CONNECTION BETWEEN ROAD DENSITY AND LANDSCAPE FRAGMENTATION IN HUNGARY USING KERNEL DENSITY BASED ON GIS METHODS

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Abstract
Humans have recently caused significant landscape fragmentation by developing transportation infrastructure. We used Kernel density estimation (KDE) to analyze the road density distribution in Hungary, and then we assessed landscape fragmentation after imposing the road density onto the land-use map of Hungary, using Mean Patch Area, Patch Density, and Number of Patches as three important landscape metrics. Our analysis shows that roads, as expected, are mainly located in artificial lands (58.15%) and farmland (28.16%) landscapes. PD and NP increased by 69.59% and 69.51%, respectively, at the landscape scale, while AREA MN decreased by 41%. It has been proved by Spearman's rank correlation coefficient analysis which showed that the road density showed a positive correlation with PD and NP and a negative correlation with AREA_MN. This means that the higher the road density, the higher the PD and NP values, and the smaller the patch area. Furthermore, landscape fragmentation is positively related to road density, and as the road system became denser, the landscape became more fragmented. Understanding the effects of road networks on various land uses can aid in the development of sustainable road systems in Hungary.

Introduction
Landscape fragmentation is one of the consequences of increased socioeconomic pressures that many parts of the world are experiencing today [1]. However, little research has been devoted to landscape fragmentation in Hungary. Roads are considered a major environmental problem and one of the main causes of biodiversity loss and landscape fragmentation [2]. The development and presence of roads can reduce landscape permeability, leading to habitat loss, and increasing habitat fragmentation [3]. Road density (i.e., km/km^2) is a useful index of the road network in a landscape and has been linked to several ecological effects of roads [4]. The combination of road density analysis and landscape metrics may aid in predicting road ecological impacts at landscape scale [5]. In this article we first assessed the spatial structure of the road network in Hungary then we analyzed the landscape fragmentation related to the road network at landscape level based on Mean Patch Area (AREA_MN), Patch Density (PD), and Number of Patches (NP) metrics. Finally, we investigated the connection between road density and the landscape metrics in Hungary.

Experimental
We downloaded the road network dataset for Hungary from GEOFABRIK [6], which has data extracts from the Open Street Map project (OSM) which are normally updated every day. We also we downloaded Corine Land Cover 2018 published by Copernicus Land Monitoring Service with 10000 m^2 resolution. In the first step, we reclassified the road network map into 5 main classes: motorway, primary, secondary, links, and residential (figure 1). The road density map was created and visualized in Arc Map 10.6.1 and in ArcGIS Pro was the KDE function was used to calculate the density of features in a neighborhood around those features using a

distance-based filter. The distribution of the Kernel density of the road system is estimated with the KDE function based on a 10,000 m^2 grid size applied to reflect the spatial structure of the road network in the urban area of Hungary. The CORINE land use map was then reclassified into 13 classes by aggregating similar classes together (figure 2).

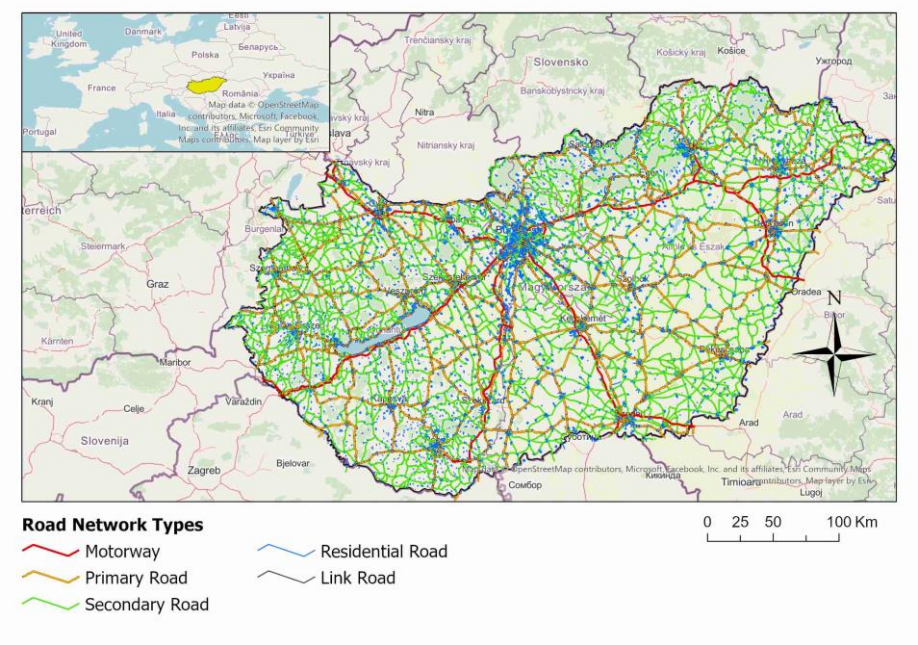

Figure 1. Reclassified road network map of Hungary.

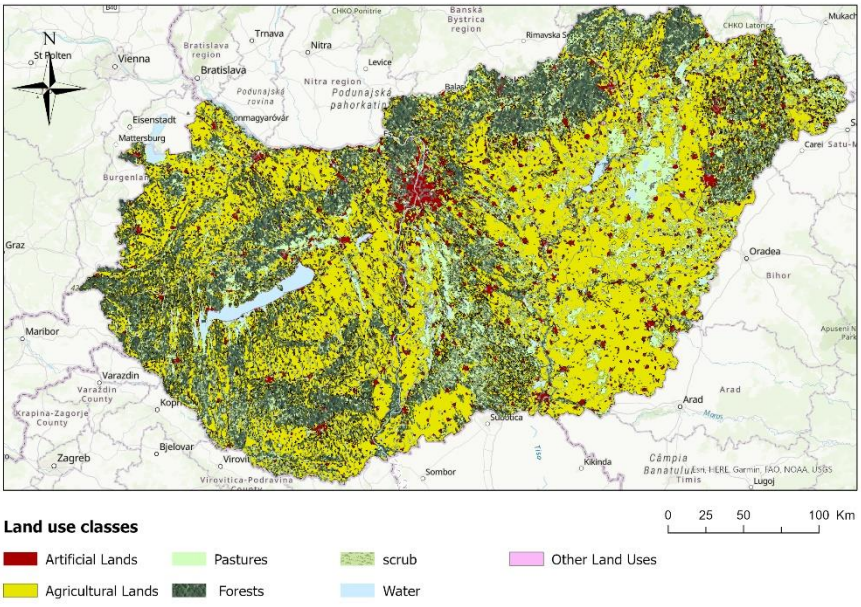

Figure 2. Reclassified CORINE 2018 land use map of Hungary.

In the following step, we calculated three landscape metrics using Fragstats software version 4: PD, AREA MN, and NP before and after superimposing roads within each land use class. The ratio of the three metric changes was used to quantify the degree of landscape fragmentation caused by roads. The metrics were selected because of their ability to describe the state of the landscape fragmentation [8]. The results of the ratio calculation based on the afore mentioned metrics were compared to earlier studies [2], [5], [9]–[11]. In addition, we used Spearman's

rank correlation coefficient in IMB SPSS Statistics software version 28.0.0 to investigate the relationship between road density and landscape metrics. The flowchart of our analysis is shown in figure 3.

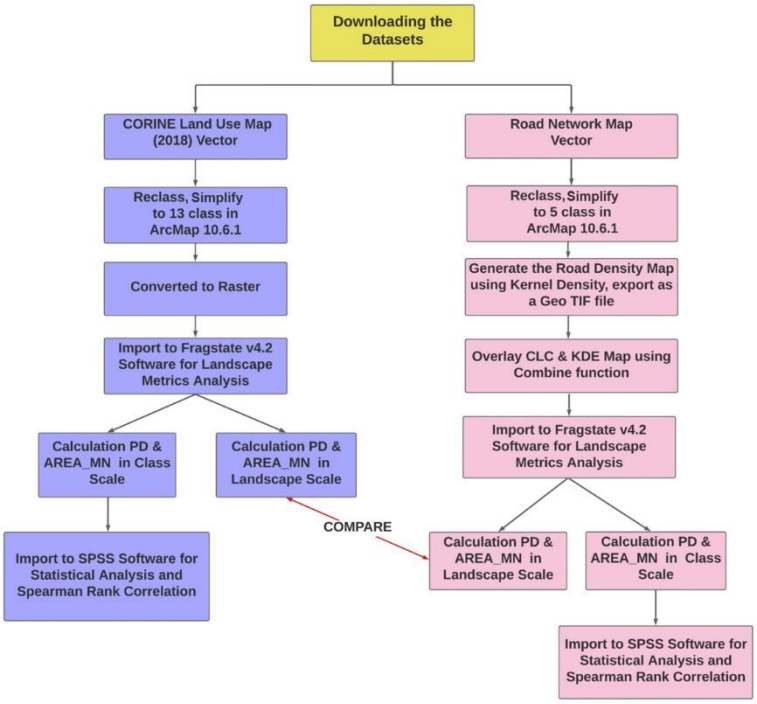

Figure 3. Flowchart of the analyzing process

Results and discussion

According to the KDE map, roads were generally concentrated in areas with a high density of residential roads close to urban areas (Budapest, Debrecen, Miskolc, Pecs, Szeged, Kecskemet, Gyor) (figure 4).

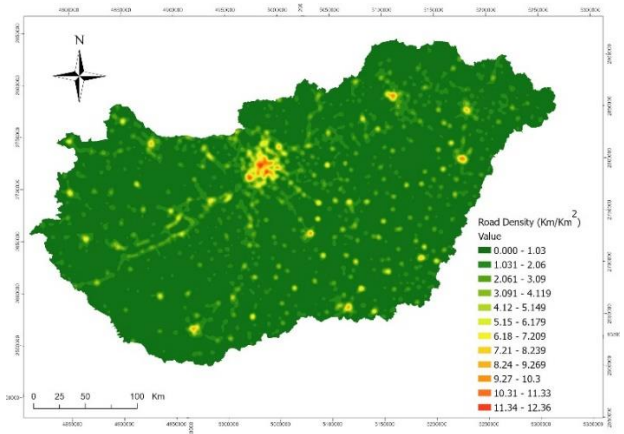

Figure 4. Road density map of Hungary.

According to our land use analysis results based on the CORINE land use map of 2018, agricultural lands cover more than half of Hungary. The outcomes are displayed on figure 5. As expected, our findings show that the majority of roads are distributed in artificial lands, with agricultural land coming in second. As a result, roads tend to cluster in artificial lands. This result is comparable to [5]. Roads are also spread throughout farmlands because farming is impossible without roads (figure 6).

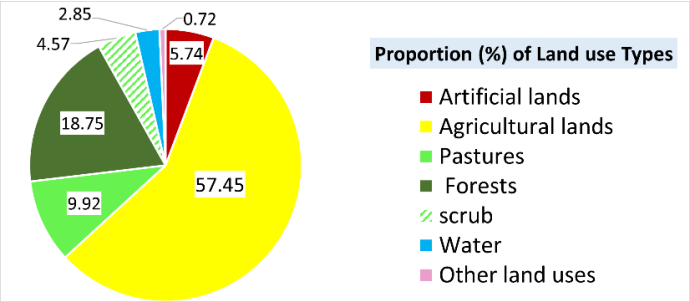

Figure 5. The proportion of main land use types in Hungary based on CORINE landcover 2018.

After imposing the road system onto the land use map, PD and NP increased at the landscape scale while AREA MN decreased (table1). Landscape fragmentation was defined as the process of decreasing AREA MN while increasing PD and NP. As a result, we can conclude that the higher the road density, the higher the PD and NP but the smaller the patch areas. It has also been confirmed by [11].

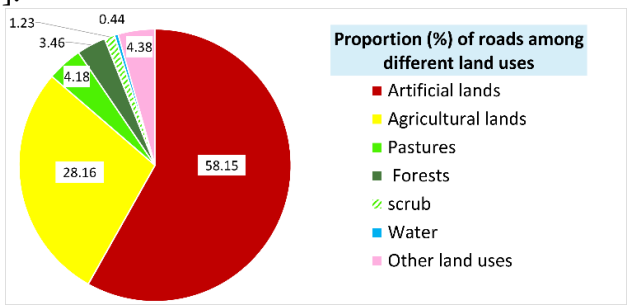

Figure 6. Proportion of roads among different land uses in Hungary. 100% is equal to total length of roads in Hungary.

Furthermore, Spearman's rank correlation coefficient revealed a positive relationship between landscape fragmentation and road density. When the road system became denser, the landscape became more fragmented (table 2). This suggests that road density has a significant positive relationship with landscape fragmentation, which is consistent with previous research [2], [5], [12] However, this is in contrast to a previous study conducted in the United States. [13].

Table 1: Values of landscape metrics before and after imposing roads in landscape scale

Description	**NP**	**PD (NP/Km^2)**	**AREA_MN (ha)**
Before imposing the Road density map	28185	0.3029	330.1483
After imposing the Road density map	47778	0.5137	194.655
Change	19593	0.2108	-135.4933
change%	**69.51**	**69.59**	**-41.04**

Table 2: Results of Spearman's rank correlation coefficient between RD and landscape fragmentation in Hungary. ** Correlation is significant at the 0.01 level (2-tailed).

		NP	PD	AREA_MN
RD_Mean	Correlation Coefficient	**0.549****	**0.547****	**-0.357****
	Number of pairs	80	80	80

Conclusion

The results showed that road kernel densities were generally concentrated in areas with a high density of residential roads close to urban areas. The density of roads varies depending on the type of land cover. More than half of all roads are concentrated in artificial lands, and 90% of all artificial lands are covered by roads. However, fragmentation analysis revealed a strong positive correlation between landscape metrics PD and NP and road density, while we discovered a negative correlation between AREA MN and road density, implying that the higher the road density, the greater the PD and NP but the smaller the patch areas. As a result, we concluded that the landscape becomes more fragmented as the road network becomes denser around urban areas.

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