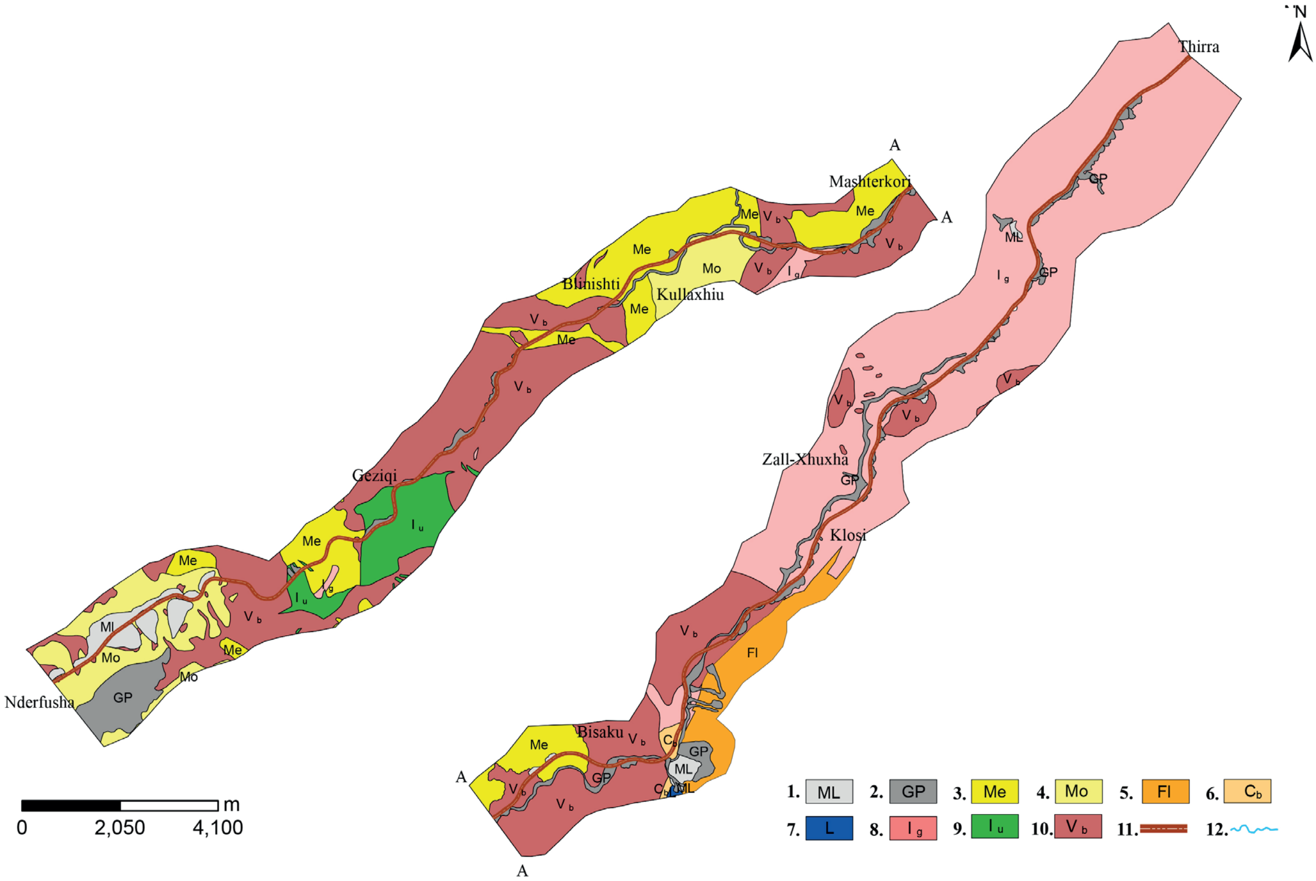
Melange: They are extended in the central and eastern part of the investigated area. These formations are represented by very weak to weak rock mass representing a heterogeneous formation that consists of alternations of gray mudstone schists, sandstone and chaotic, cohesive breccia, with intercalations of reddish cherts, as well as intensively sheared ophiolitic formations (mainly basalts and ultra-basic rocks). In the investigated area, these formations on top of the lithological profile (4.5–6.0 m) are highly to completely weathered, making these very favorable to the landslide activity.

Flysch: These formations are represented by the combination of thin layers of marls, limestones, claystones, siltstones, sandstones with conglobreccia and breccias. They are characterized by a dominance of the ophiolites in the rock matrix. It is characterized by weak to medium rock mass, which in upper part of lithological profile (1.5–4.0 m) they are highly to completely weathered.

Basaltic conglomerate: These formations consists of subrounded to angular ophiolitic and limestone clasts or blocks in the ophiolites matrix. They are medium to hard rock mass, which in upper part of lithological profile (0.5-1.8 m) are slightly to moderately weathered, mostly consisting of rock mass separated by rare cracks.

Limestones: Consist of thin to thick-bedded limestones. They are characterized of hard and consolidated rock mass. They extend in the northeastern part of the motorway area.

Volcanic formations: Basaltic, andesitic, dacitic and sheeted dykes outcrops have been found in the present area. Most of the outcrops of the basalt have a pillow-lava structure. They often develop an irregular morphology in the natural slope. They are hard rocks that are very blocky to blocky to disturbed (partly



1. Inorganic silts and very fine sands, 2. gravels, sands, 3. mélange, 4. molasses, 5. flysch, 6. basal conglomerates, 7. limestone, 8. gabbro, 9. ultrabasic 10. basaltic, andesitic, dacitic and sheeted dykes formations, 11. motorway trace, 12. river

Fig. 10 Lithological map of the studied area

due to the pillow-lava structure) rock mass. They fail structurally and in many cases, are rock fall sources. Weathering process and man-made works have affected the large discontinuities of the rock mass, which in many cases are rock fall sources.

Intrusive formations: This group is represented by harcburgites & dunites (ultrabasic), gabbros (basic) and plagiogranites (intermediate). The peridotites and dunites are included in hard rocks group with a very blocky to the sheared structure, where their rocks mass strengthening is mainly controlled by the degree of fissures and serpentinization. Later, manmade works have dramatically reduced the strength of the discontinuities which are smooth and slicken-sided, coated with slippery minerals (e.g. talc and chlorite). They fail structurally at different scales affecting a significant part of the cut and natural slopes. The present rock mass, currently are characterized by loose structure with open joints visible on the cut slope surfaces. They are susceptible to creep and gradual loosening because of the presence of the very persistent soft shear zones. Thus, there are a lot of loose blocks along of cut slopes and benches. On this cut slope is a significant potential for structural failures, rock slides and debris flow, as well as rockfalls from above the crest. The gabbros and plagiogranites are hard rocks (lower lithological profile), with blocky-very blocky to disturbed rock mass as result of weathering processes, faults and manmade works. The faults and long discontinuities dissect all of the slope areas. They are usually filled with hardened clayey sand with small angular fragments. Through these faults, weathering goes deep into the rock mass. Sometimes they carry water, forming springs on the surface. On the rock mass surface, by weathering processes are formed the residual soils. These rocks fail structurally affecting a significant part of the cut slope and the natural slope in some cases, being potential areas for landslide occurrences (debris flow and rock fall). Finally, based on the landslide location among various lithological the following results were obtained:

i) the previous engineering geological studies show that 6 landslides occurred in basalts, 7 in gabbros, 2 in plagiogranite and 5 within molasses formations [15].

ii) the latest studies confirm that after 2009 when the motorway was constructed 49 landslides occurred in molasses (39%), 27 in harzburgites and dunites (21.5%), 16 in gabbros (13 %), 7 in mélange (5.5%), 6 in plagiogranite (5%), 17 in volcanic formations (dacite, andesite, basalts and sheeted dykes) (13.5%), and 3 within flysch formations (2.5%) [16].

Thus, the different lithological characteristic shows the various favorable features for landslides occurrence. Most of motorway slopes currently present favorable areas for landslide activity. Based on this analysis and published studies [2, 12], the classes of the lithological factor were evaluated based upon their contribution, where "1" and "5" have respectively low and very high influence on the landslide occurrence (Table 1).

Table 1 The weight value for each class of the lithological factor

Classes	Code	Weight
Hills slope soils - inorganic silts and very fine sands	ML	5
River soils: gravels, sands.	GP	4.5
Melange	Me	3.5
Molasses	Mo	4
Flysch	Fl	3
Basal conglomerates	C_b	2
Limestone	L	1
Gabbro	I_g	3.6
Plagiogranite	I_p	3
Harcburgites and dunites	I_{Hz}	3.8
Basaltic, andesitic, dacitic and sheeted dykes	$V_{b.a}$	3

5 Morphology of studied area

The morphology of the studied area is closely related to the lithology and manmade works (excavations) performed for the motorway construction. It represents a hilly-mountainous zone, which is built by magmatic and sedimentary formations with above sea level varies from 320.0–350.0 m (Rrësheni area), 700.0–774.0m (Malaj village), 1015.0m (m. Kunorës), and 1091.0m (village of Domgjon), 1659.0m (Thirra village) up to 1789m (Kalimash Mountain). Along this area, it is found the valley of Fan River and some of its streams. Generally, the Fan River valley is narrow, deep and steep, forming a V-shaped valley with slope angle ranges from 35°–45° up to 55°–70°. This area made of weathered and fractured rocks, which generally are covered by delluvial deposits with a thickness ranging from 1.0–2.0m up to 5.0–8.0m. Due to man-made works, most present area was excavated, increasing the slope angle and get an escalating shape from building of protective measures (benches) against mass movements. The terrain morphology features (slope angle) and slope aspect (slope exposure to the sun rays strike) are controlling factors in landslide occurrence [11, 13, 23, 24]. The amount of sun rays strike contributes in the improvement of the geotechnical conditions of the soils (drier conditions and warmer temperatures), especially for landslides phenomena. Therefore, for the evaluation of landslide hazard of the studied area, the slope aspect was analyzed. The slope angle and aspect maps (Figs. 11, 12) were derived from the DEM using Arc_GIS10.3. The DEM was created from isolines that were extracted from the 1:10000 scale topographic maps [20, 21]. The map of slope classes was generated by separating the slope angles into ten different classes: 0°–5°, 6°–10°, 11°–15°, 16°–20°, 21°–25°, 26°–30°, 31°–35°, 36°–40°, 41°–45°, and bigger than 45° (Table 2 and Fig. 11). On the other hand, the map of aspect's slope was compiling by dividing aspect's factor in eight dissimilar classes (Table 3, Fig. 12). It is related to the effect that the sunlight plays a main role in groundwater drying of upper lithological profile. Based on scientific papers [3, 5] and geo-engineering studies [16], it was evaluated the weight's values for each class of slope angle and aspect factors (Table 2 and 3), where two thematic maps were compiled (Figs. 11, 12). It should be noted that the classes'

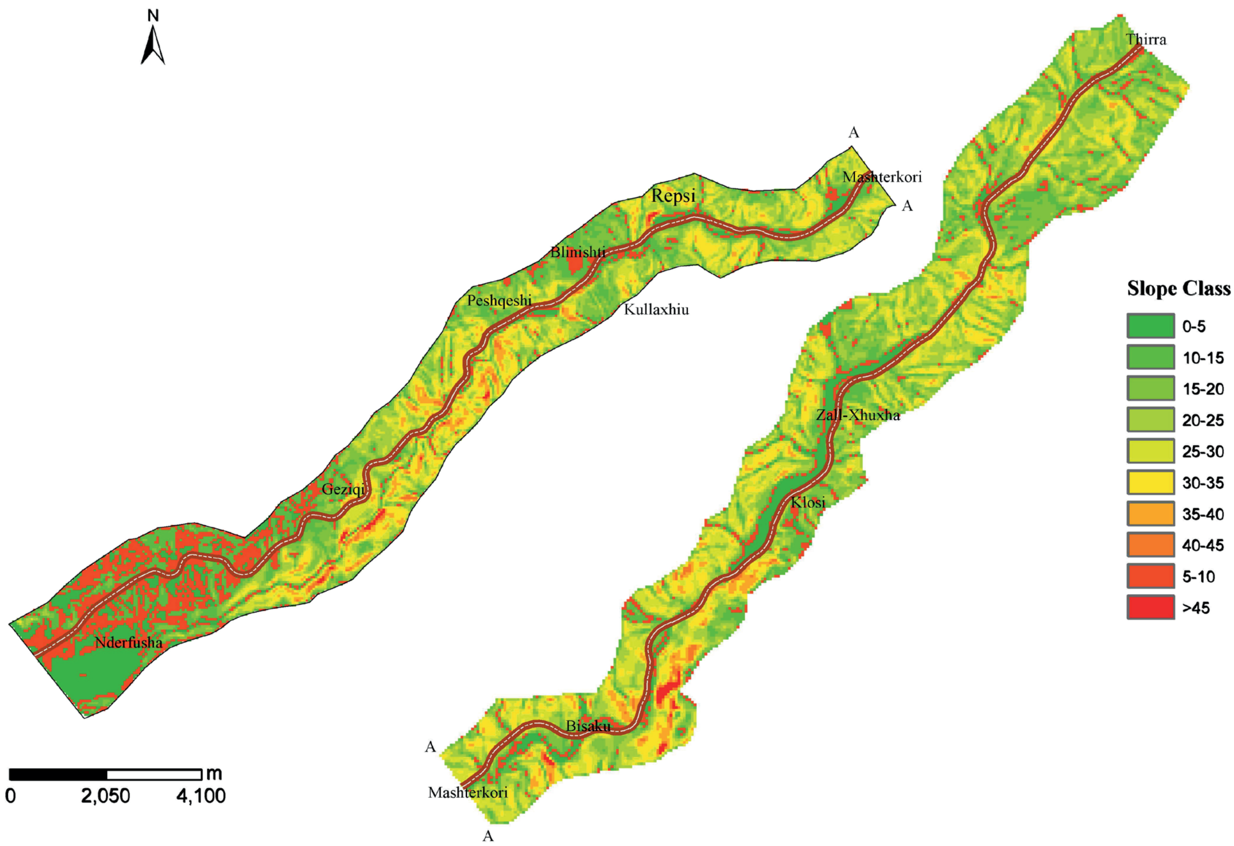
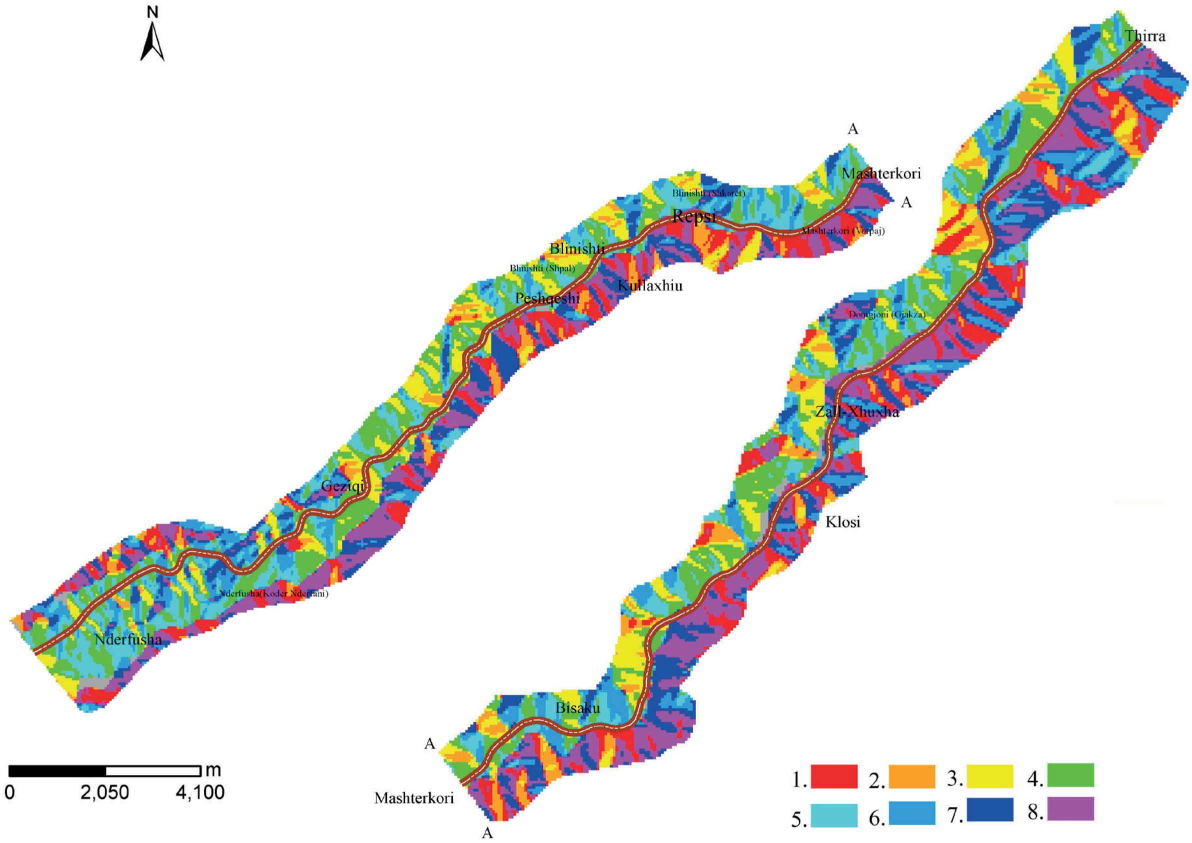


Fig. 11 Map of slope angle of the studied area



1. north (337.5–22.5), 2. northeast (22.5–67.5), 3. east (67.5–112.5), 4. southeast (112.5–157.5), 5. south (157.5–202.5), 6. southwest (202.5–247.5), 7. west (247.5–292.5), 8. northwest (292.5–337.5)

Fig. 12 Map of slope aspect of the studied area

Table 2 The weight value for each class of the slope angle

Classes (slope angle)	Weight
0–5	0.0
5–10	1.0
10–15	1.5
15–20	2.0
20–25	2.5
25–30	3.0
30–35	3.5
35–40	4.0
40–45	4.5
45–90	5.0

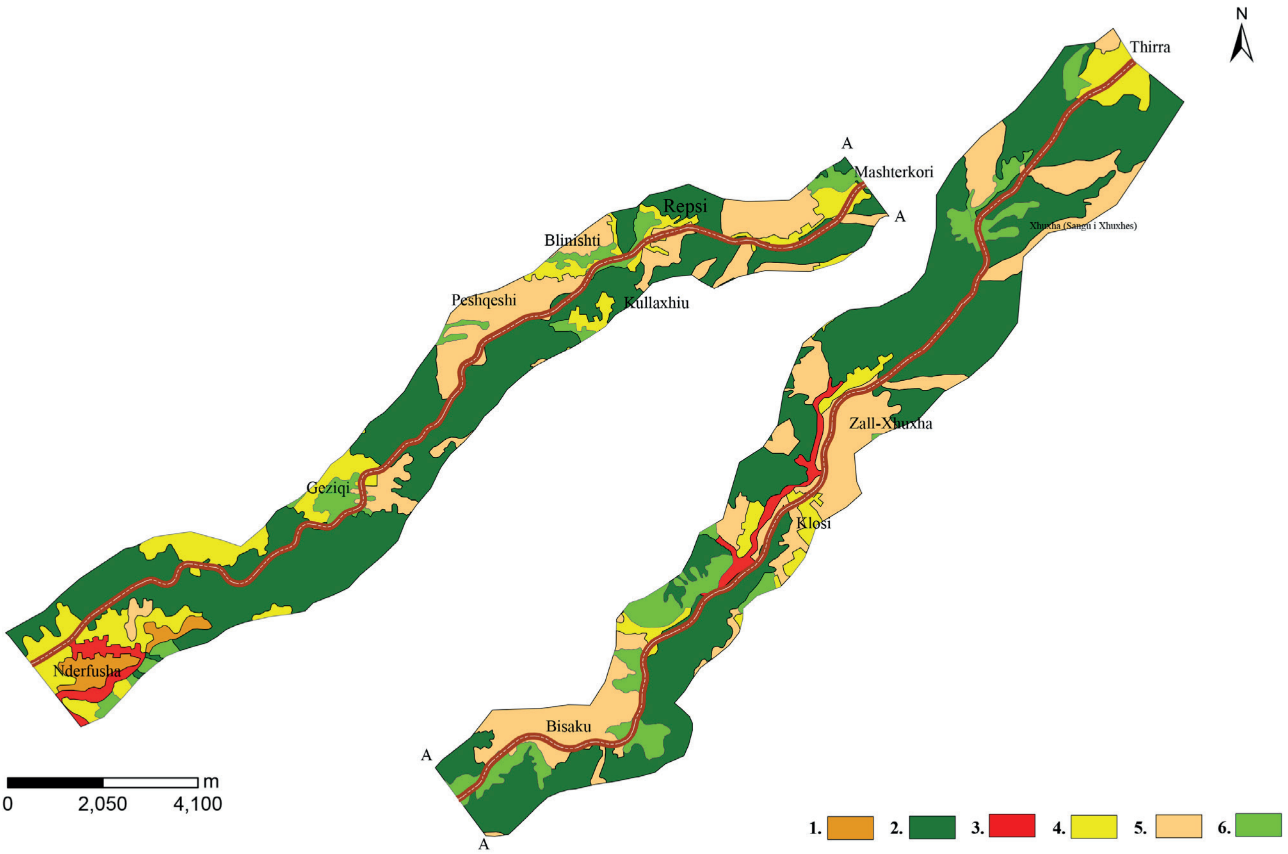
Table 3 The weight value for each class of the slope aspect

Classes (direction)	Weight
North	5
Northeast	4
East	1
Southeast	2
South	1.5
Southwest	2
West	1
Northwest	4

weights value was defined in such a way, being the most correct in determining the expected hazard level from the lowest to very high. The higher weight value "5" was addressed to steeper slopes and no exposed slopes to the sun rays strike and the lower weight value "1" for the gentler slopes and exposed slopes to the sun rays strike [2, 5, 12 and 13].

6 Land use map

Land use is a factor that influences the triggering of the landslides [9, 14]. For this reason, it has been taken into account concerning to landslide hazard evaluation, as one of the factors that controls the landslide activity. It has been observed that the deep-rooted trees (forest vegetation) offer generally a stable slope [9, 13, 14]. The non-vegetated to absence of vegetation slopes are more susceptible to landslide than dense vegetated to forest slopes. Based on this feature, were given the weights values to each class [9, 14]. The land use map was taken by the [7, 8]. The studied area was divided into six land use classes from low to dense vegetation (Fig. 13). In Table 4 are given weights for all classes, which range from "1 to 5", where "1" represents the lowest influence and "5" indicates the highest impact on the landslide hazard.



1. Complex cultivation patterns, 2. mixt forest, 3. sparsely vegetated areas, 4. land principally occupied by agriculture, with significant areas of natural vegetation, 5. transitional wood land/shrub, 6. natural grassland

Fig. 13 Landuse map of the studied area

Table 4 The weight value for each class of the land use

Classes	Weight
Complex cultivation patterns	3
Mixt forest	1
Sparsely vegetated areas	5
Land principally occupied by agriculture, with significant areas of natural vegetation	4
Transitional woodland/shrub	2
Natural grassland	3

Table 5 The weight value for each factor

Factor	Weight
Lithology	0.45
Slope angle	0.35
Slope aspect	0.05
Land use	0.15

7 Landslide Hazard Zonation

For the landslide hazard zonation, the heuristic approach or Index-Based Method (IBM) was used. After [10], the heuristic approach, based on the a priori knowledge of all causes and instability factors of mass movements in the studied area, for landslide hazard evaluation is an indirect and mostly qualitative method, that depends on how well and how much the investigator understands the geomorphological processes acting upon the terrain. Instability factors are ranked and weighted according to their assumed or expected importance in causing mass movements [10, 12]. Based on the geo-engineering studies, during the works and slope stability analysis [15, 16] for the landslide hazard zonation of the Milot-Kukës motorway were identified the factors that affect the instability of the hilly slopes, which are lithology, slope angle, slope aspect and land use. These factors were also analyzed in detail in order to determine their relation influence to the landslide occurrence. For each factor was prepared a thematic map by using of GIS technique. The weight of each factor is set based on the role that plays in the landslide's causing. The total weight of factor group is "1" (Table 5).

For compiling of the landslide hazard zonation map, the maximum value was given to the factor, which plays the crucial role in causing of landslides, while the minimum value was given to the factor that has the low influence on the slope instability (Table 5). From a detailed analysis performed in relation to the stability of the hill slopes, between factors, it has been concluded that lithology is the main cause of the hill's slopes destabilization, followed by the slope angle, land use, and slope aspect. Therefore, the highest weight value was for the lithology and minimum value for the slope aspect factor, have been assigned (Table 5). The hazard can be defined as the ratio between areas where landslides occurred to the total area [12].

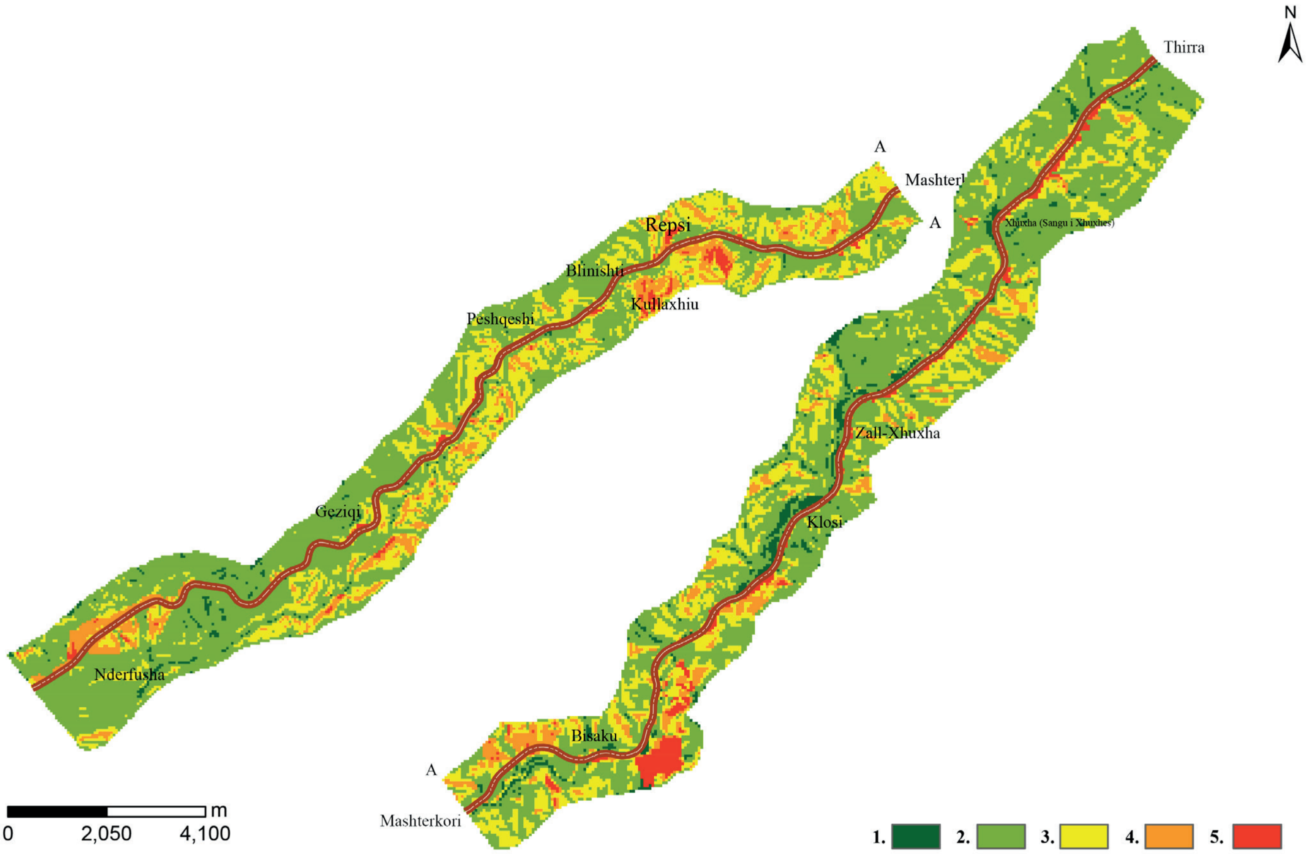
So, if the hazard value for the specified area is equal "1" or "5" it means a lower or higher probability of landslide occurrence. The hazard zonation map of the studied area was composed by using Equation (1) [12]. All "W_{ij}" layers for all the causative factors created in Arc GIS are summed of the four factors by using equation (1) [12] in raster calculator of Arc GIS 10.5, to obtain landslide hazard index map, which is classified into five landslide hazard zones as are very low, low, moderate, high and very high landslide hazard areas (Figs. 14, 15).

$$LHI = \sum_{j=1}^{n} \left(W_j * W_{ij} \right) \tag{1}$$

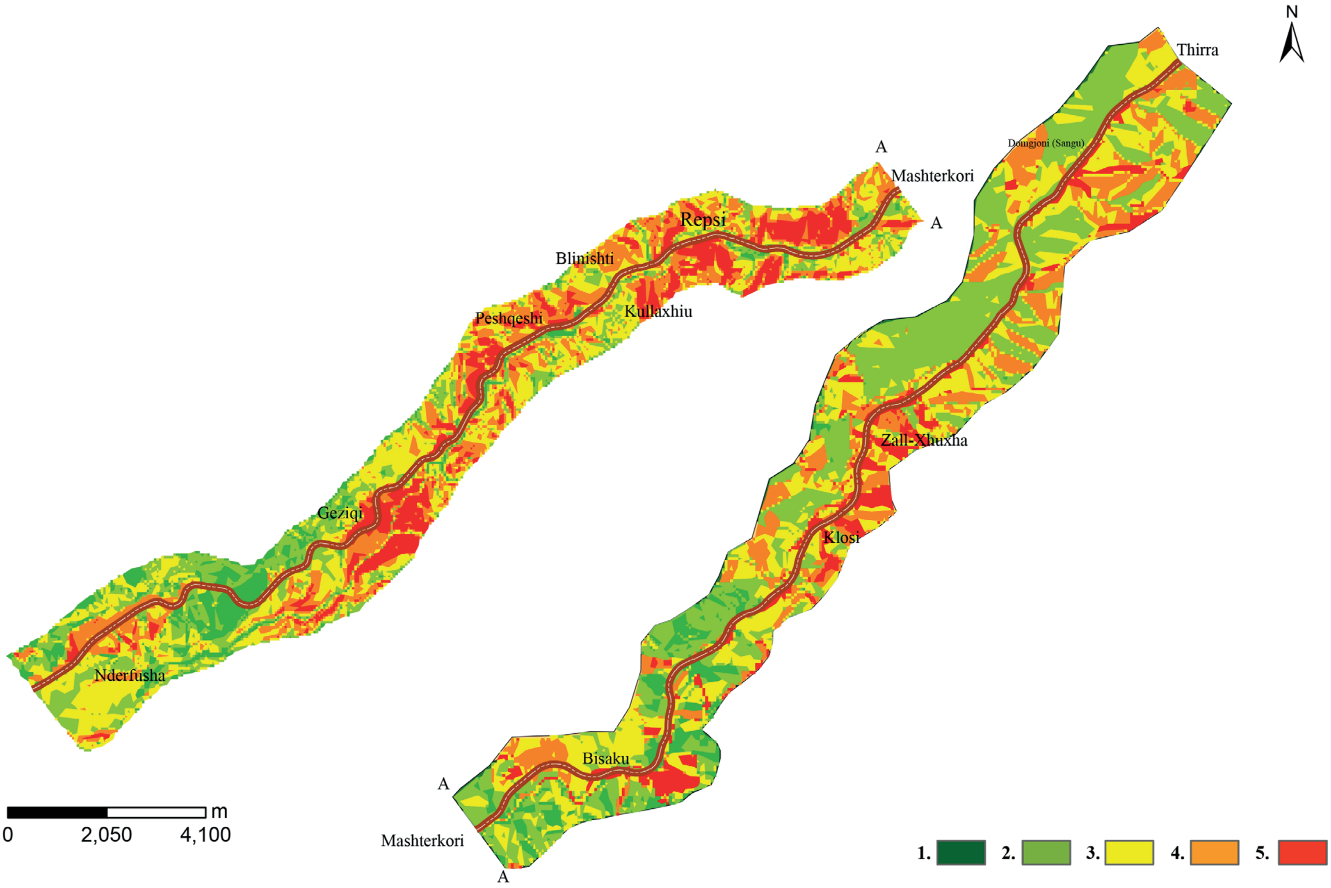
Where:
LHI : Landslide hazard index,
W_j: Weight value of each group's factor,
W_{ij} : Weight value of each class, and
n: Number of factors.

The building of the landslide hazard zonation map involves manipulating and analysing these data in the GIS. The LHI values range 1.0 to 5.0. For simplification the map interpretation, the LHI values are classified into five different hazard categories, which are i). very low landslide hazard with LHI ≤ 1.0, ii). low landslide hazard area 1.0< LHI ≤ 2.0, iii). moderate landslide hazard area 2.0< LHI ≤ 3.0, iv). high landslide hazard area 3.0 < LHI ≤ 4.0 and v). very high landslide hazard area with LHI >4.0. Thus, based of landslide hazard map is possible to determine the expected hazard level for any point on a map.

In Fig. 14 [7, 15, 20], is given LHZ map, which represents the landslide hazard evaluation of the period before the motorway construction. It shows some interesting data about the landslide hazard in the case of natural conditions of the motorway area. This map reveals that 5% of the study area is involved in very low hazard, 58% low hazard, 26 % moderate hazard, 8% high hazard and 3 % as very high hazard. While, in Fig. 15 [8, 16, 21], is presented LHZ map, which evaluate the landslide hazard after the motorway construction. As above mentioned it, for the motorway construction has been carried out a large excavation volume (blasts). Here, at the hazard level, besides natural and geological factors, the manmade works have been influenced, as well. The map indicates that 5% of the study area is involved in very low hazard, 30% low hazard, 32% moderate hazard, 21% high hazard and 12 % as very high hazard. From the analysis made of the two maps (Figs. 14 and 15), it was found that the level of high hazard and very high hazard of the studied area after the motorway construction has been increased respectively 2.62 and 4 times. Hence, it was revealed that the main reasons of the mass movement in the studied area are manmade works (blasting excavation). Consequently, from these works there is increased the mass movement occurrence, at the same time the risk to travelers, cars and road infrastructure.



1. very low hazard zone, 2. low hazard zone, 3. moderate hazard zone, 4. high hazard zone, 5. very high hazard zone.
Fig. 14 Landslide hazard zonation map before construction of motorway



1. very low hazard zone, 2. low hazard zone, 3. moderate hazard zone, 4. high hazard zone, 5. very high hazard zone.

Fig. 15 Landslide hazard zonation map after construction of motorway

Finally, it is concluded that in high and very high hazard areas, a systematic planning of protective engineering measures is required to prevent the mass movement occurrence.

8 Results and discussion

The GIS was involved to compile the landslide hazard zonation maps (Figs. 14 and 15) of the Milot-Kukës motorway and based on: landslides distribution, lithology, slope features, geotechnical conditions (weathered and fractured rocks) and land use characteristics as they are the source for landslides. The landslide hazard zonation map is classified into several hazardous categories from very low to very high. The zones with varying degrees of potential landslides were identified.

Results reported:

i). For the period before the motorway building 5% of the study area is involved in very low hazard, 58% low hazard, 26 % moderate hazard, 8% high hazard and 3 % as very high hazard (Fig. 14).

ii). For the period after the motorway building 5% of the study area is involved in very low hazard, 30% low hazard, 32% moderate hazard, 21% high hazard and 12 % as very high hazard (Fig. 15).

Very high hazard zone represents highly unstable slopes, particularly during heavy rain fall, threatening travelers. Therefore, it involved areas where mass movements have occurred. It is a non-vegetation area, of steep and cut slopes, consisting of highly to completely weathered and intensive fractured rocks, and loose blocks and unconsolidated soils.

High hazard zone involves areas of high landslide probability. The rocks mass of slopes are affected by intensive joints, which can cause additional landslide. There is a potential for wedge and planar failures as well as rockfalls, together with the accumulation of erosion debris at the toe. Also, there are unstable rock blocks on the cut slope, as well as on the natural slope that pose some hazard. Many of the landslides occurred in the studied area are located within this zone. Furthermore, in this area there are some lithological formations, where the dip angle of the geological structure and the slope angle are in the same orientation.

The southwestern (19.5–22.5km), central (29.5–70.0km) and northeastern part (78.0–89.5km) of the motorway area is categorized in as high and very high hazard zone. These zones are located within highly-completely weathered and intensive fractured of molasses, ultrabasic, gabbro, mélange and volcanoes formations. Almost the hazardous landslide areas are extended over cut slopes of motorway area. Thus, there is an urgent need to take necessary rehabilitation works, mitigation of risk and protective engineering measures against mass movement activity to avoid any potential hazard that can be occurred in the motorway area.

Moderate hazard zone is generally characterized by a stable state. Most of this zone is built by hard massive rock masses, which are not effected by weathering and discontinuity activity. The slope angle less than 45° and cover by dense vegetation. However, in the studied area, this zone consists of weak rocks (molasses), which are susceptible to landslides in case of hill slopes with >10° degrees and heavy rains. Therefore, several landslides, as earth slide have occurred.

Very low hazard zone in the studied area, involves areas with small slope angle, covered with dense, vegetation and no effected by landslides occurrences. This zone is considered safe/stable against the landslides occurrence. But in the case of human intervention on the hilly slopes, something is damaged in their natural equilibrium. Thus, the slope angle increases, vegetation, and water drainage is damaged and consequently, some landslides occurred on this zone.

Low hazard zone represent areas that are not effected by landslides and the chance of slope failure is low or impossible to occur due to its current geological and morphological setting, as well as environmental situation (relatively dense vegetation, water drainage etc.).

So, the above results show that the level of high hazard and very high hazard of the studied area after the motorway construction has been increased 2.62 and 4 times, respectively. This shows that the landslide occurrence is increased 4–5 times, at once endangering the lives of passengers, car's traffic to travelers and road infrastructure. It should be noted that the main cause for the mass movement in the studied area is the anthropogenic activities (excavation by blasting cutting).

Moreover, the validity of the landslide hazard zonation map through overlay analysis revealed that 45.5% of past landslides are included in the high risk zone and 44.7% in very high hazard zone, as well as 8.6% and 1.2 % in moderate low hazard zone (Fig. 16). Thus, 90.2% of the past landslide occurrences, point out a satisfactory compliance with the compiling of the landslide hazard zonation map. That means that GIS techniques can support engineering geological studies concerning landslide vulnerability of hazardous areas.

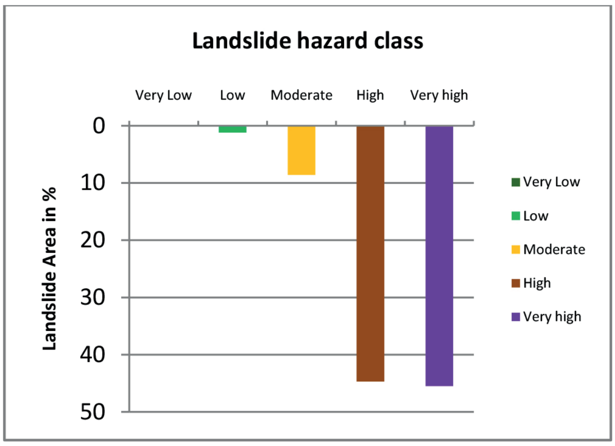


Fig. 16 It shows the correlation of landslide area hazard category

9 Conclusions and recommendations

The landslide hazard zonation maps of the Milot-Kukës motorway, were compiled using GIS techniques. For that, there are taken into consideration some factors such as lithology, slope features, slope aspect and land use characteristics, which have been considered as main cause for landslides. The landslide hazard zonation map is classified into several hazardous categories from very low to very high. It was identified the zones with varying degrees of potential landslides.

From landslide hazard evaluation is revealed:

For the period before the motorway building 5% of the study area is involved in very low hazard, 58% low hazard, 26 % moderate hazard, 8% high hazard and 3 % as very high hazard.

For the period after the motorway building 5% of the study area is involved in very low hazard, 30% low hazard, 32% moderate hazard, 21% high hazard and 12 % as very high hazard.

The southwestern (19.5–22.5km), central (29.5–70.0km) and northeastern part (78.0–89.5km) of the motorway area is categorized in as high and very high hazard zone. These zones are located within highly-completely weathered and intensive fractured of molasses, ultrabasic, gabbro, mélange and volcanoes formations. Almost the hazardous landslide areas are extended over cut slopes of motorway area. Thus, there is an urgent need for rehabilitation works, mitigation of risk and protective engineering measures against mass movement activity to avoid any potential hazard in the motorway area.

Detailed analysis of landslide hazard zonation maps, show that anthropogenic activities have increased the high hazard and very high hazard level in the studied area 2.62 and 4 times, respectively. Consequently, the landslide increased 4–5 times.

The validity of the landslide hazard zonation map through overlay analysis revealed that 45.5% of past landslides are involved in the high-risk zone and 44.7% in very high hazard zone, as well as 8.6% and 1.2 % in moderate low hazard zone. Thus, 90.2% of the past landslide occurrences, point out a satisfactory compliance with the compiling of the landslide hazard zonation map. That means that GIS techniques can support engineering geological studies concerning landslide vulnerability of hazardous areas.

The landslide hazard evaluation of the Milot-Kukës motorway reported the urgent need for rehabilitation works, mitigation of risk and protective engineering measures against mass movement activity to avoid any potential hazard in the motorway area.

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