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# LANDSLIDE SUSCEPTIBILITY MAPPING USING GIS ALONG THE NIŠ – NORTH MACEDONIA HIGHWAY

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**ABSTRACT**: *Landslide events are a serious challenge worldwide, as well as in the Republic of Serbia. According to current estimates, 25-30% of the territory of Serbia is endangered by landslides. Due to intensive landslides, residential, infrastructural, energy, water management and industrial facilities, as well as natural and cultural goods are endangered. The subject of this paper is the use of GIS for the production of a landslide susceptibility map (LSM) in the area of the corridor of the highway E-75, section Niš - border of the Republic of Northern Macedonia. Emphasis is placed on the analysis of certain factors that influence the landslide events, as well as on the modifiers of the process itself. In this paper the following factors were selected for the assessment and susceptibility mapping: lithology, pedological factors, precipitation, aspect, slope, distance from watercourses, land use and distance from roads. The AHP method was then used to determine the relative significance and priority of predisposing factors. The layers were overlapped using ArcGISPro software. The results show that 17.2% of the surface is not susceptible (very low and low susceptibility), and 31.9% of the surface is prone to landslide events (high and very high susceptibility). The remaining 49.1% of the area belongs to the area of moderate susceptibility. Adding to this dense road network in the study area, as well as a large number of populated places, it can be concluded that the damage from the activation of the landslide would be significant. The results suggest that 60.7 km of the highway is in an area of high and greatest risk of landslides.*

**Keywords:** *landslides, mapping, GIS, landslide susceptibility, infrastructure corridor*

## INTRODUCTION

Landslides are a type of general denudation process, that is widespread on the Earth's surface (Lazarević & Tošić, 2013). Cruden and Varnes defined a landslide event as the movement of a mass of rocks, debris, or earth down a slope under the influence of gravity. Radenko Lazarević (2000) described landslides as "slow, gradual or relatively fast and sudden movement of surface loose and non-resistant layers". The term "hazard" has been extensively researched and explained in the literature, however the notion of landslide susceptibility needs to be further clarified. It is necessary to make a difference between the terms "susceptibility" to landslides and "hazard". These terms mean different concepts, however, they are often used as synonyms (Guzzeti, 2005). Landslide susceptibility is the probability of landslides based on the local terrain conditions of a particular area (Brabb, 1984). The use of GIS is widely used to assess the susceptibility of terrain to sliding pro-

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cesses (Carrara et al. , 1995; Fell et al. , 2008; Awawdeh et al. , 2018). The main advantage of GIS is in the fact that a great portion of the research can be finished by cabinet work and that highly precise data about locations can be acquired in combination with field work (Durlević et al., 2018). With the increase in the number of projects on the construction of fast roads, the occurrence of landslides is increasing, the total damage from landslides is increasing, and this process and its consequences are not given enough attention in the Republic of Serbia. Landslides are largely conditioned by anthropogenic activities (Wati, 2010), especially the construction of infrastructure systems (Jaiswal et al. , 2009; Chakraborty & Anbalagan, 2009). In addition to causing landslides, infrastructure corridors are also very sensitive areas due to the economic and functional consequences they can have due to landslide damage. The most sensitive is the highway itself, where the occurrence of landslides can take human lives. The subject of this research is a GIS analysis of landslide risk on the infrastructure corridor Niš-border with Northern Macedonia. The main goal of the research is to establish a connection between the construction of an infrastructure facility and the occurrence of landslides in the studied environment. The beginning of the research starts from the assumption that the construction of such a complex facility as an infrastructure corridor due to the physical scope and changes in the natural state initiates various processes in the immediate environment and leads to the occurrence of landslides. The increase in the number of landslides, as well as the consequences of the same in Serbia, requires the innovation of data and methodologies related to this topic, including the use of new technologies, such as geoinformation systems.

## STUDY AREA

The study area includes the main infrastructure corridor Niš-border with Northern Macedonia (a southern branch of Corridor 10), as well as the wider area of influence of the infrastructure corridor. Corridor 10 is one of the most important pan-European traffic corridors passing through Serbia. The area presented in this paper is wider than the scope of the spatial plan, so that the analysis of the factors influencing the occurrence of landslides would be more comprehensive and valid. The area analyzed covers 6401. 2 km² with a length of 135 km (Figure 1). The mentioned infrastructure corridor is one of the most demanding projects in Europe, which is why it was chosen as the topic of the research. Several landslides on the highway through the Grdelica gorge forced the Corridors of Serbia to hire world experts with experience in repairing slopes and potential landslides and spend significant financial resources.

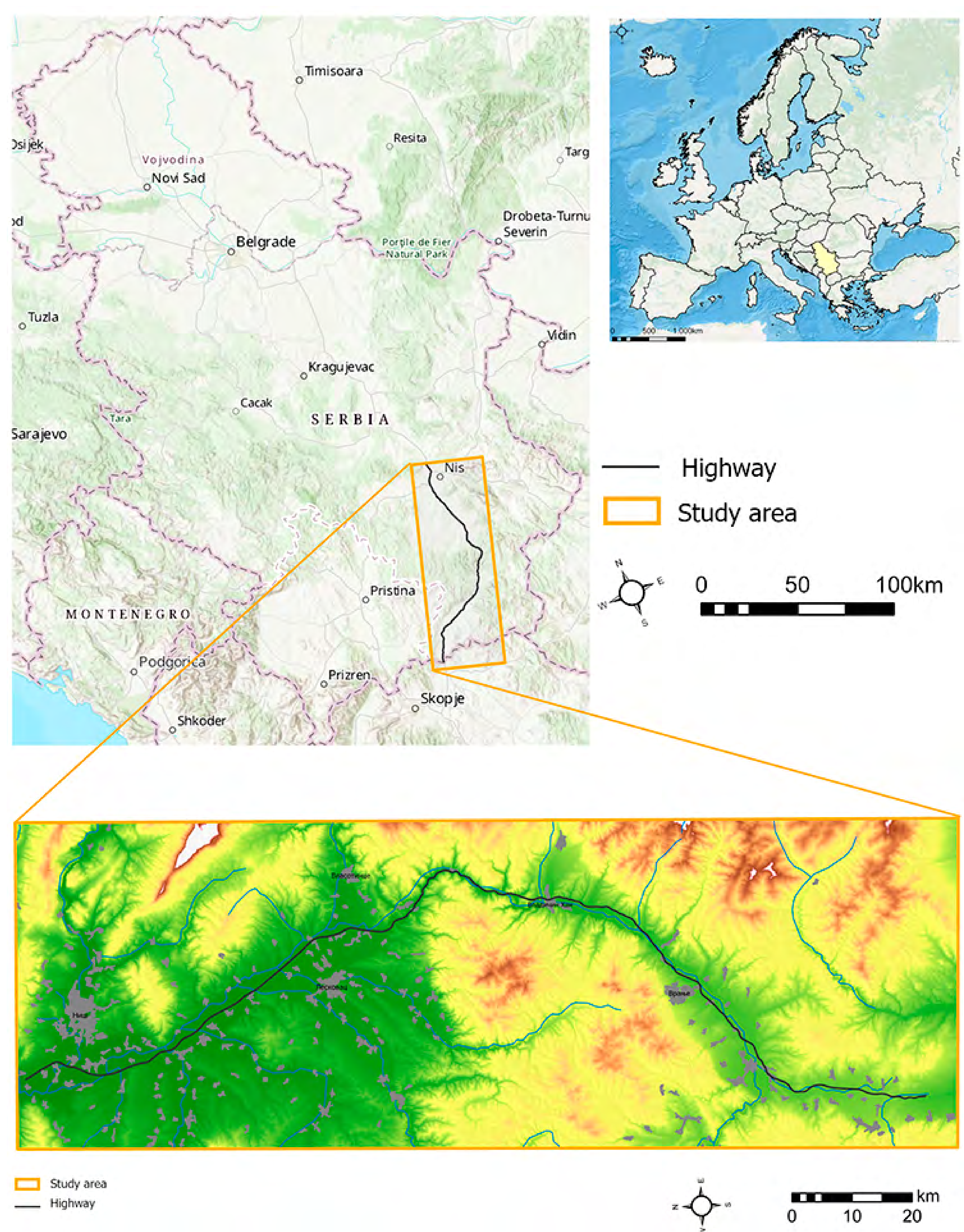


**Figure 1.** Location of the study area
*Source: Author's mapping*

# MATERIALS AND METHODS

In order to assess landslide susceptibility in the most efficient way, it is necessary to have knowledge of how predisposing factors affect terrain instability. The choice of factors depends on the characteristics of the exploration area, the type and mechanism of the landslide, as well as the availability of data at a given time. In this study, the following predisposing factors were selected for the assessment and mapping of landslide susceptibility: geology, pedology, slope angle and aspect, land use, precipitation, distance from watercourses and distance from roads. The data used to assess the landslide susceptibility in this study were collected from various sources and presented in Table 1.

**Table 1.** Data and data sources

| Data | Source |
|---|---|
| Digital Elevation Model | search. asf. alaska. edu |
| Rainfall | http://www.hidmet.gov.rs/ |
| Roads | http://download.geofabrik.de/ |
| Land use | https://www.copernicus.eu/en |
| Slope | ALOS PALASAR DEM (12.5 m) |
| Aspect | ALOS PALASAR DEM (12.5 m) |
| Streams | ALOS PALASAR DEM (12.5 m) |
| Geology | Basic Geological map of Serbia 1:100,000 |
| Pedology | Pedological map of FNRJ 1:1,000,000 |

*Source: Author*

In the process of data collection, there were limitations to obtaining certain data. One such limitation is related to the insufficient number of meteorological stations in the study area. Rainfall data were obtained from meteorological yearbooks in the period from 1990 to 2020. The IDW (Inverse distance weighted) method in ArcGIS Pro 2. 5 was used for spatial interpolation of precipitation data. A Corine Land Cover (CLC) database was used to analyze land use patterns, which can be considered a relevant source of land cover information at the country level. The CORINE database is widely used in research due to spatial coverage across Europe, high thematic accuracy, and open data policy (Bielecka & Jeneworicz, 2019). The CORINE approach allows unique identification of land cover, while connecting this database with GIS applications allows easier data manipulation. Also, another limitation is related to the landslide inventory covering the test area, which is the basis for LSM. Creating an inventory of landslides in one area is a long-term and financially demanding project. For this reason, most places in the world, including the study area, lack a historical landslide inventory database. Therefore, this paper uses a qualitative heuristic approach which is the optimal approach for LSM, especially when landslide inventory data are not available (Tešić et al. , 2020). The following step is to process and analyze the thematic data to calculate the scores of all classes for AHP (Analytic hierarchy process) and WOM (Weighted Overlay Method). The AHP approach established by Saaty (1980) is used worldwide, mostly in academia for multicriteria analysis. AHP is a powerful multi-criteria decision-making tool which is decompositioning a complex problem into a hierarchy. There is a hierarchy where the goal is at the top level and the criteria, sub-criteria and alternatives are at lower levels (Tadić & Mihajlović, 2020). Then it is needed to define the spatial distribution of the adopted weight values (Wi) and individual parameters (Mi) using the following equation; (Equation 1) (Abolmasov et al., 2017).

$$\sum_{i=1}^{n} W_i M_i = M_{AHP} \quad (1)$$

Assigning weight values to individual parameters is a two-step procedure. First, the procedure requires an overall assessment of the relative importance of each parameter relative to the others and is defined by expert judgment. In this study, the weight of the criteria is based on the expert opinion, literature and landslides in Serbia. If n is the number of factors that influence the sliding process, the total number of comparisons between the factors is n · (n-1) / 2, which makes this procedure suitable when the number of factors is up to 10 (Albomasov et al. , 2017). As a result of the AHP analysis, the following equation was obtained; (Equation 2)

$$LSM = \sum_{i=1}^{n} \left( R_i \cdot W_i \right), \tag{2}$$

where Ri is the evaluation class of each parameter, and Wi is the weight value for each of the predisposing factors. In this paper, a landslide susceptibility map was obtained by layer overlap using the Weighted overlay method (WOM), a method used in ArcGIS software. In order to prepare data for WOM, it is necessary to assign a value to each range. The Reclassify tool in ArcGIS Pro software was used for this process. The obtained LSM values were then divided into 5 susceptibility zones: very low susceptibility (VLS), low susceptibility (LS), moderate susceptibility (MS), high susceptibility (HS), and very high susceptibility to landslides (VHS).

# RESULTS

## Geology

Geology is reckoned as major factor influencing the landslide events. A cracked geological bedrock or a bedrock that stands parallel to the slope of the terrain represents a landslide-prone zone (Walker & Shiels, 2013). Landslides occur in loose, loosely bound and plastic rocks. In solid, compact rocks they are usually absent (Dragićević & Filipović, 2016). The sheets ofBasic Geological map of Serbia were digitized, and the corresponding databases were filled in according to the interpreters of the maps and the markings of the mapped

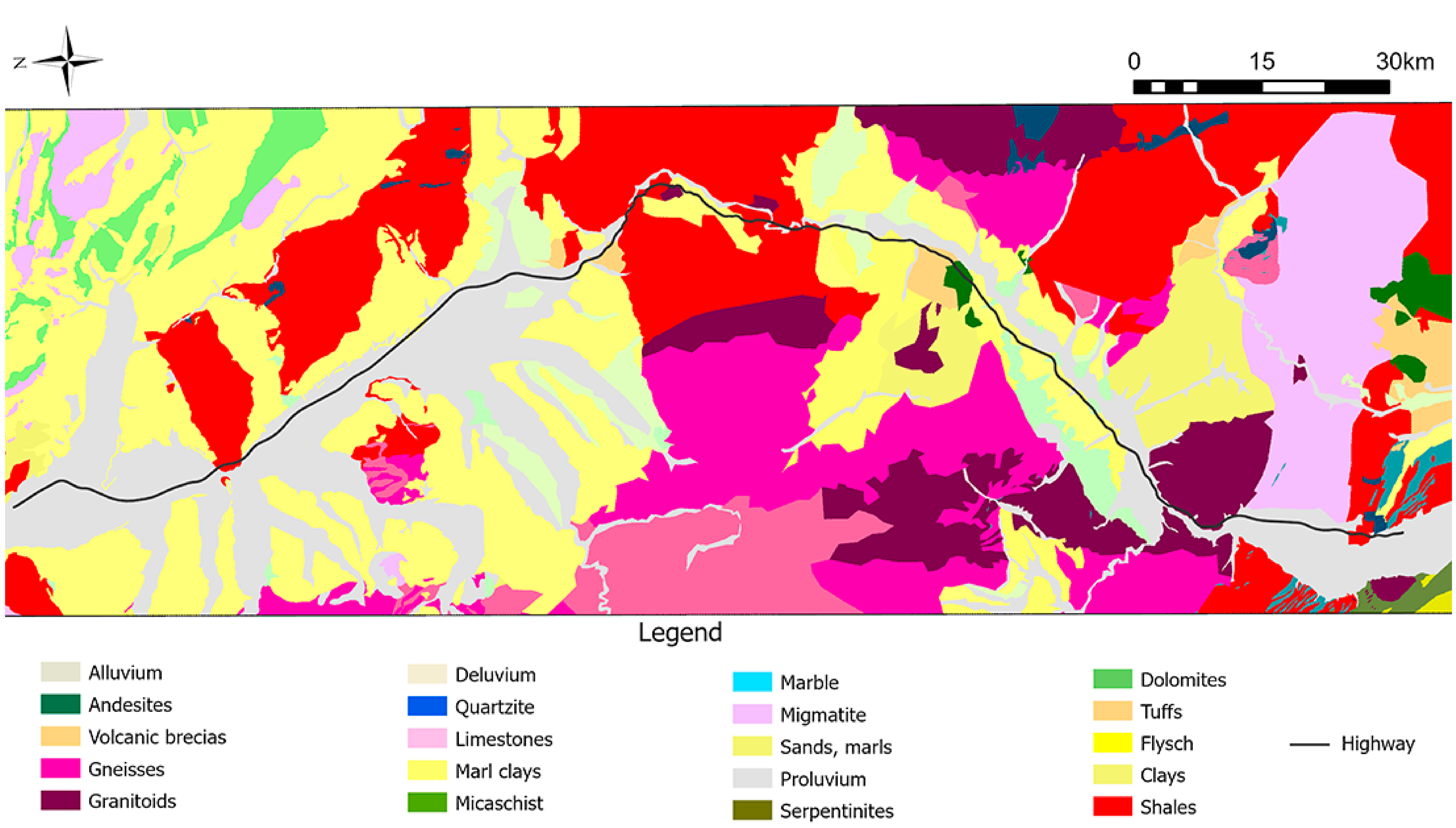


**Figure 2.** Geological map
*Source: Author's mapping*

units (Figure 2). The biggest part of the study area is covered by shales (17%), followed by alluvium (12. 2%), gneisses (11. 1%), migmatites (6. 2%) and granitoids (5. 8%). The lowest grades are given to surfaces whose lithological composition does not meet the conditions for landslides. These include all resistant and permeable rocks (limestones and dolomites), as well as non-resistant but permeable rocks, and then resistant and impermeable rocks (igneous, etc. ). When such types of rocks are excluded, then there remain rocks where landslides are possible: unbound rocks (sands, clays, loess), flysch series, marly-clay rocks, eluvial-deluvial deposits, etc. (Lazarević, 2000). Therefore, these lithological groups were assigned with the highest grade.

## Pedology

A pedological cover can increase the risk of landslides, especially if the pedological class has a higher power of water retention (Wati, 2010). The pedology of a terrain is most exposed to weather conditions, such as prolonged rains, which can significantly affect the permeability of the soil and thus have a significant impact on the occurrence of landslides. The study area is dominated by three soil types (Figure 3): acidic, brown and podzolic soils (28.3%), recent alluvial deposits (18.1%) and podzol and brown podzolic soils (15.4%). Smonitza and metamorphic smonitza are found mainly in the northern and western parts of the area. The remaining classes are red soils on tertiary sediments (10.9%), groves (8.3%), parapodzol and podzolic soils (8.2%), brown soils (1.3%) and parapodzolic and undeveloped soils on flysch and marl (0.5%). Higher grades were given to the potential of soil class to retain water during precipitation.

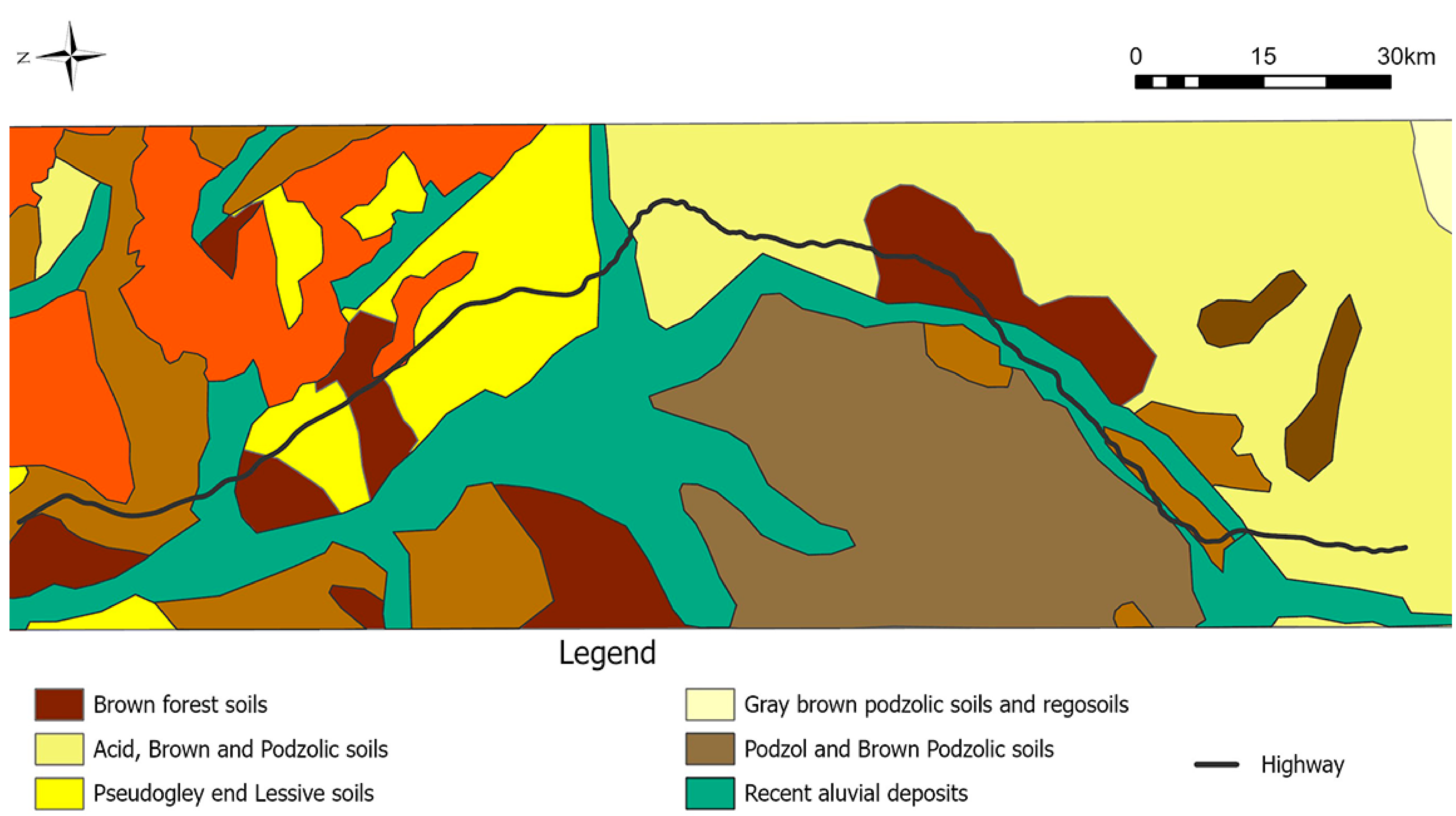


**Figure 3.** Pedology map
*Source: Author's mapping*

## Slope

The slope of the terrain is, in addition to geology, the most important factor in the analysis of the susceptibility of a certain area to the occurrence of landslides. Research has shown that landslides can occur on slopes above 5 °, but are most common on slopes above 15 °. For the formation of landslides on smaller slopes, the fall of the layers and the magnitude of the fall in the direction of the slope slope play an important role (Dragićević & Filipović, 2016). The global digital elevation model ALOSPALASAR (DEM, resolution 12.5 m) was used to obtain information on slope angles and terrain exposure. Terrain slope angles and terrain exposures are calculated in the ArcGISPro 2. 5 software. The slope of the area ranges from 0 ° to 79.1 °, and is divided into six classes (Figure 4). The largest angles of inclination are located in the northeastern and southeastern part of the study area. The largest areas are occupied by slope classes of 0 - 5 ° (26.46%) and 20 ° - 25 ° (25.52%). Each class is assigned a grade depending on the influence of the class on the occurrence of landslides. For terrain slopes of 0-5 ° assigned value 1, for slopes of 5-10 ° value 2, for slopes of 10-15 ° value 4, for slopes of 15-35 ° value 5 and for slopes over 35 ° assigned value 2.

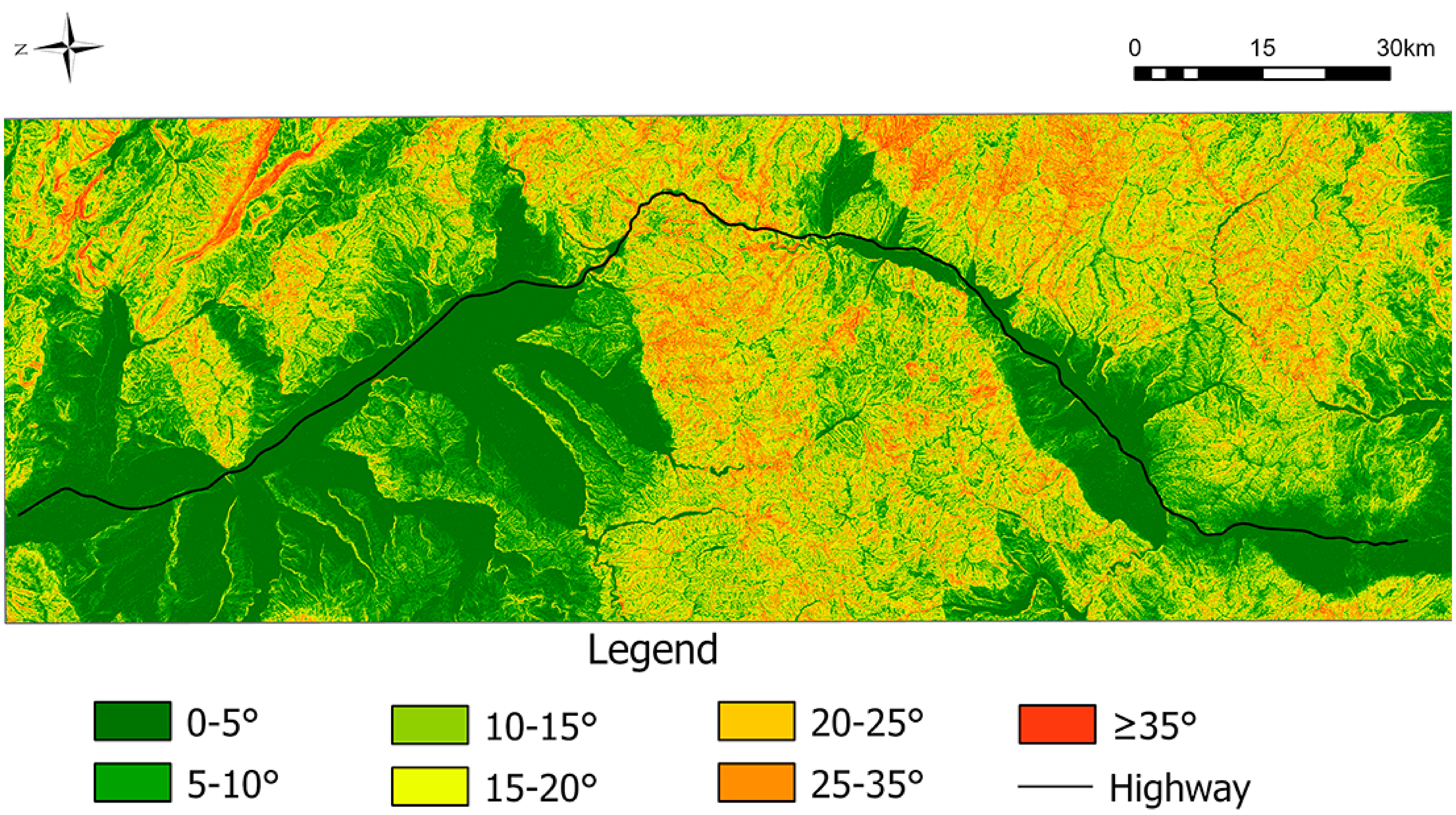


**Figure 4.** Slope map
*Source: Author's mapping*

## Aspect

The aspect of the relief represents its characteristic which indirectly influences the intensity of the process in nature, but also the degree of anthropogenic activity. The reception and duration of sunshine, temperature sum and their amplitude depend on the exposure of the terrain, and all this directly and indirectly affects the processes of physical decay and denudation (Dragićević & Filipović. 2016). In our latitudes, the greatest amount of sun radiation is received by the southern exposure, where the strongest heating of the topographic surface occurs, but also the greatest temperature amplitude. Accordingly, the southern exposures were assigned a value of 5. The western and southwestern exposures cover almost 30% of the research area (Figure 5).

## Land use

Landslides are common in places with a prominent anthropogenic factor, i. e. in places intended for agriculture (Salvatici et al., 2018), while the process of landslide is less frequent on terrains with dense vegetation. Therefore, areas rich in vegetation were considered less prone to landslides. The largest part of the study area is occupied by deciduous forests (38.9%), followed by land mainly occupied by agriculture (13%), non-irrigated arable land (12.5%) and transitional forest and shrub (10.2%) (Figure 6). By reclassifying the data, forests are assigned a grade of 1, agricultural areas a grade of 3 or 4, depending on the class, and the highest grades are given to areas under the influence of anthropogenic activity.

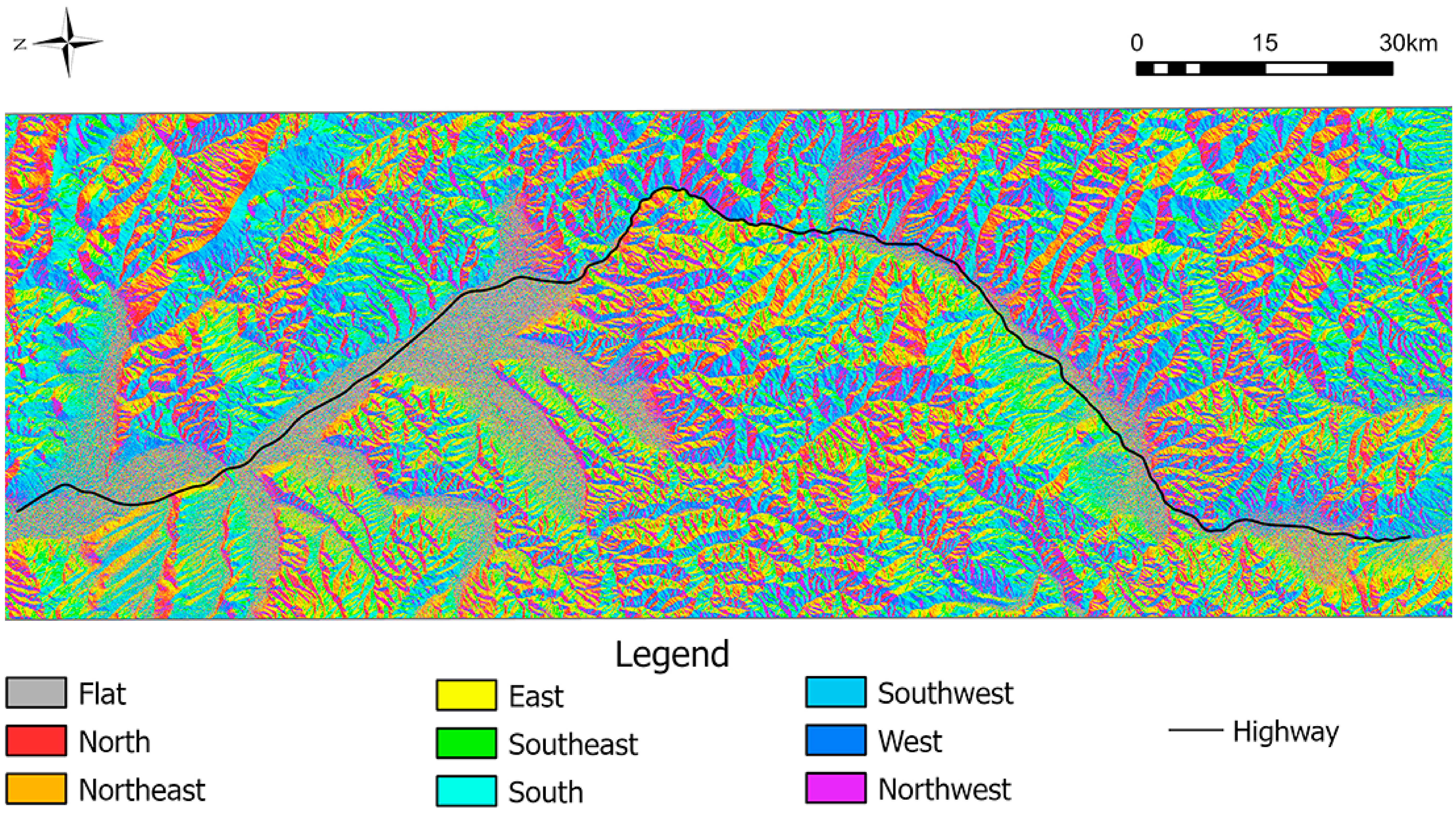


**Figure 5.** Aspect map
*Source: Author's mapping*

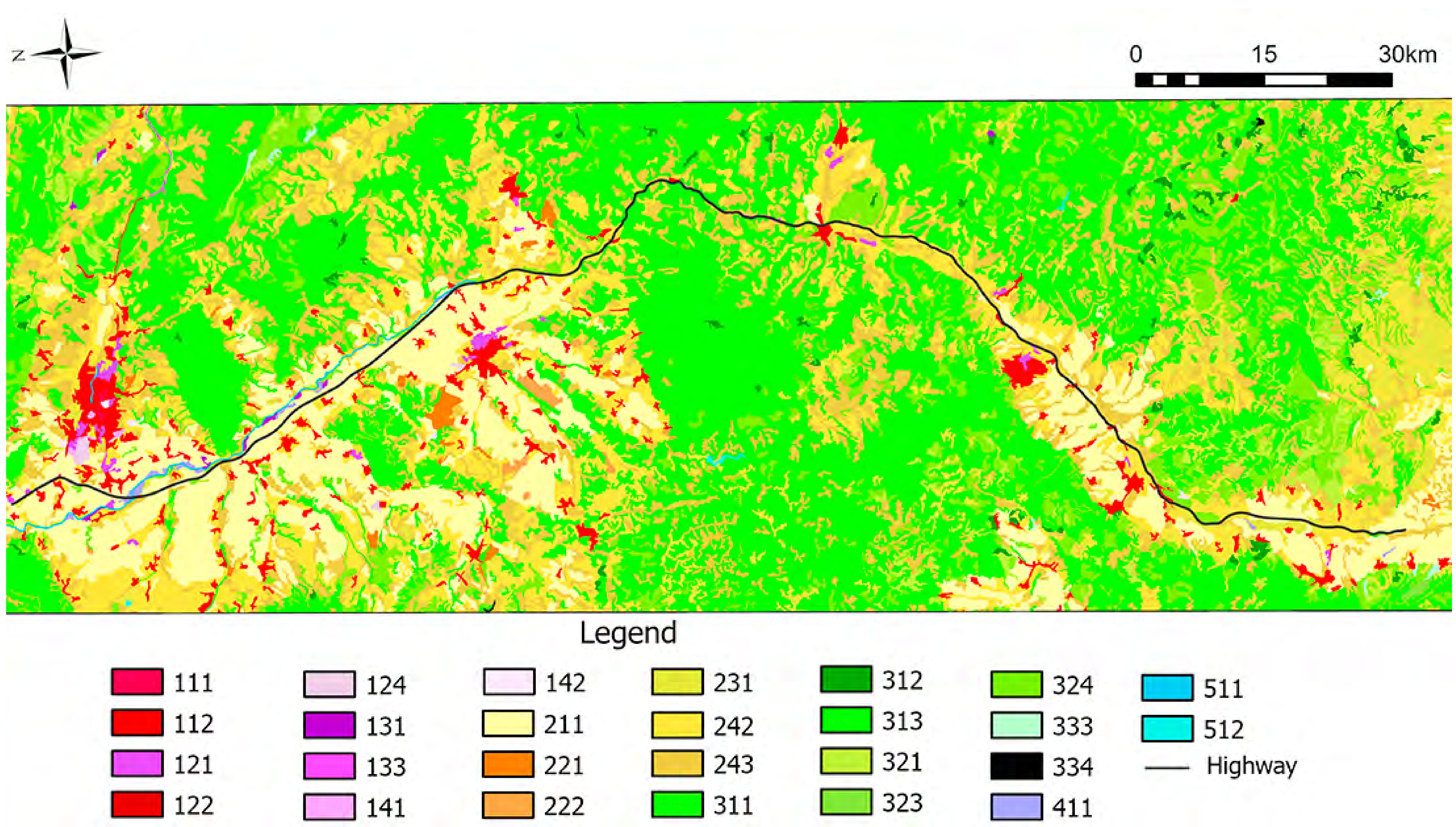


**Figure 6.** Land use map
*Source: Author's mapping*

## Rainfall

The amount of rainfall is a very important parameter in landslide analysis because a larger amount of water, in combination with other factors, negatively affects the stability of the slope and generally quickly destabilizes them. This is confirmed by the fact that the landslide process is most often activated in the spring, when the largest amount of precipitation occurs on the territory of the Republic of Serbia, and the surface loosening layer is heavy due to increased humidity (Dragićević & Filipović, 2016). The average annual rainfall amounts of the study area were obtained on the basis of data from climatological yearbooks. The total annual values for the period from 1990 to 2018 were analyzed. Using the tools of the GIS interpolation method, the average amount of precipitation for the territory of the study area was determined (Figure 7). Since there are only 4 meteorological stations on the territory of the study area, some larger spatial variations of the average annual precipitation are not so pronounced. Therefore, it was possible to classify only 5 classes of precipitation amounts. The area where the amount of precipitation of 600-620 mm was recorded was assigned a coefficient of 2, 621-650 mm of coefficient 3, and the area with 651-700 mm of precipitation was assigned a coefficient of 4. The area where 701-750 mm of precipitation falls was assigned a coefficient of 5.

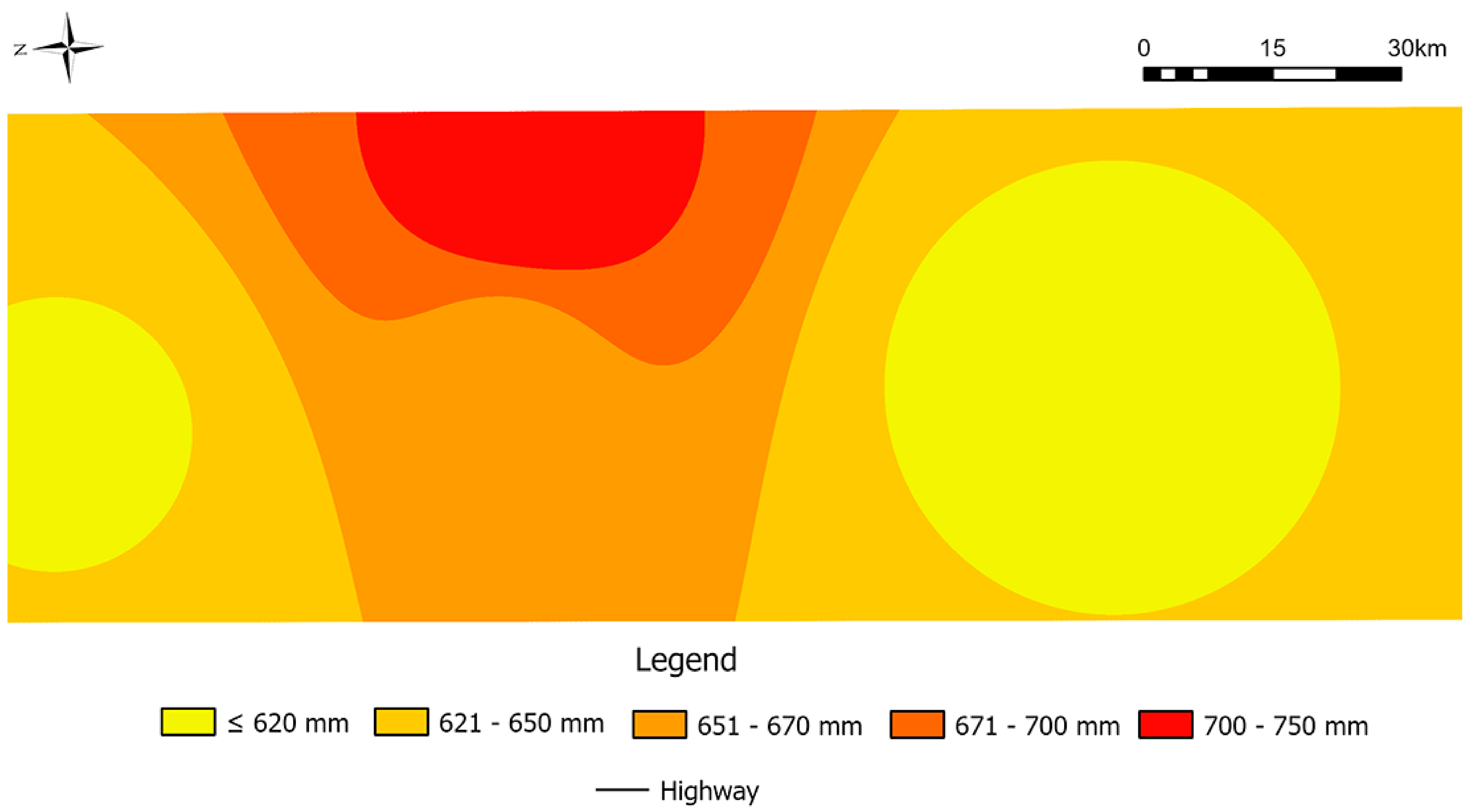


**Figure 7.** Rainfall map
*Source: Author's mapping*

## Distance from watercourses

Watercourses are an important factor influencing the occurrence of the sliding process, due to the fact that river erosion can cut the previously stable slopes. Rivers support the conditions for landslides and change the previously stable state, which can enable landslides to occur more easily. This factor was obtained using the EuclideanDistance tool in ArcGISPro 2. 5 software and is classified into five classes: (1) 0–50, (2) 50–100, (3) 100–500, (4) 500–1000, and (5)> 3000 m (Figure 8). In the area of the study area, there is a high possibility that landslides will appear in regions near 0 to 50 m from the watercourse, especially due to the fact that the infrastructure corridor follows the course of the South Morava River.

## Distance from roads

The existence of traffic infrastructure is the triggering factor of landslide events mainly due to slope trimming, excavation and changes in hydrological conditions (Kanwalet al., 2017). Also, when the distance from the roads increases, the vibration caused by vehicles decreases, thus reducing the chances of the danger of instability due to the proximity of roads. The construction of the highway itself significantly increases the probability of landslide processes. Having in mind the stated facts, a high grade was given for classes up to 100 m distance from roads, a medium grade for a class up to 500 m distance from the road network, while low grades were given for distances over 1000 m (Figure 9).

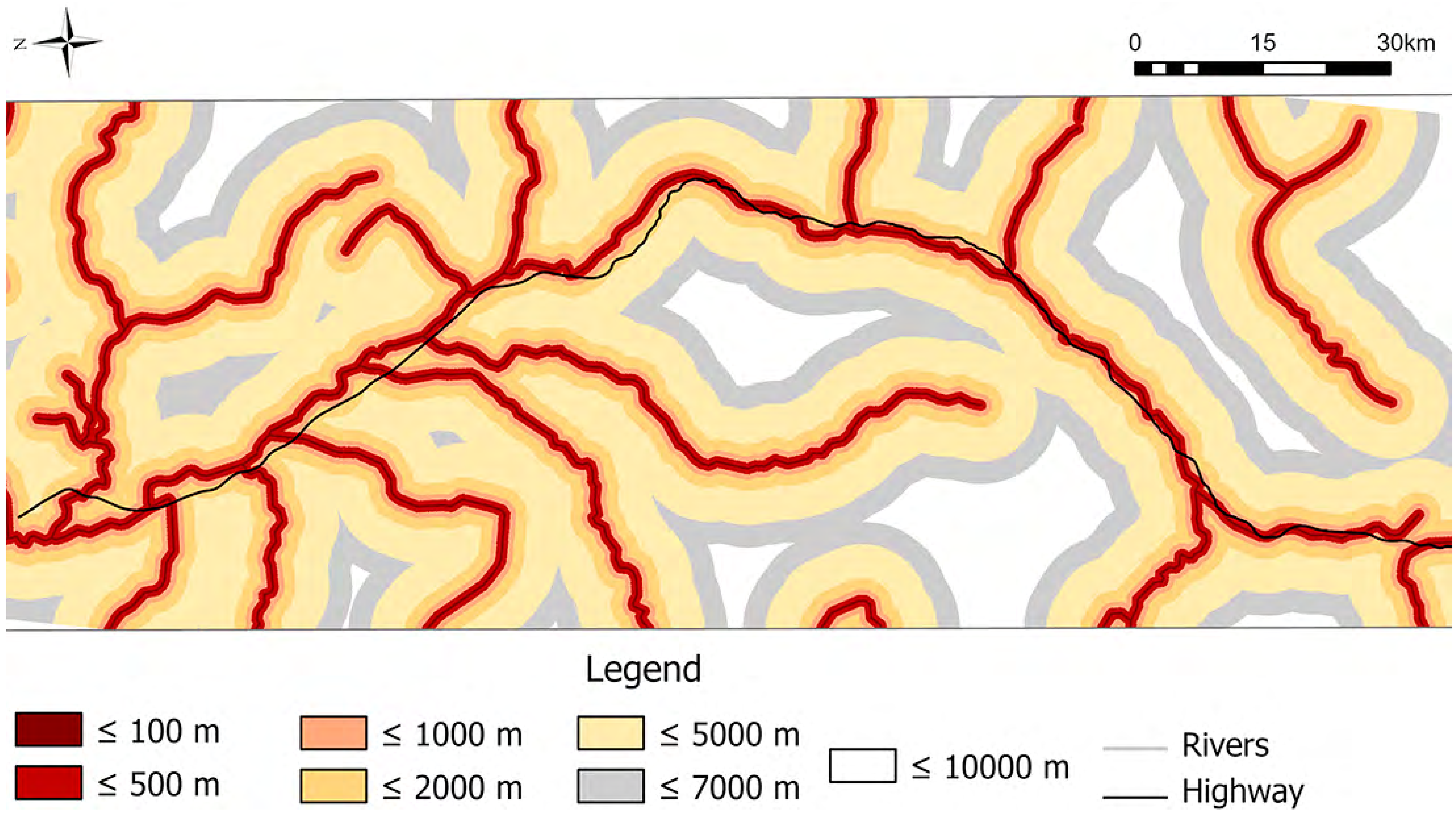


**Figure 8.** Distance from watercourses map
*Source: Author's mapping*

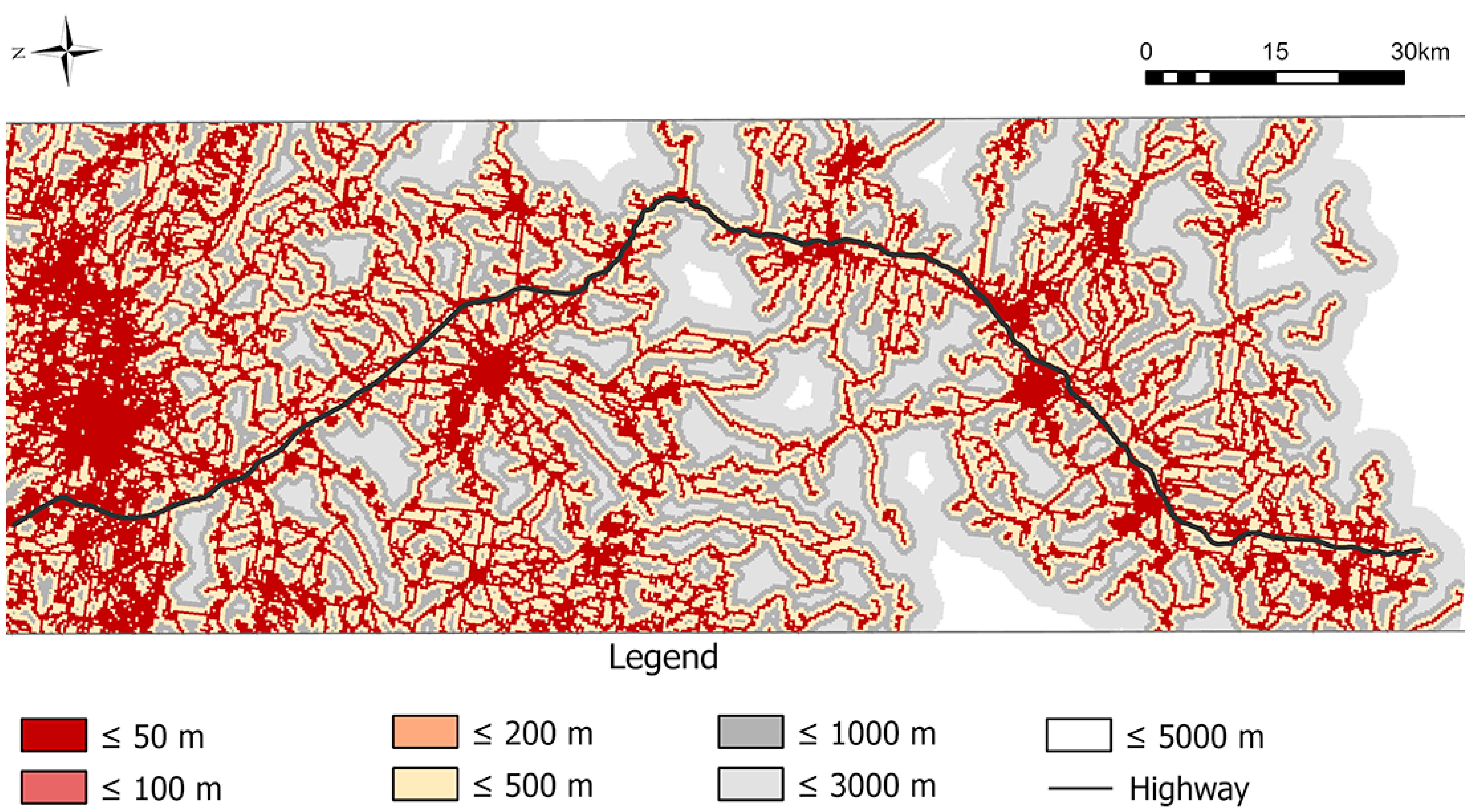


**Figure 9.** Distance from roads map
*Source: Author's mapping*

## Synthesis map

After evaluating all factors, a WOM analysis was performed. A five-point landslide sensitivity scale was used for WOM: very low, low, medium, high and very high sensitivity.

The AHP method was used to determine the significance of each factor (Table 2). Geology (27%) stood out as the main factor for landslide risk assessment. The second most important factor is land use, which has proven to be highly important for assessing the risk of landslides in the field (existing landslides in Serbia) and in the literature. Aspect is the least important factor at the locations of existing landslides, not only in the study area, but also in other territories of the Republic of Serbia. This is mainly because it is extremely variable, and therefore aspect cannot be considered a key risk assessment factor, although it is often reported in the literature. After the analysis, the results were obtained, which indicate that 31.9% of the surface is susceptible (high and very high susceptibility) to the occurrence of landslides (Figure 10). The area of moderate susceptibility includes 49. 1% of the territory, while 17.2% of the area is not susceptible (very low and low susceptibility). The obtained data indicate that the northern, northeastern and northwestern parts of the study area are the most susceptible to landslides. Other parts of the study area are less susceptible, but it is important to emphasize that in the parts of the area near the highway, susceptibility levels are medium or high.

**Table 2.** Factor estimates for WOM

| Factor | Weight (%) |
|---|---|
| Geology | 27 |
| Pedology | 10 |
| Slope | 15 |
| Aspect | 3 |
| Rainfall | 14 |
| Landuse | 17 |
| Distance from roads | 7 |
| Distance from watercourse | 7 |

*Source: Author*

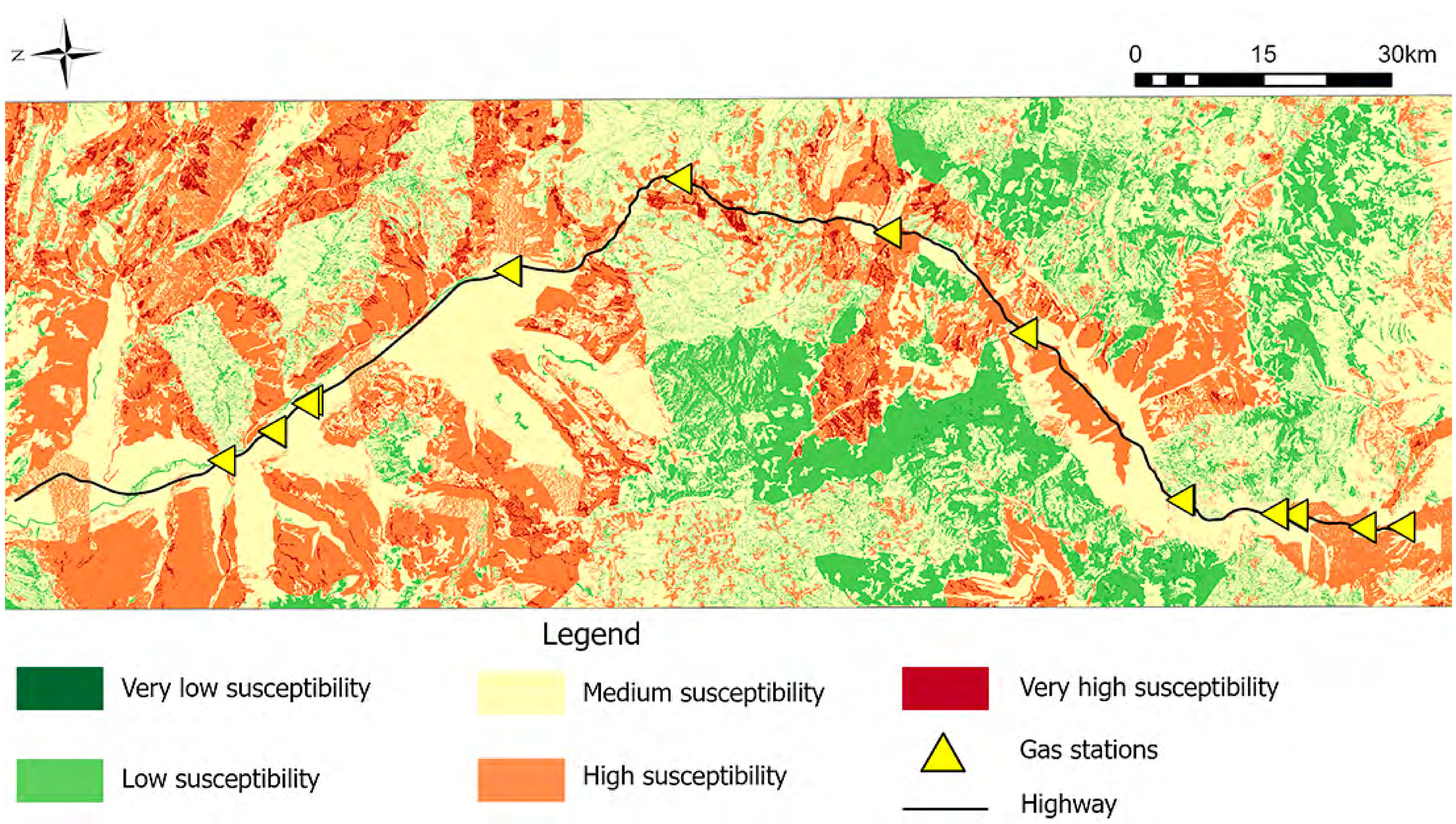


**Figure 10.** Synthesis map
*Source: Author's mapping*

The largest part of the highway is located in the medium susceptibility zone (94.1 km), but the existence of infrastructure facilities such as gas stations, etc., significantly increases the risk of catastrophe, even in medium susceptibility zones (Figure 11). The highway mostly goes underground (tunnels) through a high-risk areadue to the extremely risky terrain for infrastructure construction. Also, a very large number of bridges and overpasses on the newly built highway confirms that this is a demanding and risky terrain.

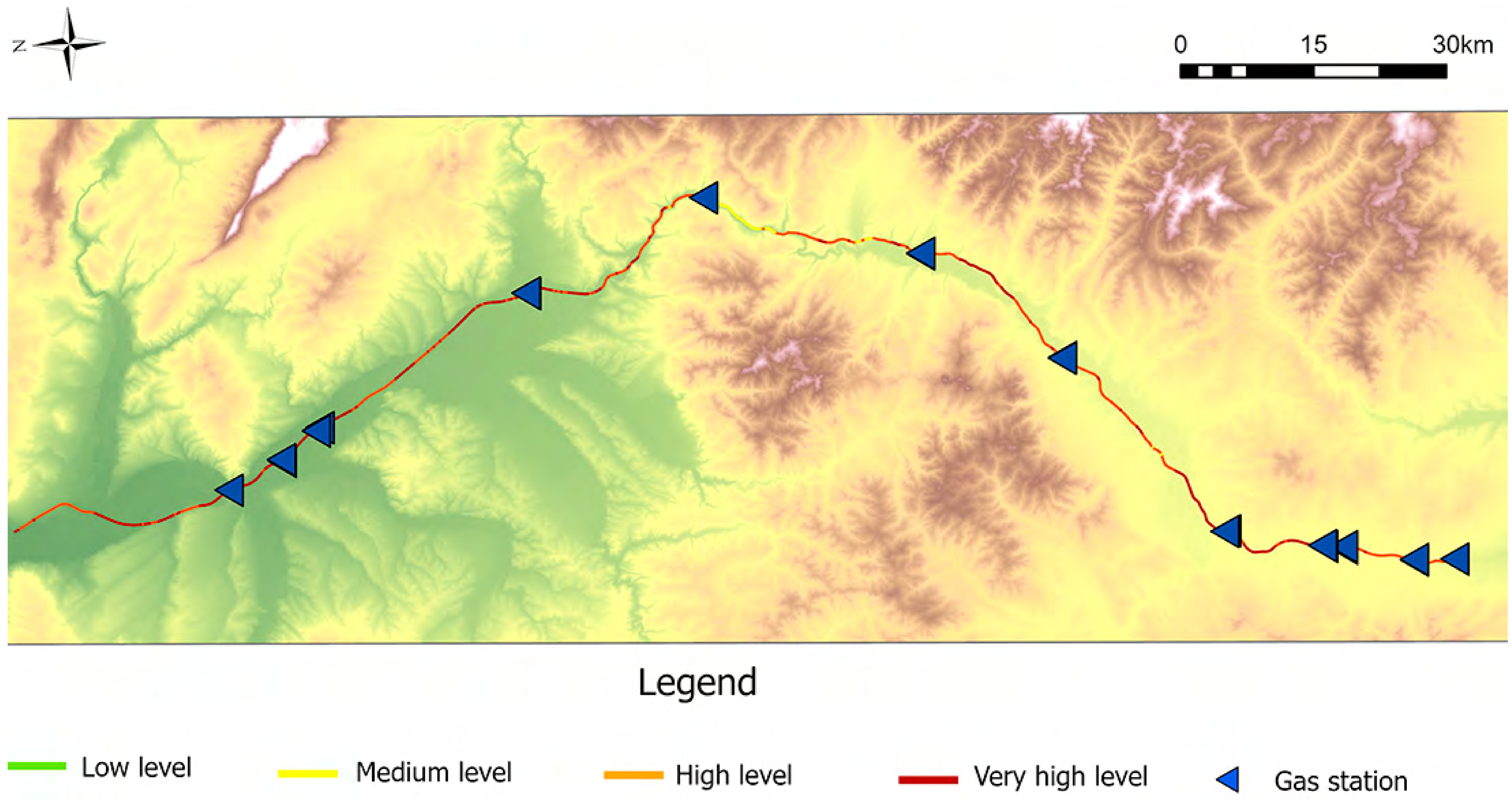


**Figure 11.** Highway endangerment map
*Source: Author's mapping*

## DISCUSSION

In this study, geographic information systems were used to calculate the levels of landslide susceptibility in the wider area of the infrastructure corridor Niš - border with Northern Macedonia. The AHP model is usually based on a grading system by experts who provide their expert opinion. Nevertheless, this approach has certain limitations, such as uncertainty and subjectivity (Jazouli et al. , 2019). Due to the very high percentage of endangered territory (31.9%), additional factors should be measured in the field to increase the reliability of the results. These factors should be applied in future studies. The spatial distribution of susceptibility levels is a consequence of the geology of the area and morphometric parameters of the terrain. The development of LSM is a useful tool in spatial planning, especially for defining land use zones and for planning future construction projects. Given that, when drafting Spatial Development Strategies and Spatial Plans, special attention must be paid to the analysis of areas endangered by this process (Spatial Plan of the Infrastructure Corridor Niš - Border of the Republic of Macedonia, 2014). In the case of the construction of the southern branch of Corridor 10, it should be mentioned that the retaining wall on this route collapsed three times in 5 months during 2018. During the third collapse, the landslide destroyed 500 $m^2$ of concrete gallery above the place where the right lane of the highway was being built. All this indicates that traffic safety is a broad and multidisciplinary issue and that it attracts the attention of scientists working in different disciplines. The mentioned problem should be viewed from different aspects, so that future highway projects and traffic safety can be improved. This research can provide a basis for further improvement of the methodology. Ideally, in future planning and construction, on the territory of the study area, landslide susceptibility zones would be taken into account as an important source for future regional planning and development, as well as for landslide risk management. Negative results of building construction in the past period are visible during and after construction, and especially during intense rainfall. Natural disasters are a warning for everything that is inadequately done or missed to be done in the process of building facilities.

## CONCLUSION

Based on the acquired results, it is deduced that the study area, and thus the existing road network, is significantly endangered by instability processes, which cause enormous damage. With the help of the LSM map, conclusions can be drawn about future activities, such as the construction of residential and line infrastructure facilities in identified zones of low susceptibility to landslides. Special attention during the construction of facilities should be paid in zones of high and very high susceptibility to landslide events, because in these zones such activities can very easily lead to destabilization of the terrain. The greater the susceptibility to landslides, the greater the caution required in planning. Highway construction combined with natural factors such as unfavorable lithological substrate and slope of terrain have made most parts of the research area prone to landslides. Although the middle zone of susceptibility includes areas that are stable, land use activities should be properly planned in order to preserve its current status. Then, it is necessary to direct more attention to the following activities: recording landslides and monitoring them in the endangered areas of Serbia, their detailed research, and taking appropriate reclamation measures for their rehabilitation. As previously mentioned, landslides are an underestimated and insufficiently studied problem in Serbia. This paper can serve as a proposal to make more efforts to study the landslide susceptibility in other parts of the Republic of Serbia.

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