Quantitative and Comparative Analysis of Slope Instability in Karaj-Chaloos Road (Karaj-Gachsar section) and the Under-Construction Highway of Tehran-North (Tehran-Soleghan section) Using Logistic Regression Method

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Introduction

One of the most hazardous roads in Iran is the Karaj-Chaloos road (road No. 59), which is also one of the busiest roads in the country. This road passes through the middle part of the Alborz mountain range and connects the central regions of Iran, and particularly the Tehran and Alborz provinces to the northern coasts of the country along the Caspian Sea (Figure N°1).

Due to the mountainous topography of the area, it is a winding road due to which, despite its very beautiful nature, always has high risk for travelers and moreover, it suffers frequent landslides of debris fall type (Varnes 1978; Cruden and Varnes 1996). For this reason, the Tehran-North highway is under construction, which will encompass several tunnels to avoid many turns and angles.

The present study aimed to prepare the zonation of landslide risk on the edges of the Karaj-Chaloos road and the Tehran-Soleghan highway.

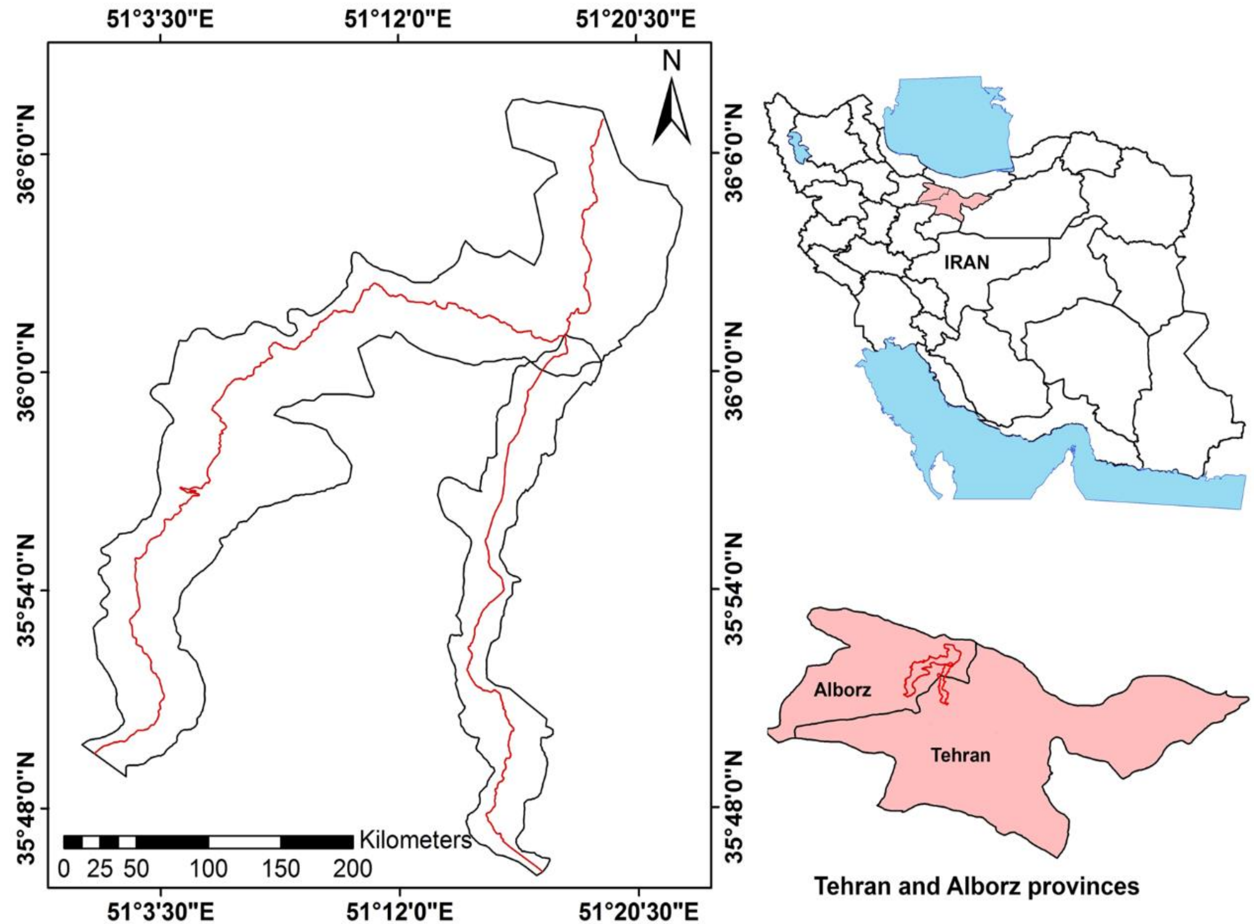


Figure 1: Location of the Karaj-Gachsar and Tehran Soleghan roads.

Coordinates and the features of the study area

The studied road areas are located in the north and northwest of Tehran province between the longitudes of 51° 39' E and51° 58' E and latitudes of 36° 07'and 36° 17' N. The Karaj-Gachsar section of the Karaj-Chaloos road has 60 km length with a total area of 1131.63 km^2, while the Tehran-Soleghan section of the Tehran-North highway is 12 km long and has a total area of 348.579 km^2.

Geomorphology of the area

The geomorphology of the study area is influenced by the nature of lithology and regional tectonic structure, and the geomorphic features follow the major tectonic structures. However, the effect of external dynamic processes in the form of river and glacier valleys, gravitational debris caused by snow and rock avalanche, Talus slopes, filled valleys, stone block and rubble flows, and river terraces are found abundantly.

The two main morphological features of the region include folds and faults. The area is generally mountainous, comprised of numerous anticlines, synclines and limbs. Also, the ridged peaks with steep and high cliffs are other features of the region. The overall trends of the mountains and folds are NW-SE. The order of the folds is disturbed by major and minor faults.

The mountains are mainly composed of tuff, shale and limestone. Tuff is the main lithology of these mountains. Due to the hardness of these rocks, mountains are quite high. In some parts of the region, thrust faults have caused that Paleo- and Mesozoic strata appear beside those of the third era.

Joints and fractures formed following the folding are widely found in the region, which have played a crucial role in mechanical and chemical weathering processes. The main thrust faults in the region include Kandovan, Mosha-Fasham, Taleghan, Ahar, and Meygoon.

Investigating the effective factors on the probability of landslide occurrence

In order to investigate the potential of landslide occurrence, 14 effective factors were identified, comprised of elevation classes, slope, aspect, geology, land use, precipitation, distance from fault, river and road, normalized difference vegetation index (NDVI), climate, slope length (LS), stream power index (SPI) and topographic wetness index (TWI). Consequently, maps of the factors affecting the landslides were prepared as separate layers in the GIS environment and transferred into the Idrisi software.

The whole procedure included:

(1) preparation of digital elevation model (DEM), river and fault layers based on the 1:25,000 topographic map of the area, as well as distance maps from rivers and faults, (2) creating slope and aspect maps from DEM, (3) preparation of land use and NDVI maps of the region based on unmatched classification of Landsat 8 image of OLI sensor, (4) preparation of geological map, (5) preparation of precipitation and climate layers based on the information obtained from the meteorological organization, (6) creating LS, SPI and TWI layers based on the DEM, (7) conversion of the distribution data of the regional landslides using Landsat satellite and Google Earth images, (8) correlating the information layers with the regional landslide map and calculating their density per unit area, and (9) performing the logistic regression model using Terrset software.

Results and discussion

Field surveys showed that all of the landslides occurred along both roads are of debris fall type. After preparing the information layers in the GIS, the data were entered into the Terrset software in order to perform logistic regression model. Results of the prepared layers, as well as the model implementation are presented in Figures N°2-15.

After preparing the mentioned information layers for the study areas, the landslide potential map was created based on the Google Earth images and the field control points (Figure N°16).

According to this map, landslides in the Karaj-Gachsar road area occur in about 108.55 hectares, which is equivalent to 0.41 percent of the total area. For the Tehran-Soleghan highway, this area is about 91.53 hectares, equivalent to 1.16 percent of the total area.

Consequently, after entering the data into the logistic regression model, the coefficients of the model were extracted as Table N°1, using the effective parameters in Idrisi software.

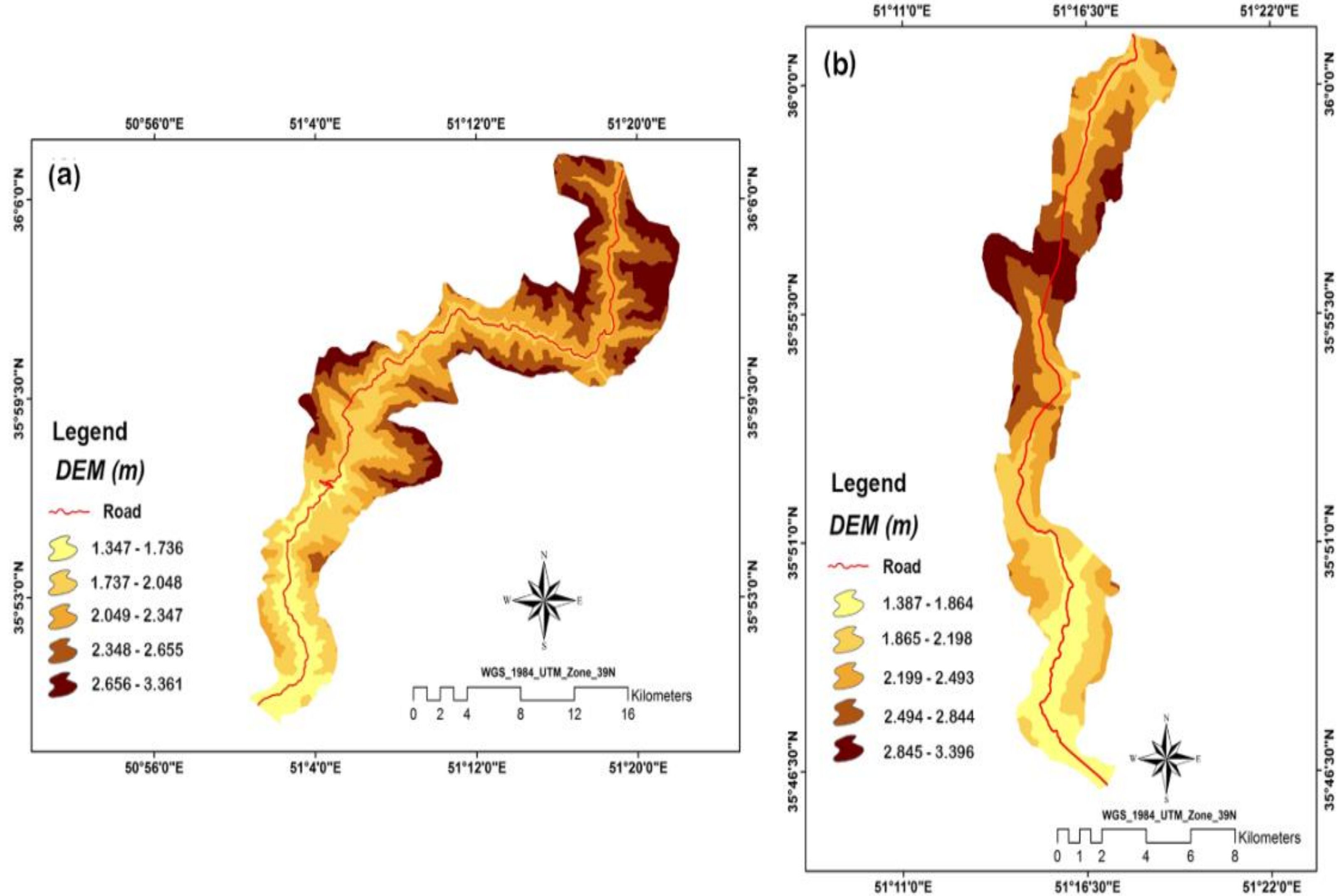


Figure 2: DEM maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

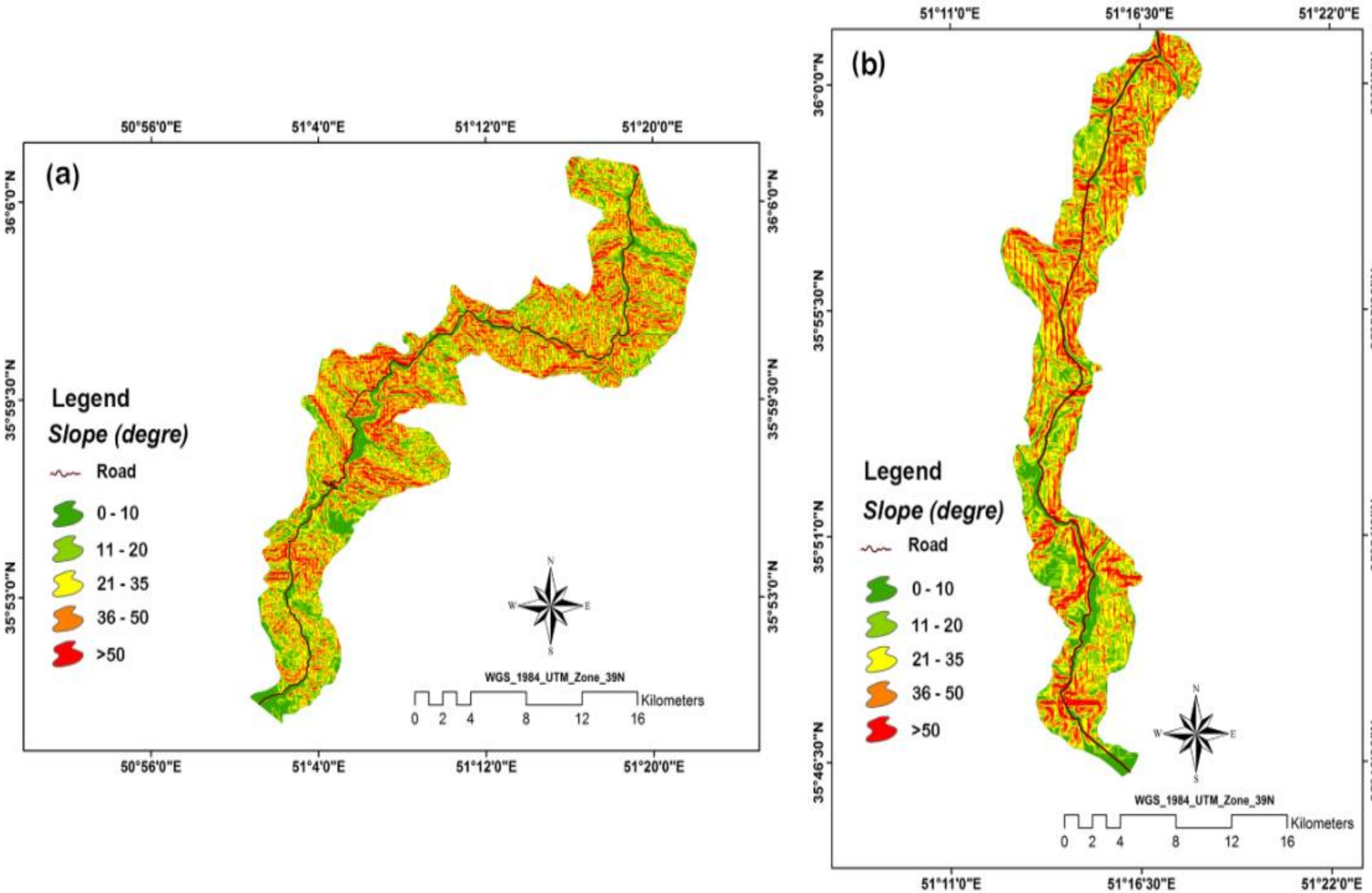


Figure 3: Slope maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

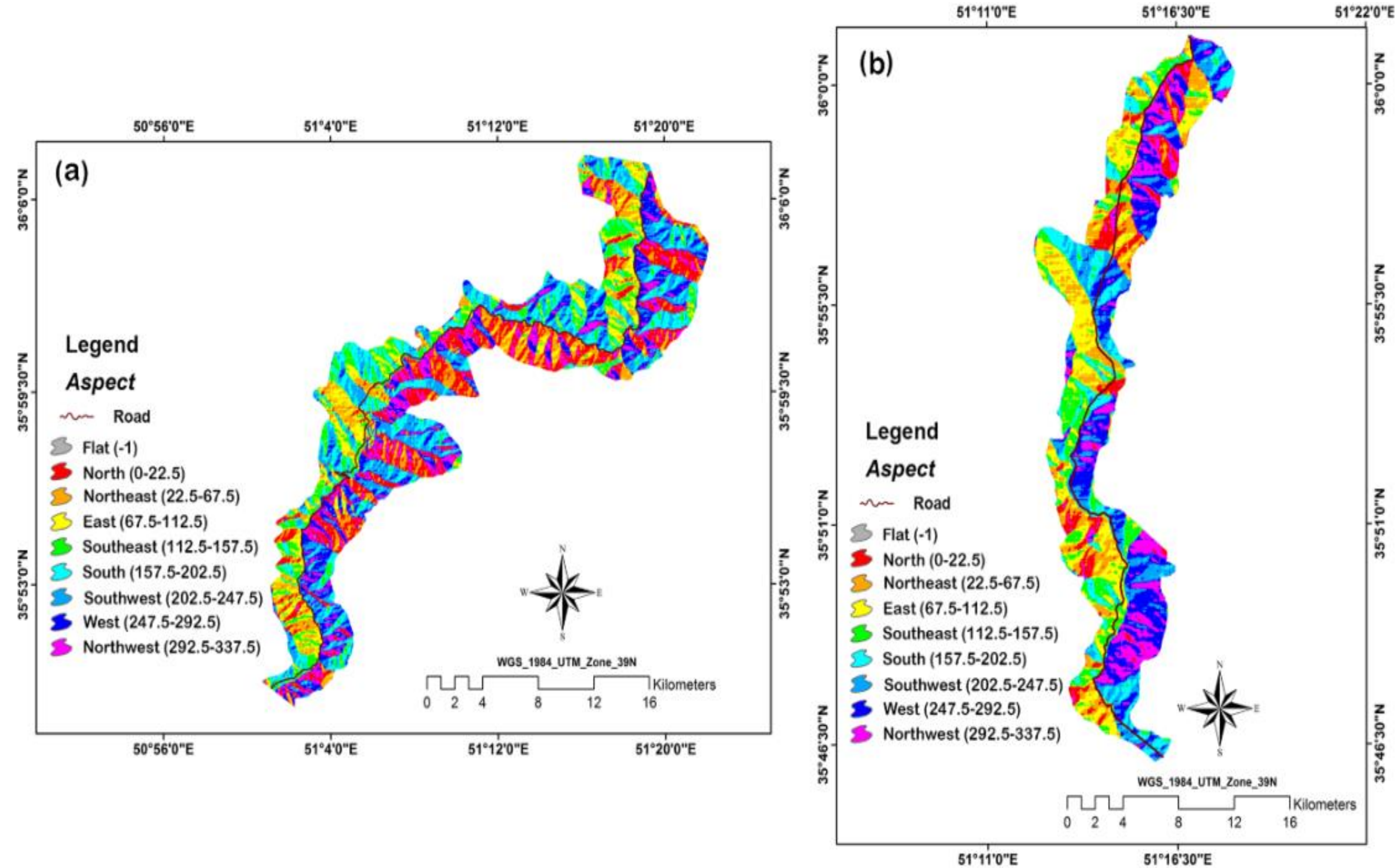


Figure 4: Aspect maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

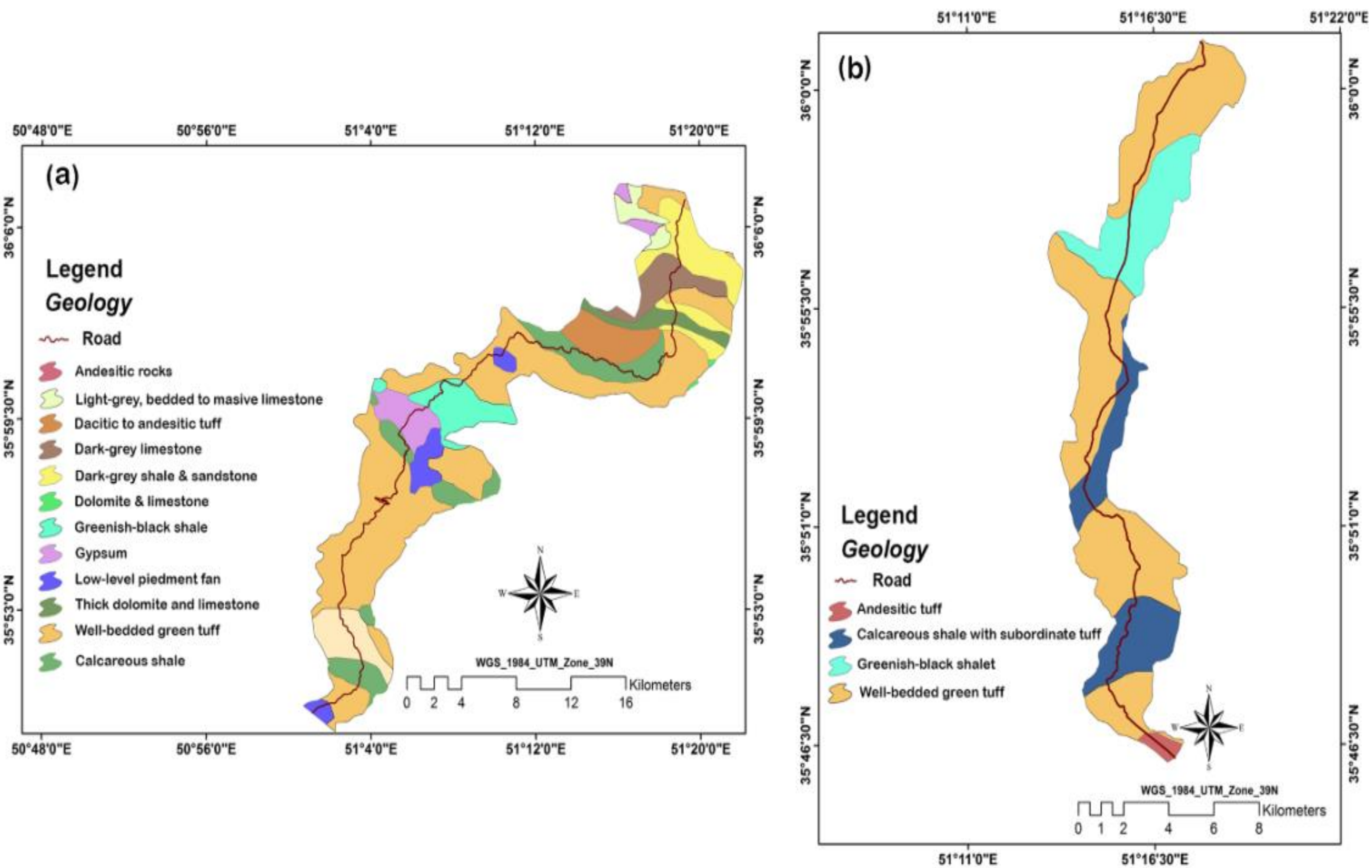


Figure 5 Geology maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

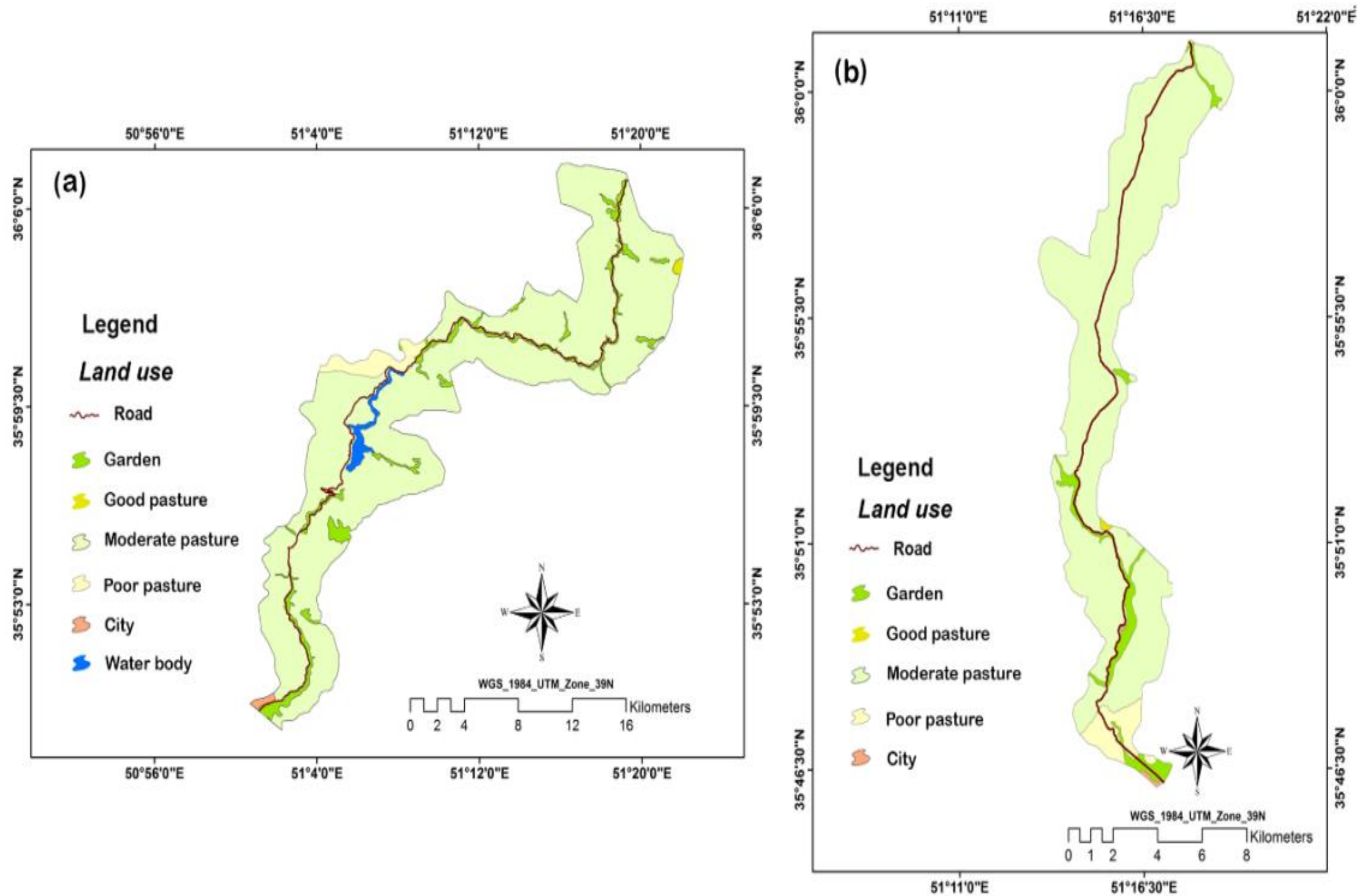


Figure 6: Land use maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

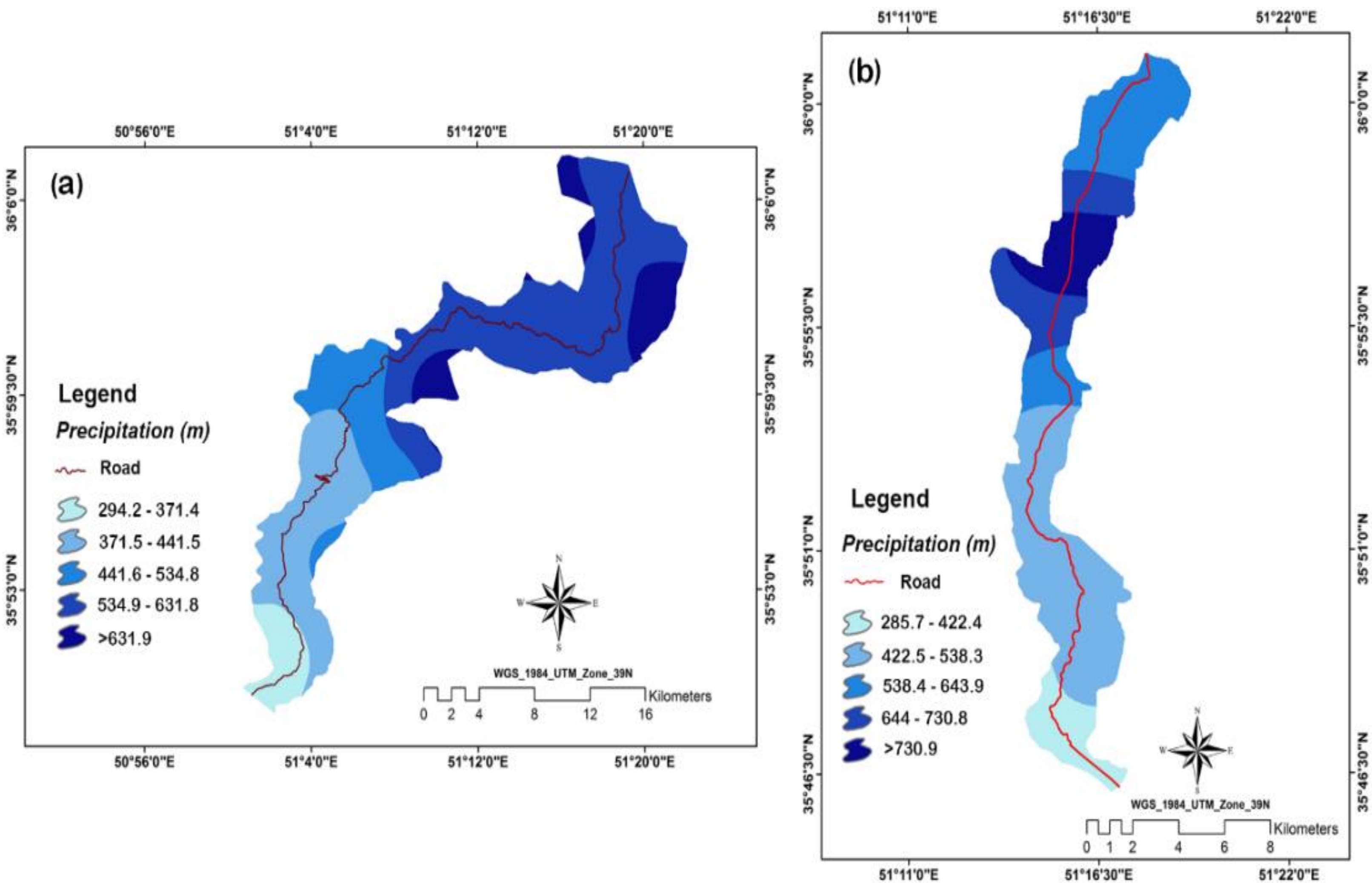


Figure 7: Precipitation maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

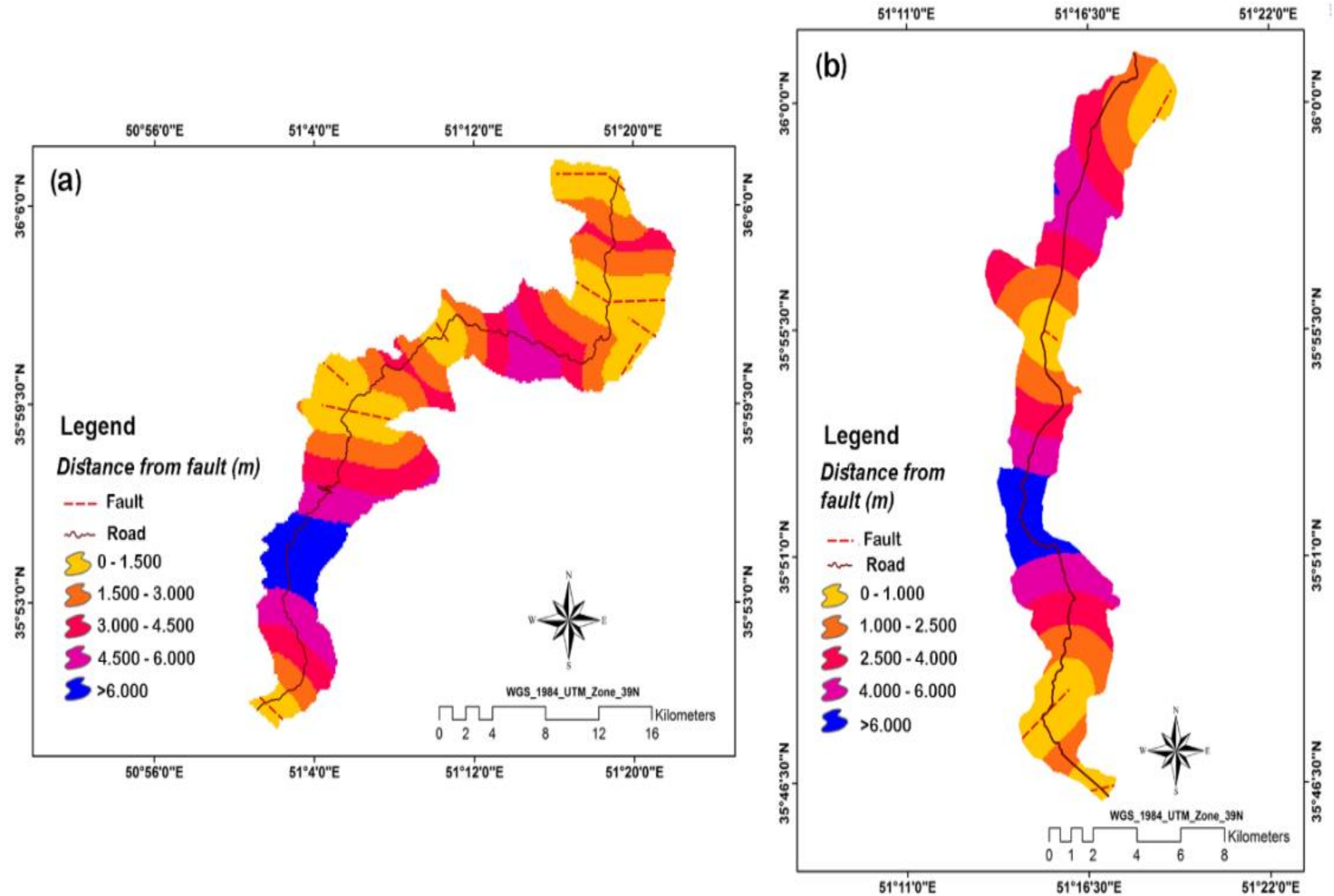


Figure 8: Distance from fault maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

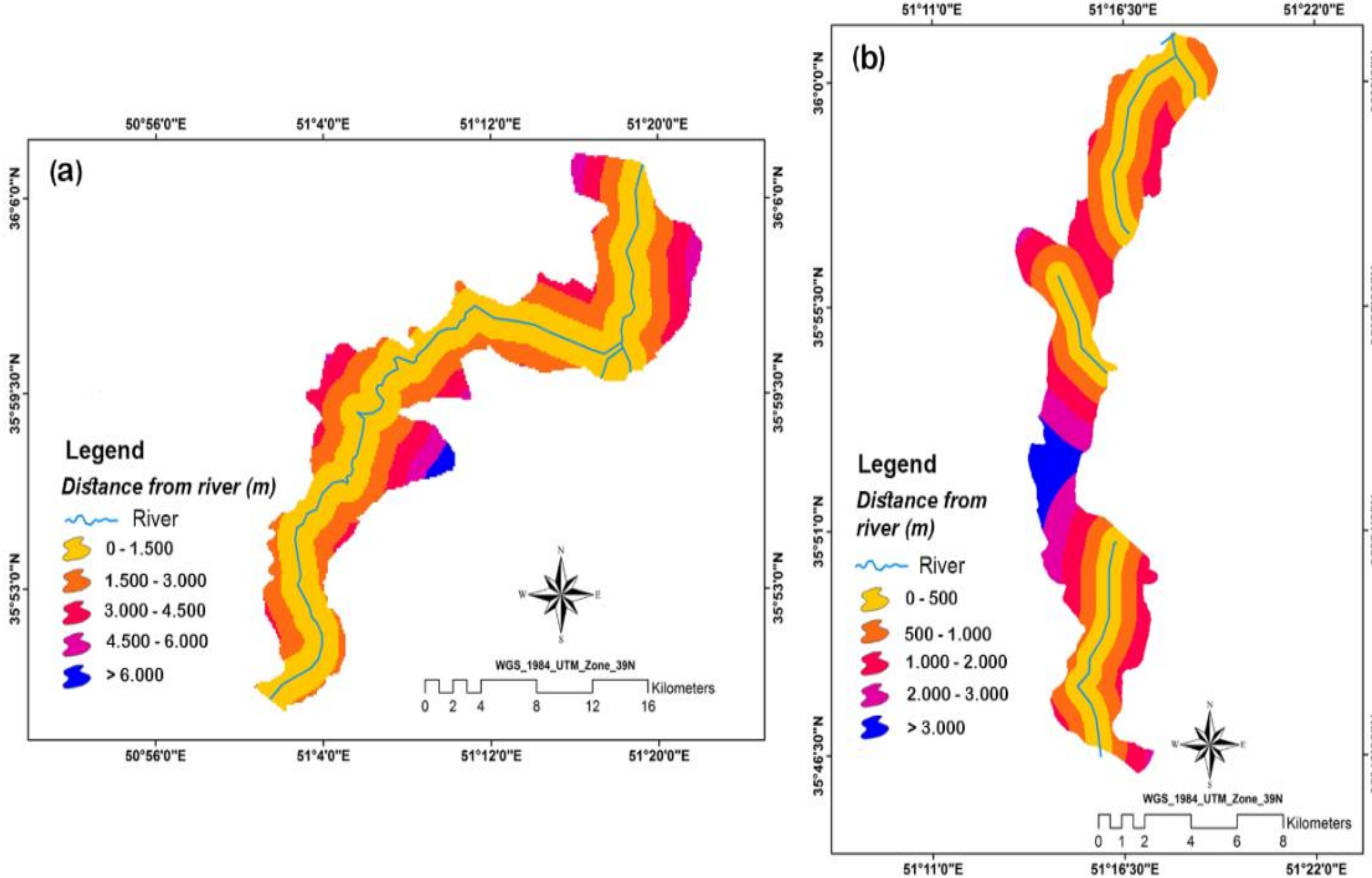


Figure 9: Distance from river maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

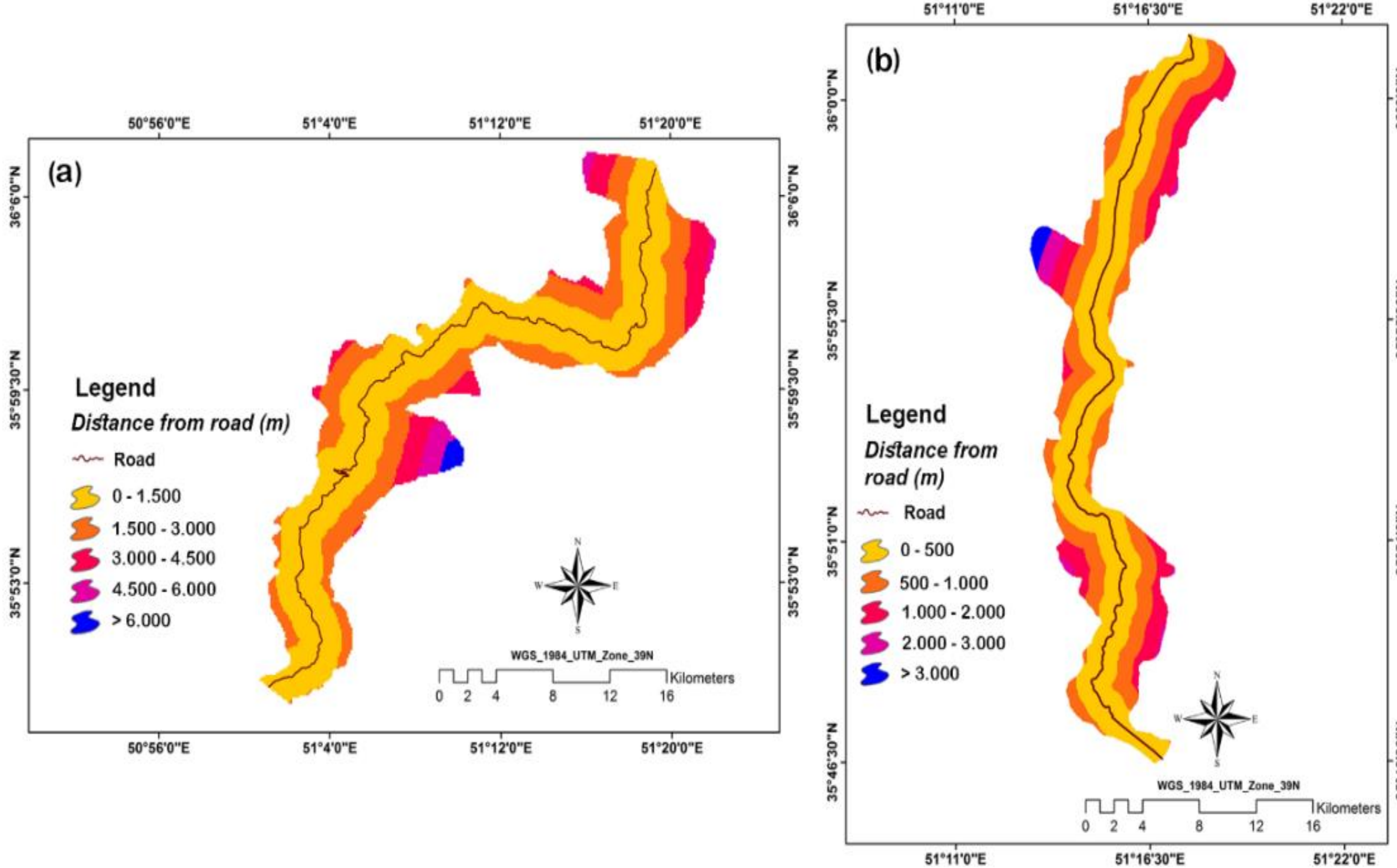


Figure 10: Distance from road maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

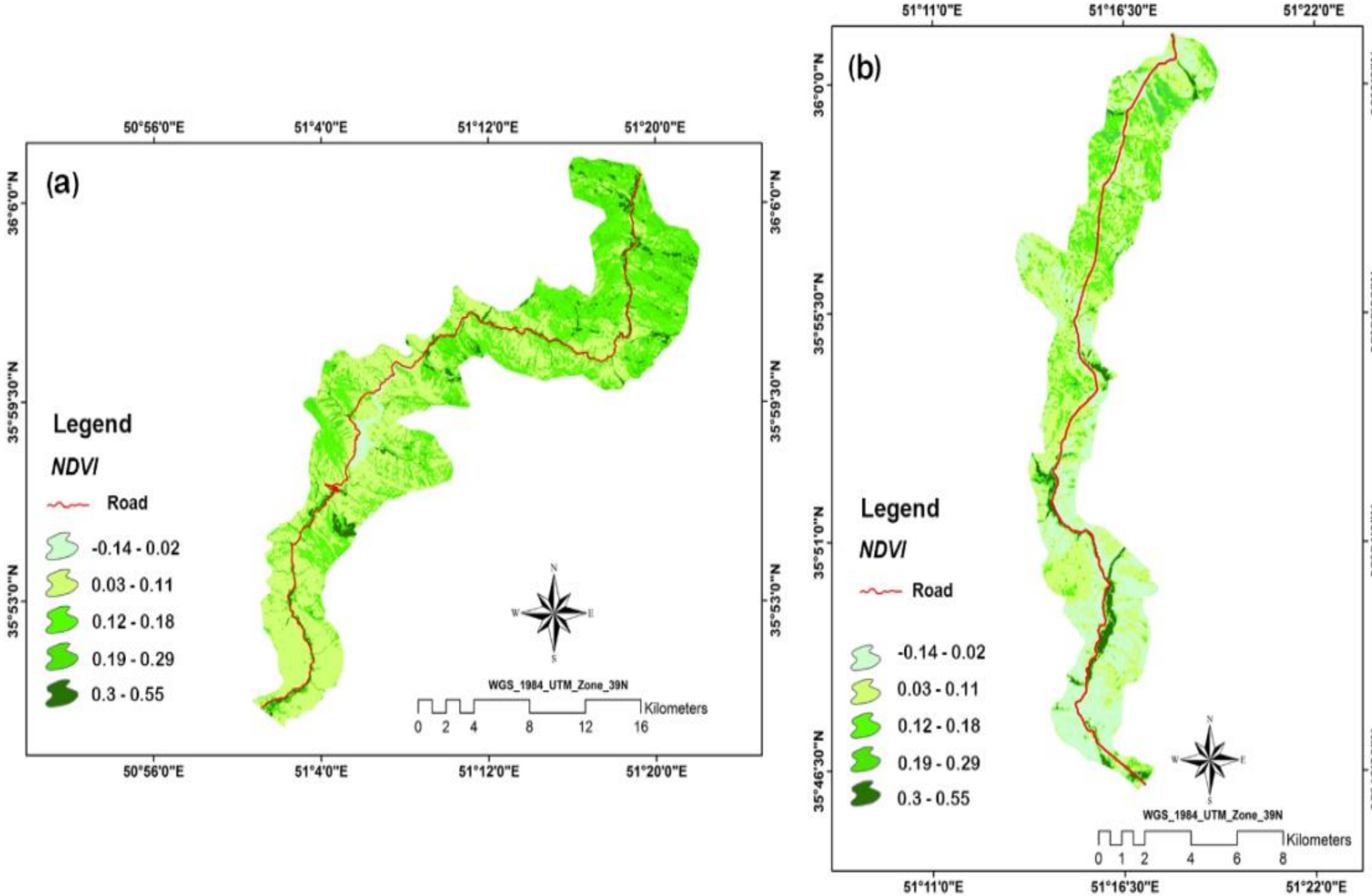


Figure 11: NDVI maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

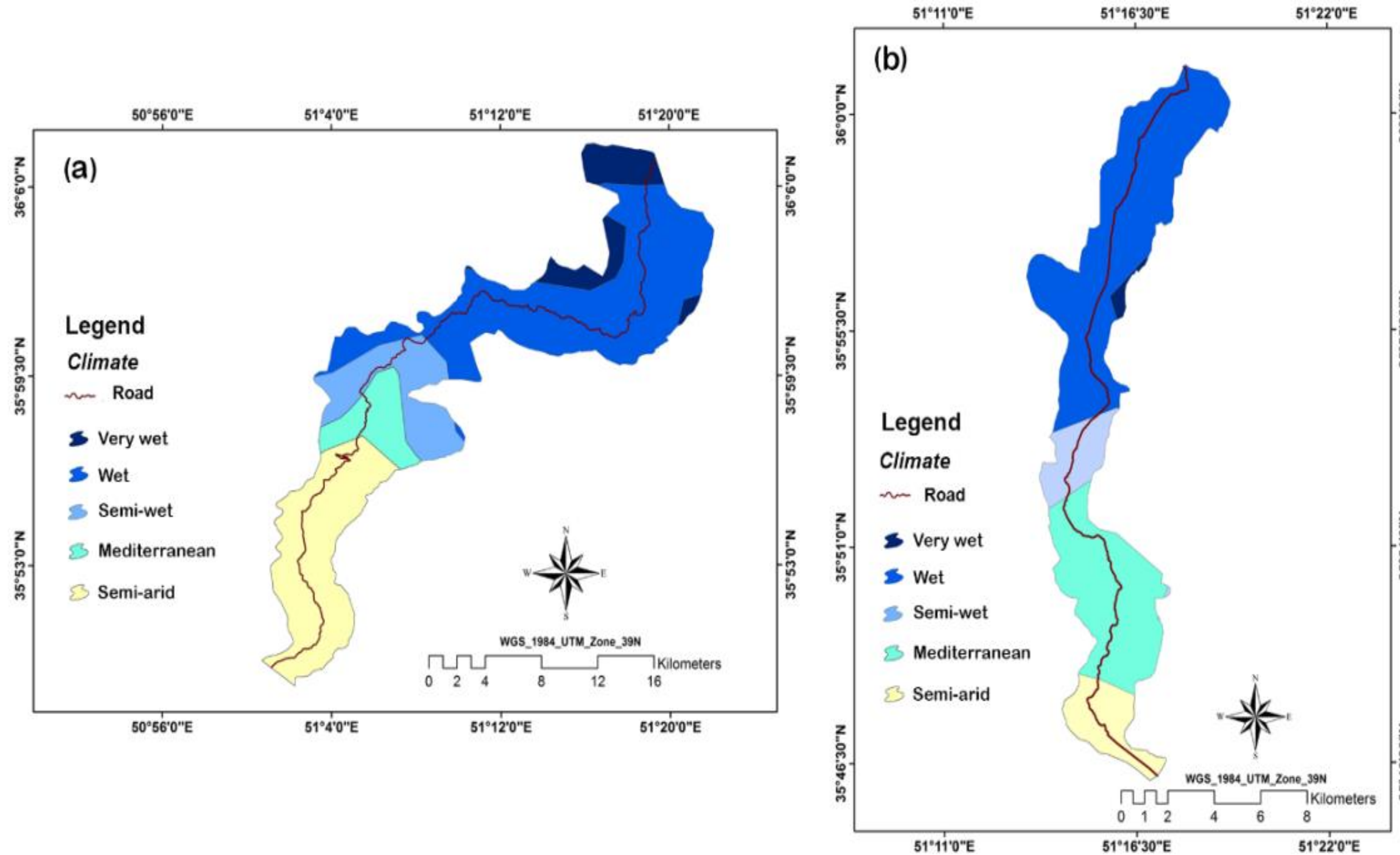


Figure 12: Climate maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

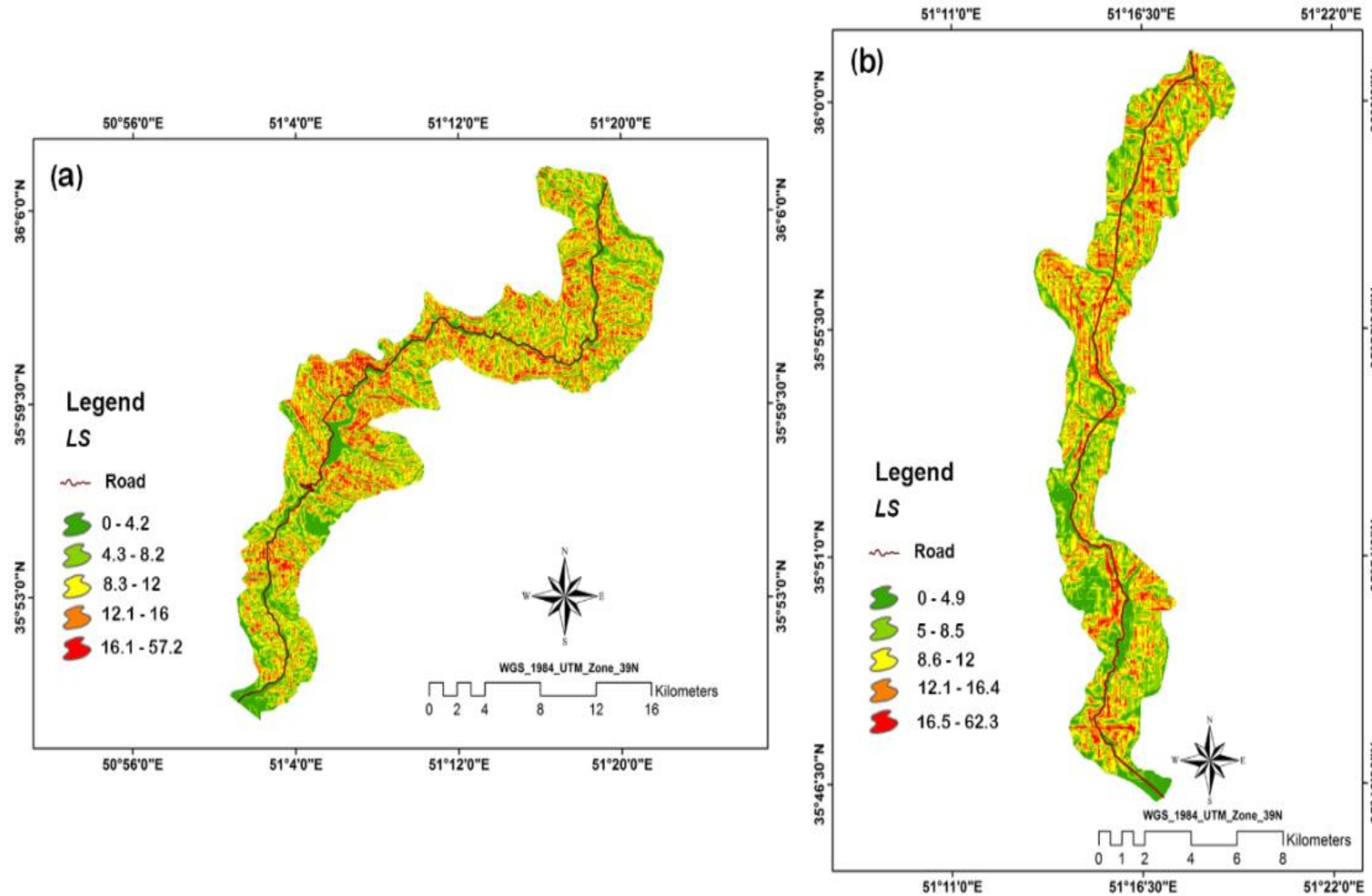


Figure 13: LS maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

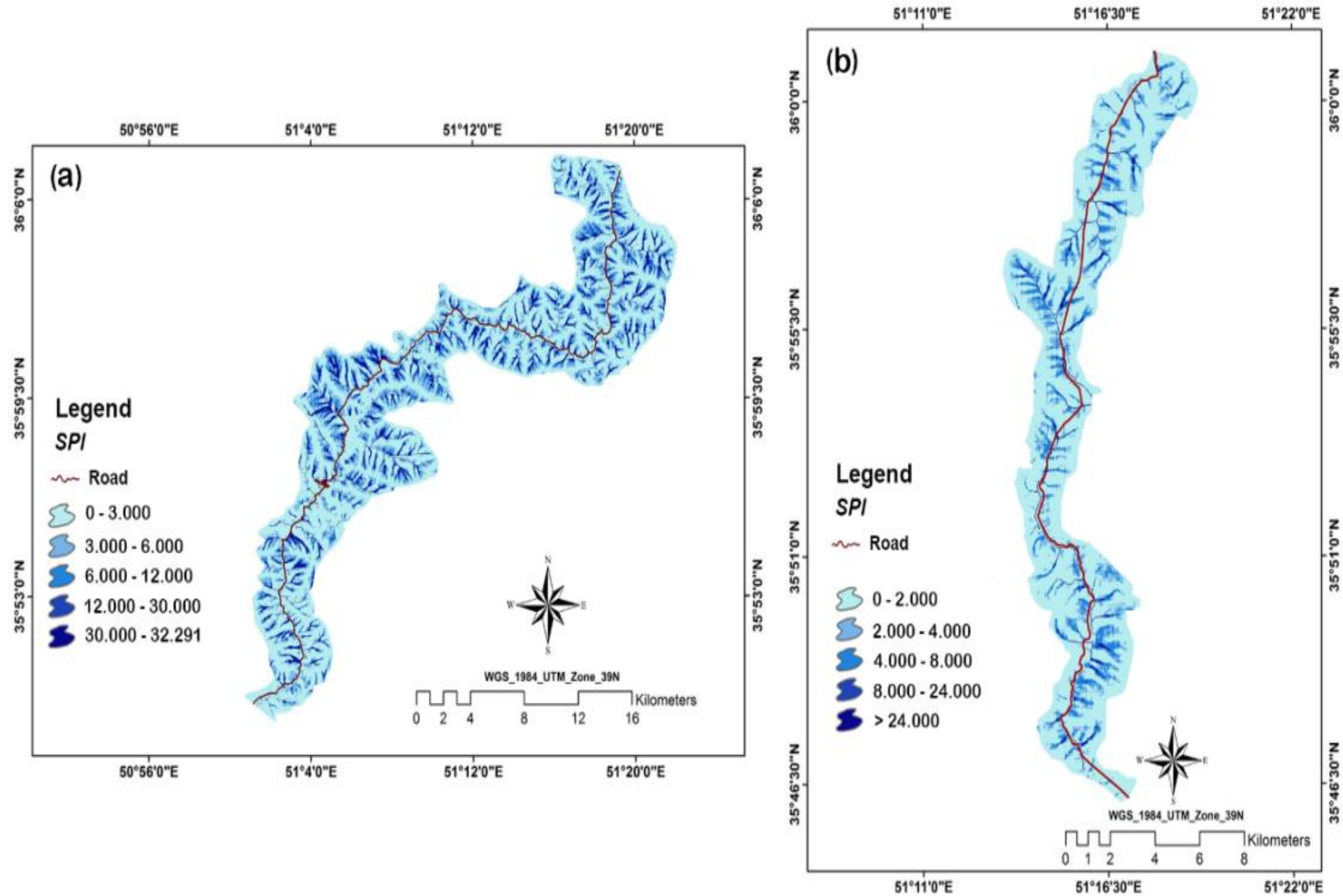


Figure 14: SPI maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

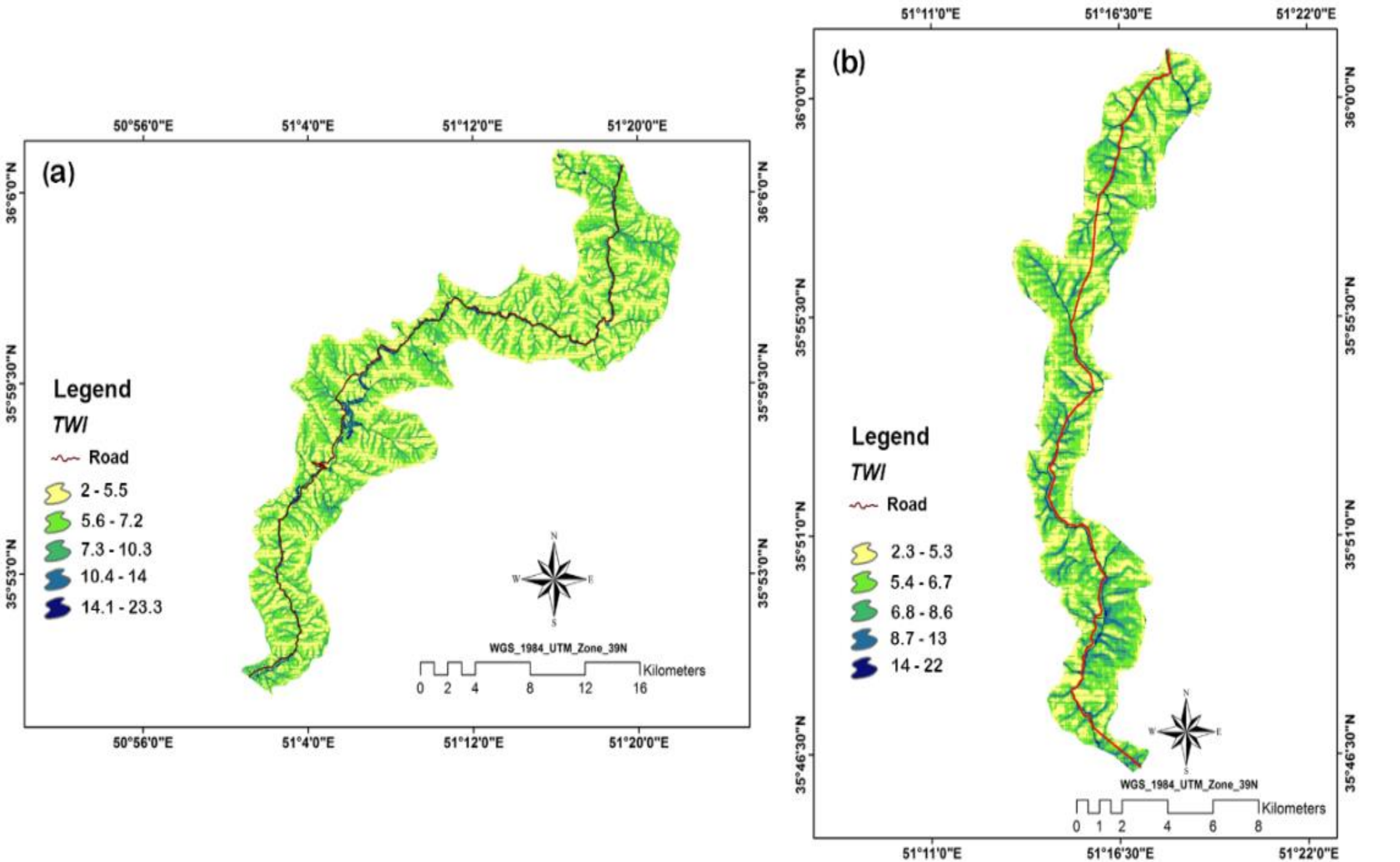


Figure 15: TWI maps of (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

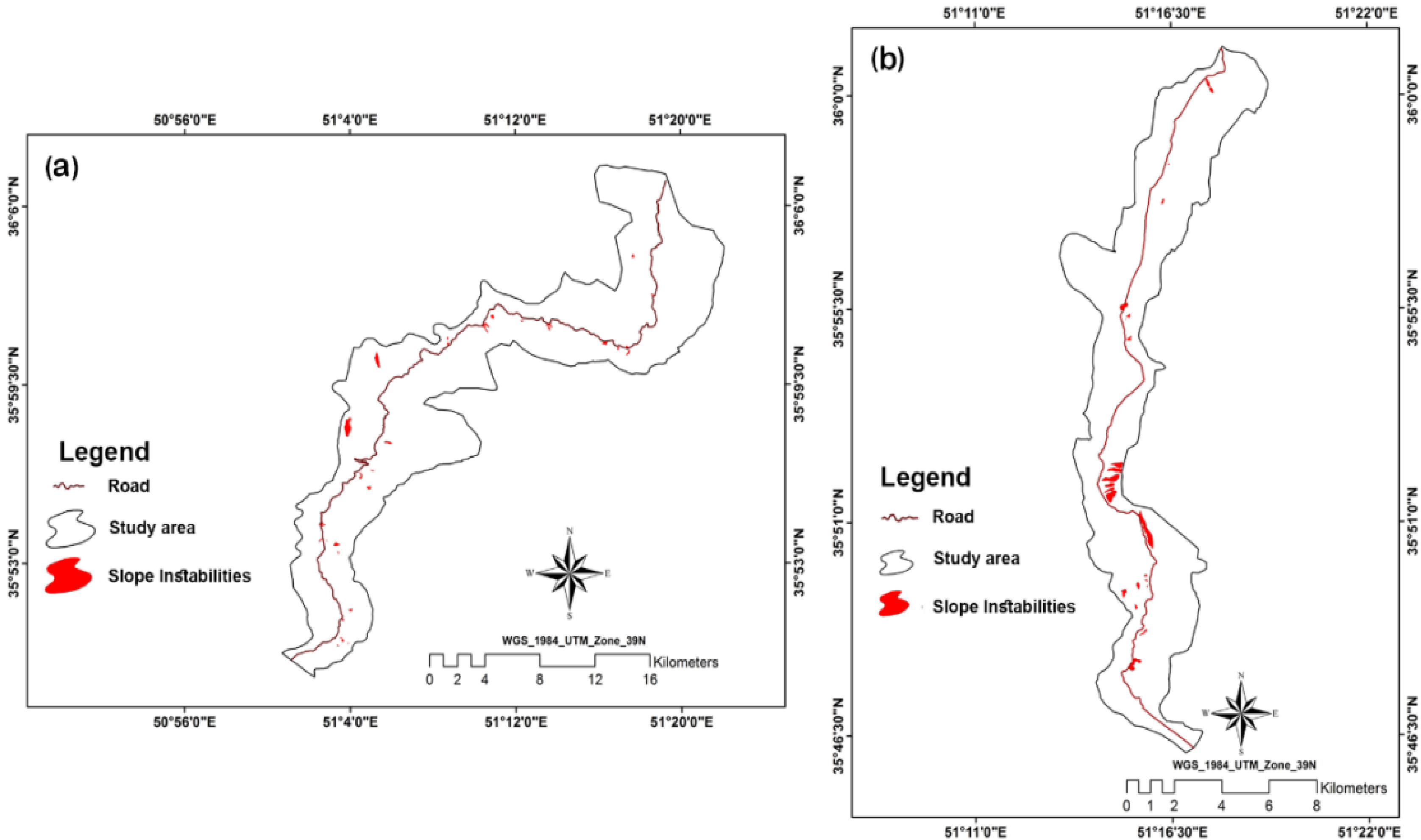


Figure 16: Distribution of landslides in (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

Table 1: Coefficients derived from the logistic regression model for the two studied road area.

	Independent variables	Coefficients derived from the model for Karaj-Gachsar road area	Coefficients derived from the model for Tehran- Soleghan highway area
X_0	Constant number	-11.1705	**-9.7687**
X_1	Elevation classes	-0.5700	**-0.5951**
X_2	Slope	0.0580	**-0.1398**
X_3	Aspect	-0.0333	**-0.9086**
X_4	Geology	0.0923	**0.2200**
X_5	Land use	-0.5800	**0.5805**
X_6	Precipitation	0.2266	**-1.3497**
X_7	Distance from fault	-0.4285	**0.7974**
X_8	Distance from river	1.2958	**0.1785**
X_9	Distance from road	0.2718	**0.7627**
X_{10}	NDVI	-0.4093	**-0.1682**
X_{11}	Climate	0.5132	**0.7325**
X_{12}	LS	0.2409	**0.5969**
X_{13}	SPI	0.3851	**-0.3887**
X_{14}	TWI	-0.0850	[illegible]

To examine the validity and accuracy of the results, Chi Square, PR^2 and ROC tests were considered (Table N°2). Chi Square test is a valid and normal test for logistic regression, which is obtained from the difference between -2Ln (L) for the best-fit model and -2Ln (L0) for the zero hypothesis. If the statistics is meaningful at 95% level (Chi Square> 14.1), the zero hypothesis (H0) is rejected (Motavali 2009). The Chi Square index for the Karaj-Gachsar and Tehran-Soleghan road sections were calculated about 365.0353 and 611.0519, respectively. By taking into account that the values obtained are much higher than the threshold value, so zero hypothesis of all the coefficients are rejected.

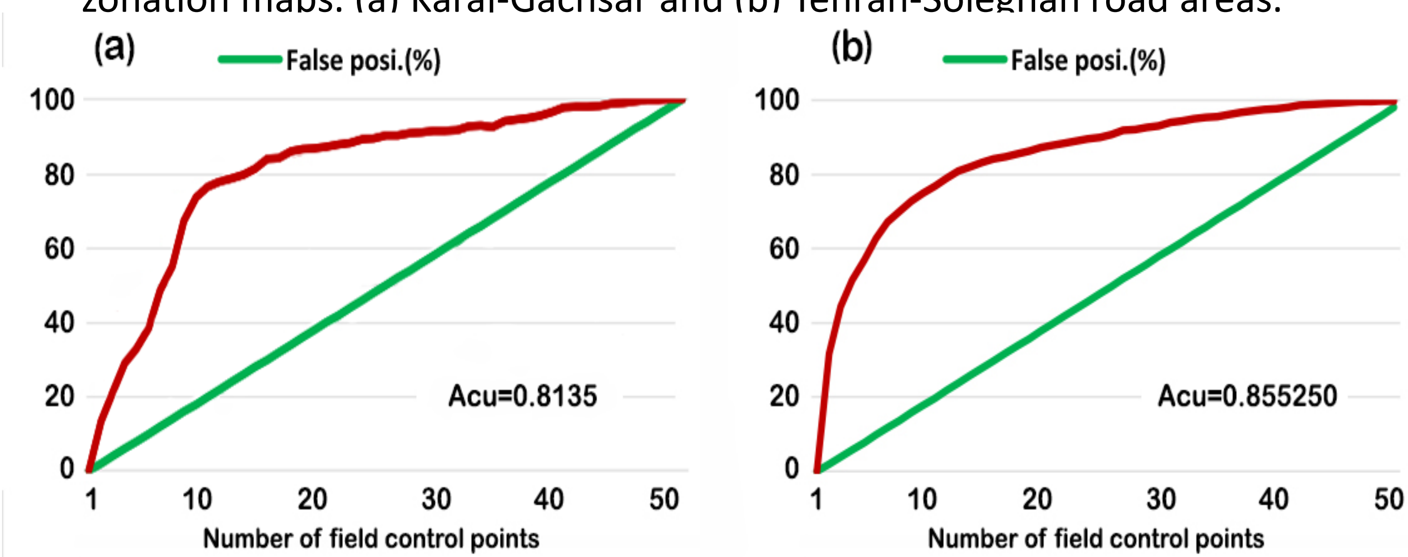
Table 2: The calculated statistical indicators for the model evaluation.

Indicator	Karaj	Soleghan
Pseudo R square	0.3161	**004211**
Chi Square	365.0353	**611.0519**
Goodness of Fit	32950.2797	**18362.3189**

The PR^2 value shows how the logit model fits with the datasets (Menard 1995). PR^2 value of 1 indicates the complete fitness of the model and 0 indicates that no relationship is present between the independent and dependent variables. In general, PR^2 values greater than 0.2 indicate a relatively good fit of the model (Ayalew and Yamagishi 2005). The PR^2 values calculated for the Karaj-Gachsar and Tehran-Soleghan road areas are 0.3161 and 0.4211, respectively, which are greater than the threshold of 0.2, indicating an acceptable fit for the implemented model.

Another criterion that is very easy to interpret is considering that how much the model can well predict the dependent variable. In this case, the Idrisi software uses the ROC curve criterion for comparing a Boolean map (existence or absence of landslides) with the probability map. The ROC value varies from 0.5 to 1. 1 indicates a complete match, while 0.5 represents a random match (Motavali 2009). The calculated ROC values of 0.9716 for the Karaj-Gachsar road area and 0.9678 for Tehran-Soleghan road area in this study testify to a very high correlation between the independent and dependent variables (Figure N°17).

Figure 17: ROC curves and the area under the curve for estimating the accuracy of the landslide zonation maps. (a) Karaj-Gachsar and (b) Tehran-Soleghan road areas.



Moreover, the results of the ROC curve analysis for logistic regression model showed that the area under curve for the landslide susceptibility maps of the studied roads are 0.835 and 0.855250 for the Karaj-Gachsar and Tehran-Soleghan road areas, signifying a very good predictive ability.

The results of the ROC model for the Karaj and Soleghan areas are shown as equations 3 and 4, respectively.

(3) $$\text{Logit (slope instabilities)} = -11.1705 - 0.5700{*}X_1 + 0.0580{*}X_2 - 0.0333{*}X_3 + 0.0923{*}X_4 - 0.5800{*}X_5 + 0.2266{*}X_6 - 0.4285{*}X_7 + 1.2958{*}X_8 + 0.2718{*}X_9 - 0.4093{*}X_{10} + 0.5132{*}X_{11} + 0.2409{*}X_{12} + 0.3851{*}X_{13} - 0.0850{*}X_{14}$$

(4) $$\text{Logit (slope instabilities)} = -9.7687 - 0.5951{*}X_1 - 0.1398{*}X_2 + 0.7627{*}X_3 + 0.2200{*}X_4 + 0.5805{*}X_5 - 1.3497{*}X_6 + 0.7974{*}X_7 + 0.1785{*}X_8 - 0.9086{*}X_9 - 0.1682{*}X_{10} + 0.7325{*}X_{11} + 0.5969{*}X_{12} - 0.3887{*}X_{13} - 0.0974{*}X_{14}$$

After verifying the validity of the logistic regression model using the above-mentioned tests and equations, the landslide susceptibility zonation maps were prepared for the two studied roads, the results of which are shown in Figure N°18.

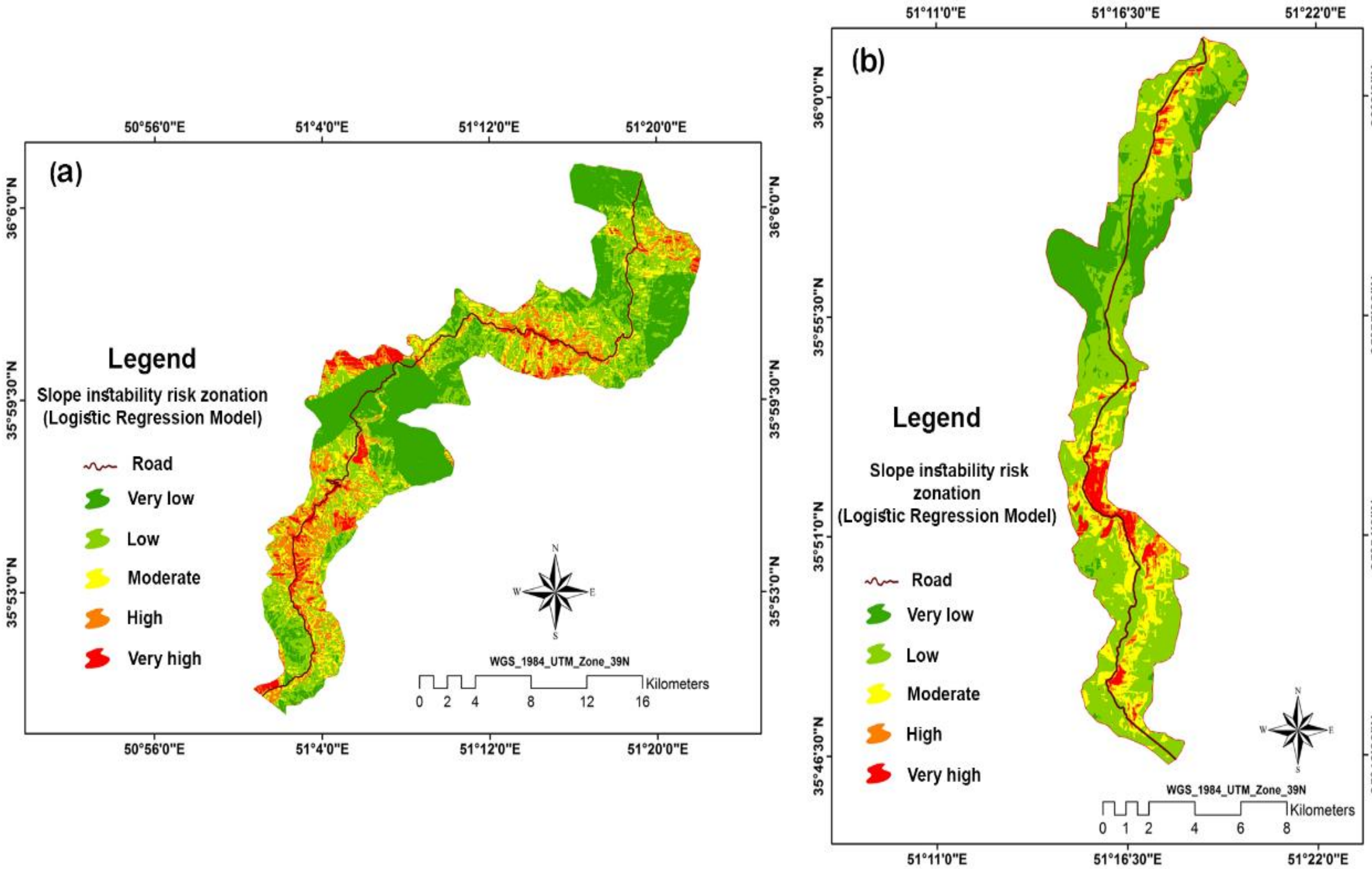


Figure 18: Landslide sensitivity zonation maps for (a) Karaj-Gachsar, and (b) Tehran-Soleghan road areas.

According to the results obtained from the current model, the distance from river factor for the Karaj road area with the highest coefficient of 1.2958 is the best predictor for the probability of landslide occurrence. The climate and SPI factors with coefficients of 0.5132 and 0.3851, respectively, have the second and third high coefficients.

For the Soleghan road area, the distance from fault factor with the highest coefficient of 0.7974 is the best predictor for the probability of landslide occurrence. The distance from road and the climate factors with coefficients of 0.7627 and 0.7325, respectively, stand in the next places.

After preparing the landslide zonation maps, the percentage of areas susceptible to each class of landslide was estimated. Accordingly, the very high risk class in the Karaj-Gachsar road area has the lowest percentage, while this risk class has the largest percentage in the Tehran-Soleghan area. Table N°3 presents the percentage of areas for each class of landslide.

Table 3: The percentages of the areas with various landslide risk classes in both Karaj and Soleghan roads

Class	Area (in percent) for the Karaj road area	Area (in percent) for the Soleghan road area
Very Low	25.04	0.30
Low	20.09	13.44
Medium	24.12	11.28
High	21.77	13.91
Very High	8.98	61.07

Assessing the risk map of landslide based on the SCAI index

SCAI index is the ratio of the area percentage of each landslide risk class to the percentage of landslides occurred in each class. This method presents a qualitative accuracy for the landslide zonation map based on the SCAI value (accuracy here means decreasing of the SCAI value from low-risk to the high-risk class). The accuracy assessments in Table N°4 show that the SCAI value decreases from low-risk class towards the very high-risk class.

Table 4: Assessing the landslide zonation maps of the Karaj and Soleghan areas based on the SCAI index.

Sensitivity class	Percentage of Karaj Area	Percentage of landslides in the Karaj area	SCAI index	Percentage of Soleghan Area	Percentage of landslides in the Soleghan area	SCAI index
Very Low	35.15	25.04	1.403	18.79	0.30	63.62
Low	29.90	20.09	1.488	45.07	13.44	35.3
Medium	15.77	24.12	0.653	18.84	11.28	1.67
High	14.21	21.77	0.652	3.73	13.91	0.26
Very High	4.97	8.98	0.553	4.57	61.07	0.07
Total	100	100	-	100	100	-

Conclusion

In the Karaj-Gachsar road area, slope, geology, precipitation, distance from river and road, climate, LS and SPI factors have positive coefficients and better correlations, while other factors have negative coefficients and correlations. For the Tehran-Soleghan road area, the positive coefficients belong to geology, land use, distance from fault, river and road, climate and LS factors.

The most important factors in the Karaj-Gachsar road area are distance from river, climate and SPI, while those of the Tehran-Soleghan road area are distance from fault and road and climate.

According to the prepared maps, the southern and middle parts of the Karaj-Gachsar road, as well as another part in the northwest of the study area have the highest potential for the occurrence of landslides, whereas in the Tehran-Soleghan road area, the middle and southern parts and a small section in the north of the area have the highest potential for landslide occurrence.

34.95 percent of the lands in the Karaj road area have medium to high potential for landslide occurrence; 54.87 percent of the occurred landslides correspond to these areas. Moreover, 4.97% of the Karaj road area has very high potential for landslides, which correlates with almost 9% of the occurred landslides. It is while 27.14% of the Soleghan road area possesses medium to high potential for landslides, within which 86.26% of the landslides have occurred. Furthermore, 4.57% of the Soleghan road area shows very high risk in terms of landslide occurrence, encompassing 61% of the occurred landslides.

Finally, areas with medium to high potential of landslides in the Soleghan road area are less than those of the Karaj road area (27.24% and 34.95%, respectively). However, the percentage of landslides occurred in the Soleghan road area is much higher (86.26%) than the Karaj road area (54.87%).

The high value of the ROC index and its proximity to the end value of 1 in both areas indicates that landslides strongly correlate with the probability values derived from the logistic regression model. Additionally, the assessment of the landslide potential map by the SCAI index showed that there is a high correlation between the prepared risk maps and the occurred landslides, which have been confirmed by field surveys. Field surveys also showed that landslides occurred along both roads are of debris fall type. The obtained results are in a good agreement with the general opinion that SCAI decreases especially in high and very high risk classes and indicates a high correlation between the prepared risk maps and the occurred landslides and field surveys in both areas.

Finally, it can be mentioned that the logistic regression model is suitable for preparing the zonation of the probability of landslide occurrence along the edges of the studied roads. As a final conclusion, it can be concluded that in addition to natural factors, the- human-made factors and particularly unsystematic road construction can play an important role in the landslide occurrences on the slopes overlooking the roads and in order to reduce the relative risks and increase the stability of the slopes, it is necessary to avoid manipulating the ecosystem and changing the current land use as much as possible, in addition to policy making for constructions in accordance with geomorphological and geological features of the area.

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