GEOGRAPHIC ROAD NETWORK DISTRIBUTION OF GREECE IN ACCORDANCE WITH LAND USE

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Abstract
This study aims into the fascinating connections amongst the road network length, road density, altitude zones, and land use across Greece's unique and varied regions. By examining these relationships, we can uncover how geography shapes the way areas develop and interact within this diverse landscape.

Using freely available online data, GIS software is used to analyze and better understand the road network's role in shaping Greece's landscape. The analysis focuses on the road network and its density calculating the road network length, the percentage and the ratio of roads (km) per area (km^2) for the thirteen regions of Greece. To explore altitude zoning, the road network is divided into distinct elevation ranges, providing a clearer picture of how roads function at different altitudes. For land use, areas are classified into categories, namely urban, agricultural, and forest, relying on the latest Corine Land Cover data to ensure accuracy and relevance.

Areas with low altitudes tend to have denser road networks and urban development, while inland mountainous regions have sparse roads and are primarily rural or forested. Integrated planning considers altitude, land use, and environmental preservation to ensure roads serve development without degrading ecosystems. Understanding this relationship is critical for developing sustainable infrastructure that balances economic growth, environmental conservation, and social equity.

Key words: *Regions of Greece, road network, road density, land use, altitude zones, GIS*

Introduction

The road network in Greece has played a crucial role in the country's economic, social, and cultural development. Over the years, the expansion and modernization of Greece's road infrastructure have significantly improved connectivity, trade, and tourism, which are essential for national growth. The structure of transportation networks over time depicts the social ability to overcome at a certain time the spatial constraints, in order the societies to communicate (Tsiotas & Polyzos, 2018). The research by Petrakos and Economou (2014)

reveals that southeastern Europe is characterized by a growing regional imbalance, the increasing strengthening of metropolitan regions and by serious discontinuities at their borders, which, in most cases, are a product of isolated border areas. Urban systems with serious deficiencies in medium-sized cities are also a characteristic of southeastern Europe. In most European countries, a great part of the national and the regional network is quite old (Papageorgiou et al., 2012). Road construction is intertwined with the development of organized societies and state structures. It presupposes the formation of collective aspirations and the allocation of resources for the development of a transport system that satisfies the military, commercial, cultural and other purposes (Papageorgiou et al., 2019).

The geography of Greek transport infrastructure is shaped by the influence of historical, economic, political and geomorphological factors and often reflects and/or contributes to the development potential and organization of the spatial network (Mavraki et al., 2020). Transportation and land use are two different aspects of a landscape, but their relationship, despite not being clearly visible, is quite strong (Jedlička et al., 2019). Greece is a country which presents several geographical peculiarities, with many islands, but also several mountainous areas in mainland Greece. The different extent and geographical characteristics of the various Greek regions as well as their different economic activities are reflected in different mobility patterns and road behaviors among the inhabitants of these regions, but also in a different degree of development of the road network (Folla et al., 2023).

While Greece has made significant progress, challenges remain, such as maintaining older roads, addressing traffic congestion in urban centers, and promoting sustainable infrastructure. Future investments in smart roads and environmentally friendly transportation will further enhance national development. Overall, Greece's road network has been a cornerstone of the country's progress, enabling economic growth, improving quality of life, and strengthening regional and international connections.

Material and methods

A Geographical Information System (GIS) is an organized collection of computer hardware, software, data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (Dale & Laughlin, 1987). A major strength of a GIS is that it can accept and merge diverse data into a single database, giving the user a flexible and powerful set of data which to work (Drosos et al., 2016). The process of gathering, managing, analyzing, and visualizing spatial or geographic data to understand patterns, relationships, and trends is the geospatial analysis. We also compute the Pearson's correlation coefficient (PCC) for the road network. PCC is a statistical measure that quantifies the strength and direction of the linear relationship between two continuous variables (Rodgers & Nicewander, 1988).

The road network data obtained and analyzed with the use of open data which are available on the basis of the OpenStreetMap (OSM). The project OSM is a collaborative GIS project with a crowd-sourced approach (Kaur et al., 2017). It is also known as the wikification of GIS, that encourages the volunteers throughout the world to contribute spatial data (Graser & Straub, 2017). In this study was calculated the kilometers and the road network percentage of the thirteen Greek Regions and also the ratio of roads in km per area in km^2.

For altitude zones the data from Digital Elevation Model over Europe from the GMES RDA project (EU-DEM) was used. The EU-DEM is a Digital Surface Model (DSM) representing the first surface as illuminated by the sensors. The EU-DEM dataset is a realization of the "Copernicus" the European Union's Earth observation programme, managed by the European Commission, DG Enterprise and Industry. The EU-DEM is a 3D raster dataset with elevations captured at 1 arc second postings (2.78E-4 degrees) or about every 30

meters (Liampas et al., 2018). Four altitude zones created because each one presents distinct characteristics that influence land use, including climate, topography, and accessibility (Kazaklis et al., 2014).

For land use the data form CORINE Land Cover 2018 (CLC) was used. CLC is the oldest and most sought-after database of CLMS. CLC was specified to standardize data collection related to land in Europe to support environmental policy development (CLC, 2018). CLC data contribute to a wide range of studies and applications with European coverage. In this study three of the five main land cover / use groups are considered: 1) Artificial surfaces, 2) Agriculture, 3) Forests and seminatural areas. All the data and the categorization used in this study is presented in Table 1.

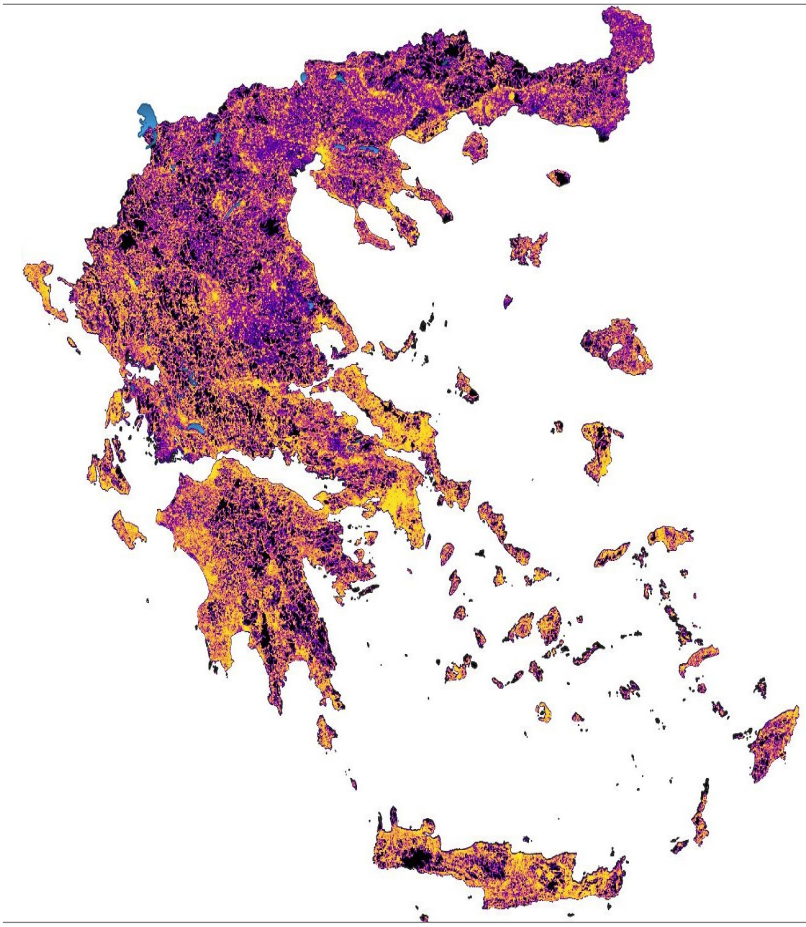
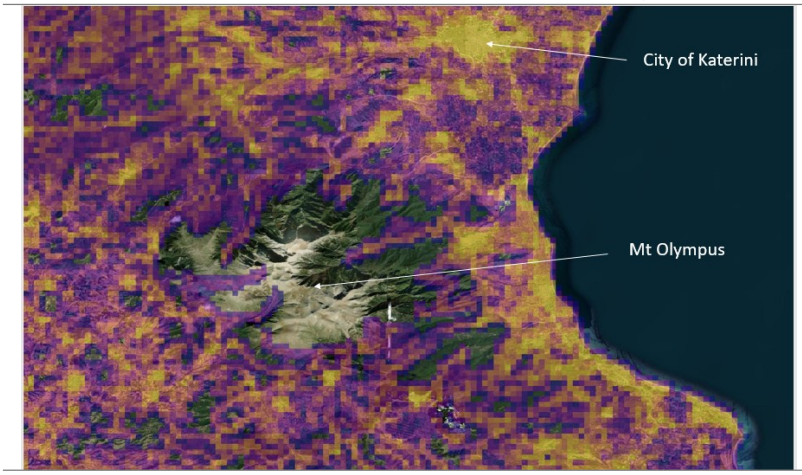
Table 1: Categorization of data that stand for the present study

Source	Categorization	Related mapping
OpenStreetMap (OSM) road data and Regions of Greece	Roads with green color and Regions borders with black Total road length in Greece: 416,701 km	
Altitude zones (EU-DEM) Each zone exhibits distinct characteristics that influence land use, including climate, topography, and accessibility.	1. 0 - 300 m. coastal areas and lowland plains (yellow) 2. 300 - 800 m. maquis or phrygana shrubland (brown) 3. 800 - 1800 m. temperate forest zone (green) 4. >1800 m. alpine zone (grey)	
Corine 2018 database categorization (European Environment Agency)	1. Artificial Surfaces (grey) 2. Agricultural Areas (orange) 3. Forest and Seminatural Areas (green)	

Results

The first geospatial analysis was a road network density heat map which is a visual representation that illustrates the concentration of roads in Greece. For the density calculation was used a square cell of 500 meters and the color gradients indicate the varying levels of density. Table 2 shows the produced heatmap, the yellow color indicates high road density, the purple color medium road density and the black color are areas without roads.

Table 2: Road network density heat map

	**High-Density Zones (Yellow): Concentrated around Athens, Thessaloniki, and major urban centers.** **Coastal regions, especially around major ports and tourism hubs, show higher road density.** **Medium-Density Zones (Purple):** Found in semi-urban and rural areas where road networks are less extensive but still present. Some mainland regions with agricultural land and mid-sized towns fall into this category. **Low/No Road Zones (Black):** Mostly in mountainous regions, such as Pindus in central Greece. Certain islands and nature reserves have little to no road infrastructure. Areas with natural obstacles (e.g., national parks, forested regions) show minimal road presence.
Indicative zoom	
	Area of Mt. Olympus and City of Katerini and to the developed costal areas.

The heatmap effectively highlights Greece's infrastructure distribution, with dense road networks in urban and economically significant regions, while rugged terrain and natural landscapes limit road expansion in other areas. The accessibility provided by road networks facilitates economic activities and population growth in the high-density areas.

The second geospatial analysis was the distribution of the road network which categorized by CLC classes across altitude zones of Greece. The results are presented in following Table 3. Moreover, a road network density analysis was also performed to identify the concentration of roads in Greece and the results are presented in Table 4.

Table 3: Percentage of roads distribution in Greece

Corine Class	Altitude zones				Sum
	0-300	300-800	800-1800	>1800	
Class 1: Artificial areas	13.304%	2.262%	0.343%	0.005%	15.914%
Class 2: Agricultural areas	40.061%	13.418%	1.880%	-	55.359%
Class 3: Forest and semi-natural areas	8.596%	11.760%	8.241%	0.130%	28.727%
Greece's total	61.961%	27.440%	10.465%	0.134%	100%

The above table highlights a clear pattern of human activity that is concentrated in lower altitudes, with natural areas more prevalent at higher elevations. The overall Greece's land distribution is mostly (61.961%) in the 0-300 m zone, while higher altitudes account for smaller proportions.

Specifically:

- Artificial areas: Highest percentage is in the 0-300 m zone (13.304%), gradually decreasing as altitude increases. Total: 15.914%.
- Agricultural areas: Dominant in the 0-300 m zone (40.061%) but decline significantly with altitude. Total: 55.359%.
- Forest and semi-natural areas: More evenly distributed, peaking in the 300-800 m zone (11.760%). Total: 28.727%.

Table 4: Road network density in Greece

Corine Class	Altitude zones				Overall
	0-300	300-800	800-1800	>1800	
Class 1: Artificial areas	16.53	12.04	11.24	8.61	15.54
Class 2: Agricultural areas	4.69	4.08	4.06	0.00	4.50
Class 3: Forest and semi-natural areas	1.94	1.62	1.41	0.49	1.61
Greece's total	4.50	2.55	1.65	0.50	3.21

The data reveals patterns in road density across land cover types and altitude zones, providing insights into the relationship between human activity, topography, and road network development. In the following Table 5 the results are analyzed by category.

Table 5: Road network density patterns in Greece

Findings by Land Use	Findings by Altitude Zones
Class 1: Artificial Areas (Overall: 15.54 km/km²) Highest road density among all classes, reflecting intensive urban and industrial development. Road density decreases with altitude: 0–300 m: 16.53 km/km² (highest density in urbanized flatlands). >1800 m: 8.61 km/km² (lowest, as urbanization is minimal in high-altitude areas). Key Insight: Urban and industrial areas, concentrated at lower altitudes, demand extensive road networks for connectivity and infrastructure. **Class 2: Agricultural Areas (Overall: 4.50 km/km²)** Moderate road density, second to artificial areas, as agriculture requires roads for transportation and access. Minimal variation across altitude zones: 0–300 m: 4.69 km/km² (slightly higher due to larger agricultural zones in flat areas). 800–1800 m: 4.06 km/km² (stable density, as agriculture persists in hilly/mountainous areas). >1800 m: 0.00 km/km² (no agriculture in high altitudes). Key Insight: Agricultural areas maintain consistent road density across altitudes, except in high altitudes where farming is infeasible. **Class 3: Forest and Semi-Natural Areas (Overall: 1.61 km/km²)** Lowest road density among all classes, reflecting limited human activity and development in these areas. Significant decline with altitude: 0–300 m: 1.94 km/km² (roads provide access for forestry and tourism). >1800 m: 0.49 km/km² (minimal road presence in remote, high-altitude forests). Key Insight: Forests and semi-natural areas are less accessible, with road density decreasing sharply as terrain becomes more challenging.	**0–300 m (Overall: 4.50 km/km²)** Highest road density, driven by: High density in artificial areas (16.53 km/km²) and agricultural areas (4.69 km/km²). Low-density forests (1.94 km/km²) contribute less but still align with human activity in lowlands. Key Insight: Flat, low-altitude areas dominate Greece's road network, reflecting urbanization and farming needs. **300–800 m (Overall: 2.55 km/km²)** Moderate road density, with: Roads supporting agriculture (4.08 km/km²) and semi-natural areas (1.62 km/km²). Key Insight: Transition zones (hilly areas) have less dense road networks than flatlands but still support mixed land uses. **800–1800 m (Overall: 1.65 km/km²)** Low road density, as: Roads primarily serve forests (1.41 km/km²) and agriculture (4.06 km/km² in limited areas). Key Insight: Higher altitudes see reduced road density, reflecting less intensive human use. **> 1800 m (Overall: 0.50 km/km²)** Minimal road density, with: Sparse roads in forests (0.49 km/km²) and virtually none in agriculture. Key Insight: Very high altitudes are the least accessible, with roads limited to isolated or strategic purposes.

The overall observations for road network density in Greece are:

- Urban Dominance: Artificial areas have the highest road density, emphasizing the concentration of infrastructure in urban regions, particularly at low altitudes.
- Consistency in Agriculture: Agricultural areas show stable road density across most altitudes (except > 1800 m), supporting the essential role of road networks in rural areas.

- Forests and Altitude: Forests and semi-natural areas have the lowest overall road density, with a sharp decline at higher altitudes.
- Altitude as a Limiting Factor: Road density decreases consistently with altitude, reflecting the challenges of infrastructure development in mountainous terrains.
- Greece's Overall Road Density (3.21 km/km²): Reflects a mix of high-density urban areas and low-density rural and natural areas, balancing accessibility and conservation.

Pearson's correlation is a measure of the linear relationship between two variables. It quantifies how strongly and in what direction the variables are related. If the data have positive correlation close to 1 it means that the one variable increases and the other also increases. If the data have negative correlation close to -1 it means that the one variable increases and the other decreases, and if the value is close to 0 there is no linear correlation. In the following Tables 6 and 7, the PCC for the road length (km) and land use (km^2), as well as the road length (km) and altitude zones area (km^2), are computed, respectively.

Table 6: Pearson's correlation for land use

Pearson Correlation Coefficient - Road length (km) & Area (km^2)	Artificial areas	Agricultural areas	Forest and semi-natural areas	Overall
	0.98	0.98	0.95	0.90

The Pearson correlation coefficients between land cover type (area) and road length show the strength of association across different land use categories.

- Urban and Agricultural Dominance: The highest correlations are observed in artificial areas (0.98) and agricultural areas (0.98), underlining their importance in shaping road networks. These land types require extensive connectivity for economic activities and mobility.
- Forested Areas Play a Secondary Role: Although the correlation for forest and semi-natural areas is slightly lower (0.95), it remains very strong, showing the significance of maintaining access to these areas.
- Overall Correlation Reflects Land Use Balance: The overall correlation (0.90) confirms that road distribution is closely tied to the proportions of land cover types, with urbanization and agriculture being primary drivers.

Table 7: Pearson's correlation for Altitude zones

Pearson Correlation Coefficient - Road length (km) & Area (km^2)	Altitude zones				Overall
	0-300	300-800	800-1800	>1800	
	0.88	0.80	0.96	0.85	0.68

These findings show that road distribution aligns strongly with human needs at lower altitudes while maintaining consistency at higher altitudes for connectivity and access.

- Highest correlation (800 – 1800 m): Suggests that forested and mountainous areas are particularly important in explaining the overall road distribution, possibly due to the connection of isolated regions or key infrastructure like highways cutting through mountainous terrain.
- Strong correlation in low-altitude zones (0 – 300 m): Highlights the dominance of urban and agricultural development in influencing road density.

- Consistent contribution across zones: Despite some variation, all altitude zones show a strong positive relationship, indicating a relatively uniform distribution pattern when viewed holistically.
- Overall alignment with human geography: Correlations reflect the interplay between human activity, topography, and road network development.

The third geospatial analysis was a road network analysis per region for Greece. The Figure 1 shows the comparison of the percentage of road length to the percentage of the area of each region of Greece. The Figure 2 shows the road length for land use class and altitude zones of each region of Greece. The Table 8 present the percentages of the data of Figure 2 in order to identify spatial patterns between the Regions of Greece.

Figure 1: Comparison of percentages for road length and area of each region of Greece

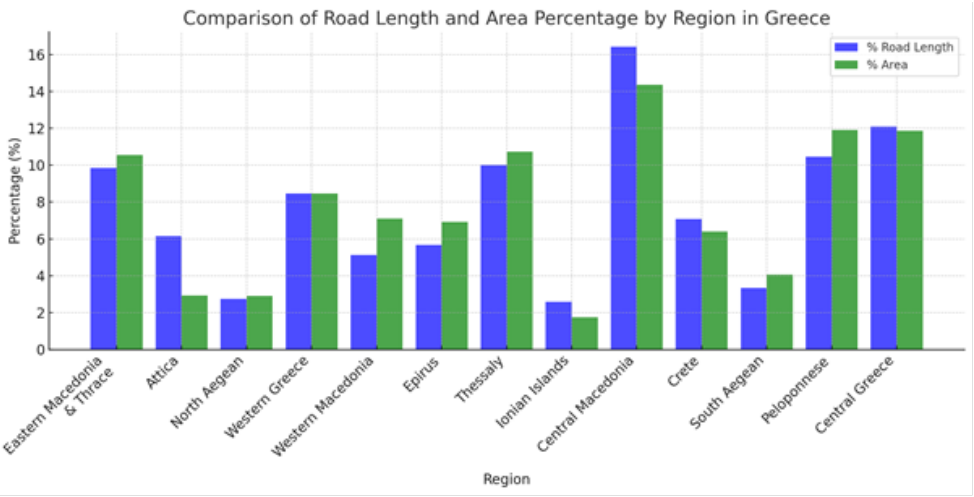


Figure 2: Comparison of percentages for road length and area of each region of Greece

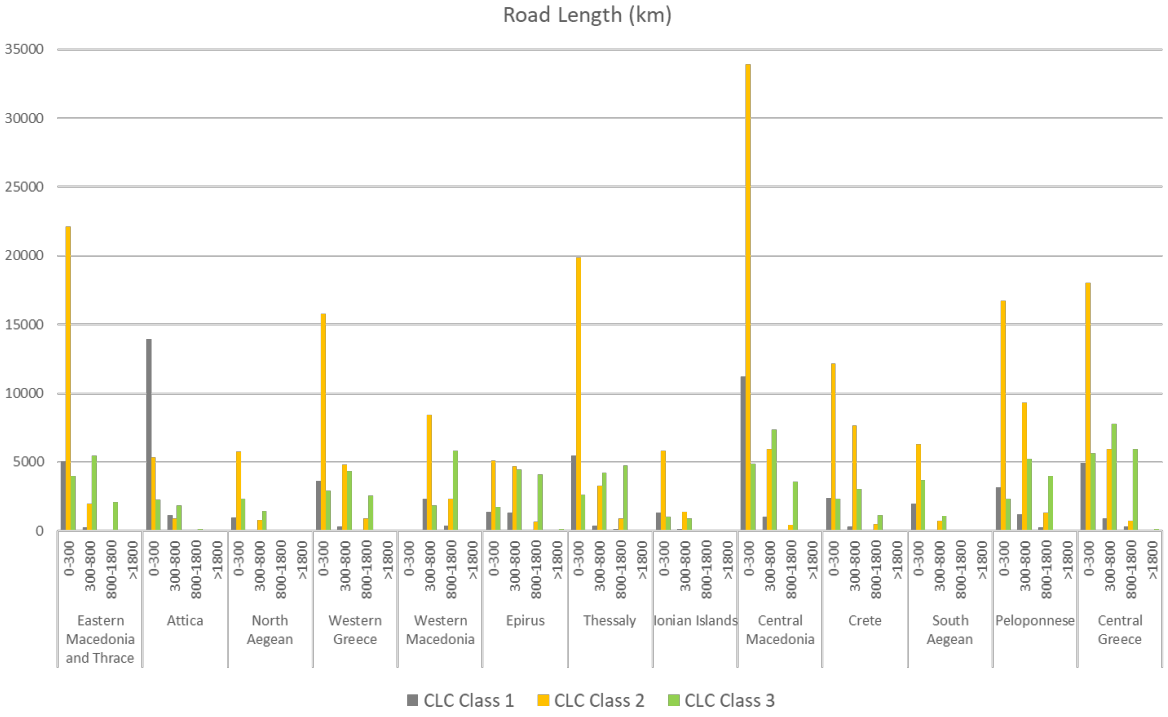


Table 8: Percentage of roads distribution in Regions of Greece

Region	Corine Class	0-300	300-800	800-1800	>1800	Sum
Eastern Macedonia and Thrace	1	12.318%	0.639%	0.067%	0.001%	13.025%
	2	53.865%	4.825%	0.152%		58.842%
	3	9.693%	13.340%	5.079%	0.022%	28.133%
	Region Sum	75.875%	18.804%	5.298%	0.023%	100 %
Attica	1	54.220%	4.451%	0.045%		58.716%
	2	20.898%	3.608%			24.506%
	3	8.944%	7.209%	0.626%		16.778%
	Region Sum	84.062%	15.268%	0.670%		100.000%
North Aegean	1	8.462%	0.422%			8.884%
	2	50.552%	6.993%	0.076%		57.621%
	3	20.361%	12.430%	0.704%		33.495%
	Region Sum	79.375%	19.845%	0.780%		100%
Western Greece	1	10.341%	0.822%	0.154%		11.317%
	2	44.675%	13.666%	2.552%		60.893%
	3	8.213%	12.235%	7.299%	0.044%	27.790%
	Region Sum	63.228%	26.723%	10.005%	0.044%	100 %
Western Macedonia	1	0.000%	11.031%	1.783%	0.030%	12.845%
	2	0.253%	39.518%	10.848%		50.619%
	3	0.087%	8.618%	27.373%	0.459%	36.537%
	Region Sum	0.340%	59.167%	40.003%	0.489%	100 %
Epirus	1	5.816%	5.664%	0.324%		11.804%
	2	21.488%	19.952%	2.716%		44.156%
	3	7.292%	18.826%	17.372%	0.549%	44.039%
	Region Sum	34.597%	44.442%	20.412%	0.549%	100.000%
Thessaly	1	13.065%	0.843%	0.342%		14.251%
	2	47.643%	7.873%	2.194%		57.711%
	3	6.353%	10.157%	11.406%	0.123%	28.039%
	Region Sum	67.061%	18.873%	13.942%	0.123%	100 %
Ionian Islands	1	12.362%	1.162%	0.152%		13.676%
	2	54.263%	13.079%	0.222%		67.564%
	3	9.476%	8.350%	0.934%		18.760%
	Region Sum	76.101%	22.591%	1.308%		100%
Central Macedonia	1	16.423%	1.490%	0.119%		18.032%
	2	49.537%	8.644%	0.604%		58.785%
	3	7.141%	10.733%	5.230%	0.079%	23.183%
	Region Sum	73.102%	20.867%	5.952%	0.079%	100.000%
Crete	1	7.996%	1.040%	0.100%		9.135%
	2	41.151%	25.897%	1.763%		68.812%
	3	7.894%	10.302%	3.825%	0.032%	22.054%
	Region Sum	57.041%	37.239%	5.687%	0.032%	100%
South Aegean	1	14.409%	0.426%			14.834%
	2	45.384%	5.224%	0.005%		50.613%
	3	26.541%	7.849%	0.164%		34.553%
	Region Sum	86.333%	13.499%	0.168%		100%
Peloponnese	1	7.211%	2.809%	0.628%		10.648%
	2	38.324%	21.398%	3.036%		62.757%
	3	5.389%	12.065%	9.114%	0.027%	26.595%
	Region Sum	50.923%	36.272%	12.778%	0.027%	100%
Central Greece	1	9.830%	1.780%	0.668%	0.024%	12.302%
	2	35.811%	11.742%	1.403%		48.956%
	3	11.239%	15.433%	11.749%	0.321%	38.742%
	Region Sum	56.880%	28.955%	13.819%	0.345%	100%

Analyzing the above data, it is observed that altitude dictates land use, lower altitudes are heavily dominated by artificial and agricultural areas, while forests and semi-natural areas dominate mid-to-high altitudes. The road distribution aligns with human activity and urbanized and agricultural regions have the most roads, while higher altitudes remain less developed. The Regional differences reflect geography with mountainous regions (e.g., Western Macedonia, Epirus) to have more roads at higher elevations, whereas coastal and island regions (e.g., Attica, South Aegean) focus on low altitudes. The regional pattern identification of roads distribution is presented in Table 9.

Table 9: Regional pattern identification of roads distribution

Land Use (Corine Class) Patterns	Class 1 (Artificial Areas): Dominates in urbanized regions like Attica (54.220% in 0–300 m) and South Aegean (14.409% in 0–300 m). Class 1 presence sharply declines with altitude, as urban areas are concentrated in lower, flatter zones. Class 2 (Agricultural Areas): Most significant class overall, dominating road distribution in nearly every region and altitude: Accounts for 40-55% of roads in 0–300 m zones across most regions. Substantial even in mid-altitudes (300–800 m) for areas like Crete (25.897%) and Epirus (19.952%). Higher altitudes (>800 m) show minimal agricultural activity, likely due to unsuitability of terrain. Class 3 (Forest and Semi-Natural Areas): Becomes prominent at mid-to-high altitudes, especially in regions like: Western Macedonia (27.373% at 800–1800 m). Epirus (17.372% at 800–1800 m). Peloponnese (9.114% at 800–1800 m). Lower altitudes (0–300 m) see limited road presence for this class, as forests are less common there.
Altitude Zone Patterns	Roads Concentrated at Low Altitudes (0–300 m): Across most regions, the majority of roads are concentrated in the 0–300 m altitude zone (e.g., 75-86% of roads in Eastern Macedonia, Attica, North Aegean, etc.). This reflects human activity being centered at lower altitudes, likely due to urban areas, agricultural activity, and flatter terrain. Mid-Altitudes (300–800 m) Are Secondary: Regions like Western Macedonia, Epirus, and Crete have substantial road coverage in mid-altitudes (25-45%), often due to hilly agricultural zones or smaller settlements. Minimal Road Coverage at Higher Altitudes (>800 m): Regions above 800 m typically have less than 10% of roads, except in areas with mountainous terrain like Western Macedonia (40%), Epirus (20%), and Peloponnese (12%). These patterns suggest that higher altitudes are less developed, with roads mostly serving forested or semi-natural areas.
Regional Patterns	Regions With Heavy Low-Altitude Focus: Attica, South Aegean, North Aegean, Central Macedonia: Over 75% of roads are in the 0–300 m zone, often linked to dense population centers or islands with limited high-altitude terrain. Regions With Balanced Distribution: Crete, Western Greece, Peloponnese: Significant roads in both 0–300 m and 300–800 m zones, reflecting mixed land use (agriculture, settlements, and semi-natural areas). Regions With High-Altitude Dominance: Western Macedonia and Epirus: Stand out for substantial road presence in 300–1800 m zones, with forests and semi-natural areas being a key focus.

The fourth geospatial analysis done in order to focus to the third land use category to the forest and semi-natural areas. The road network length in 3rd CLC category is 119,706 km (28.7%) but the area is that the 3rd CLC category covers in Greece is 74,207 km2 (57.21%). The Table 10 presents the percentage of road length and the Table 11 presents road density in forest and semi-natural areas of Greece.

Table 10: Road length percentage in forest and semi-natural areas of Greece

Corine Class	Altitude zones				Sum
	0-300	300-800	800-1800	>1800	
311 Broad-leaved forest	2.329%	8.421%	6.297%	0.022%	17.070%
312 Coniferous forest	3.092%	2.789%	5.692%	0.012%	11.586%
313 Mixed forest	2.300%	3.667%	3.298%	0.001%	9.266%
31 Forest Total	**5.595%**	**14.082%**	**15.702%**	**0.123%**	**35.501%**
321 Natural grassland	4.049%	4.591%	3.554%	0.221%	12.417%
322 Moors and heathland	0.007%	-	0.431%	0.075%	0.514%
323 Sclerophyllous vegetation	12.357%	13.160%	3.457%	0.018%	28.992%
324 Transitional woodland/shrub	4.372%	7.512%	5.112%	0.015%	17.010%
32 Shrubs Total	**18.139%**	**25.666%**	**15.208%**	**0.809%**	**59.821%**
331 Beaches, dunes, and sand plains	0.677%	0.067%	0.029%	-	0.772%
332 Bare rock	0.018%	0.022%	0.049%	0.010%	0.099%
333 Sparsely vegetated areas	0.636%	0.579%	0.767%	0.076%	2.059%
334 Burnt areas	0.085%	0.130%	0.002%	-	0.217%
33 Open spaces	**1.123%**	**1.074%**	**1.919%**	**0.561%**	**4.678%**
Greece's total	**29.922%**	**40.938%**	**28.688%**	**0.452%**	**100%**

Table 11: Road density in forest and semi-natural areas of Greece

Corine Class	Altitude zones				Sum
	0-300	300-800	800-1800	>1800	
311 Broad-leaved forest	1.73549	1.607511	1.556236	0.743673	1.601722
312 Coniferous forest	2.906565	1.934227	1.479344	0.329159	1.812818
313 Mixed forest	2.165038	1.789255	1.792725	0.148468	1.868227
321 Natural grassland	1.731014	1.59756	1.35669	0.658418	1.519887
322 Moors and heathland	1.185433	0.110489	1.334237	0.794083	1.205309
323 Sclerophyllous vegetation	1.736661	1.426831	1.117803	0.948333	1.490562
324 Transitional woodland/shrub	2.450132	1.971177	1.507211	0.287356	1.881978
331 Beaches, dunes, and sand plains	3.843237	1.506916	4.116315		3.396236
332 Bare rock	0.577061	0.839703	0.410441	0.129423	0.388112
333 Sparsely vegetated areas	1.419158	1.086627	0.72264	0.28379	0.890497
334 Burnt areas	2.086565	2.080223	1.137046		2.064416
Greece Total	1.94185	1.617696	1.409688	0.488108	1.613125

Analyzing the road data in forest and semi-natural areas of Greece, it is observed that there is lowland dominance. The roads are concentrated in the 0 – 300 m (29.92%) and 300 – 800 m (40.94%) altitude zones, where most human activities like agriculture, settlements, and semi-natural land use occur. The most roads are in areas with sclerophyllous vegetation, this class accounts for 28.99% of total road length, emphasizing its role in Greece's semi-natural and rural infrastructure. About the forest areas with broad-leaved, coniferous, and mixed forests collectively contribute 38% of road length, highlighting the role of forestry-related

infrastructure. Also, there is minimal high-altitude infrastructure in the >1800 m zone there is only 0.45% of road length, indicating limited accessibility in mountainous regions.

Moreover, the altitude impact on the road density is identified. The road density consistently declines with altitude, peaking at 0 – 300 m (1.94 km/km²) and reaching its lowest at >1800 m (0.49 km/km²). This trend aligns with terrain challenges and reduced human activity at higher elevations. The broad-leaved forest (1.60 km/km²) is the most balanced forest class in terms of density across altitude zones and in bare rock (0.39 km/km²) there is minimal infrastructure investment, reflecting its remote nature. The dominant road density classes are transitional woodland/shrub (1.88 km/km²) and sclerophyllous vegetation (1.49 km/km²) which contribute significantly to the road network in natural areas.

The road network in Greece aligns closely with land use and altitude. Sclerophyllous vegetation and forested areas dominate road coverage, highlighting the importance of rural and natural land infrastructure in the country. The road network density in Greece is highest in low-altitude areas (0 – 300 m) and decreases with elevation. The densest networks are found in beaches, transitional woodland/shrub, and burnt areas, reflecting intensive human and economic activity in these regions. Forested areas and semi-natural landscapes exhibit moderate densities, supporting rural and forestry-related activities. Sparse and bare lands, particularly at higher altitudes, have the least road infrastructure.

Conclusions

The road network distribution in Greece reflects the interplay between human activity, land use, and topographic constraints. The density of roads varies significantly across different land cover types and altitudes, highlighting the country's diverse landscape and socioeconomic patterns.

About the altitude zones and road density, it is observed that the low-altitude areas (0 – 300 m) are the most densely covered, driven by urban centers, agricultural zones, and coastal tourism infrastructure. Road density sharply declines with altitude, with the least-developed road networks found in high-altitude areas (> 1800 m) due to rugged terrain and limited human settlement.

On the subject of the Land Cover Types and Distribution, it is noticed that artificial Areas with urban and developed zones (e.g., cities, towns) have the highest road density across all altitude zones, reflecting the concentration of economic and social activities in these regions. The agricultural areas have moderate road density that supports agricultural activities, primarily in low- and mid-altitude zones. The forest and semi-natural areas have lower road density but they still maintain networks to support forestry, rural access, and tourism. The most roads in of the 3rd CLC category are in transitional woodland/shrub and sclerophyllous vegetation and for this reason these areas used to connect 1st and 2nd CLC categories.

Also, specific patterns show that Regions like Attica, Crete, and Central Macedonia perform high density road networks, corresponding to high population density and economic activity, and remote regions such as Western Macedonia and Epirus feature lower road densities, especially at higher altitudes, due to challenging terrain and lower population density.

Greece’s road network has economic and tourist influences, the coastal and island regions, especially in the Ionian Islands, South Aegean, and Crete, show high road density in proximity to beaches and tourist hubs. The road network in Greece is highly concentrated in low-altitude urban, coastal, and agricultural areas, driven by population distribution and economic activity. In contrast, higher altitudes and sparsely populated areas have sparse road infrastructure, reflecting the natural limitations of the terrain and reduced human impact. This

distribution mirrors Greece's dual character as both a center of modern urbanization and a country with vast, rugged landscapes that remain relatively untouched.

The impact of road network altitude zones on land use patterns in Greece is profound. Understanding these dynamics is crucial for informed policy-making and fostering sustainable development.

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