

Road Infrastructure and Forest Landscape Fragmentation: Evidence from the Tangier–Tanger Med Motorway, Northern Morocco

Ilham ESSOUSSI¹

1. History and Geography Teacher (Secondary Education) and PhD Candidate in Geography, Faculty of Arts and Human Sciences, Mohammedia, ilham.essoussi@gmail.com

Abstract

Road infrastructure projects are among the most significant factors affecting natural environments, as they bring about changes to the environment and impact the continuity of forest ecosystems. This study aims to assess the impact of the motorway linking the city of Tangier to the Port of Tangier-Med on forest cover in the Dar al-Fawal Forest between 2000 and 2023, by analysing the spatial changes that accompanied the project's completion.

The results showed a decline in the area of forest cover in the Dar al-Fawal Forest by approximately **50 hectares** during the study period. They also indicated that the Aleppo pine (*Pinus halepensis*) was the most affected species, with **1,835 trees** removed. These findings suggest that the construction of the motorway led to the loss of part of the forest cover and caused changes in the forest's spatial structure, thereby accelerating the process of erosion.

The study emphasises the importance of integrating environmental considerations into the planning and implementation of infrastructure projects, and of utilising spatial analysis tools and geographic information systems to assess their impacts on forest ecosystems, thereby contributing to a better balance between development requirements and the conservation of natural resources.

Keywords: Tangier (Morocco), degradation, forest environment, Dar al-Fawal, motorway.

Introduction

Transport infrastructure has been one of the key drivers of spatial change in recent decades, owing to its pivotal role in improving territorial connectivity, promoting economic development, and facilitating the movement of people and goods. However, the expansion of transport networks, particularly motorways, has, in turn, become one of the main factors causing changes to the landscape, as it leads to the removal of parts of the vegetation cover, and causing changes to the spatial structure of ecosystems, which in turn affects the continuity of ecological processes, biodiversity and the functional capacity of natural systems, particularly in the context of increased erosion in fragile environments.

Forest ecosystems are among those most affected by linear infrastructure projects, due to the disruption of spatial connectivity between their components, increased edge effects, and a reduction in the area of contiguous forest patches. Consequently, the assessment of the impacts of motorways has moved beyond simply measuring the areas directly affected to include an analysis of changes in landscape structure, the dynamics of forest cover, and the level of connectivity between forest patches, utilising remote sensing techniques, geographic information systems (GIS) and field surveys.

The motorway linking the city of Tangier to the Port of Tangier-Mediterranean is one of the most important strategic projects completed in northern Morocco, having contributed to enhancing logistical performance, improving access to the port and connecting it to the national motorway network. However, the fact that this road corridor passes through forested areas of environmental value raises concerns regarding its impact on the sustainability of the forest's morphological balance and land-use patterns – aspects which have not yet been sufficiently addressed by quantitative studies based on spatial analysis.

Although numerous studies have addressed the economic and logistical dimensions of the Tangier-Mediterranean Port, research assessing the environmental impacts of the motorway on forest landscapes remains limited, particularly studies that combine time-series analysis of remote-sensing data, with geographic information system (GIS) techniques and landscape fragmentation indices, thereby enabling an understanding of the dynamics of spatial changes resulting from the motorway's construction.

Accordingly, this study aims to assess the impact of the motorway linking the city of Tangier to the Port of Tangier-Mediterranean on forest ecosystems in northern Morocco, by analysing the spatial and temporal changes in forest cover before and after the motorway's construction, measuring changes in landscape composition and spatial structure, and assessing the degree of forest fragmentation and the level of ecological connectivity using established quantitative indicators in the landscape context. The study also seeks to provide a scientific basis for integrating environmental considerations into the planning of infrastructure projects, thereby striking a balance between development requirements and the conservation of forest ecosystems and the sustainability of their ecosystem services.

1. Introduction to the study area and the role of natural factors in forest formation

1.1. Geographical location and extent

The study area is situated in the far north of Morocco, within the Tangier–Tetouan–Al Hoceima region, and covers the entire route of the motorway linking the city of Tangier to the Port of Tangier-Mediterranean, which crosses the territory of the Al-Fahs-Angera province. The study area extends over a length of 54 km between latitudes $35^{\circ}43'$ and $35^{\circ}56'$ north, and between longitudes $5^{\circ}48'$ and $5^{\circ}20'$ west (Map 1). It is characterised by diverse topography and natural features, passing through a number of Mediterranean forest areas, most notably the Dar al-Fawal Forest.

This road is a strategic artery linking the city of Tangier with the Port of Tangier-Mediterranean, and has contributed to enhancing transport and logistics activities. However, its route through forested areas of environmental value has led to changes in forest cover and land use, making this area a suitable case study for examining the environmental impacts of road infrastructure on forest ecosystems.

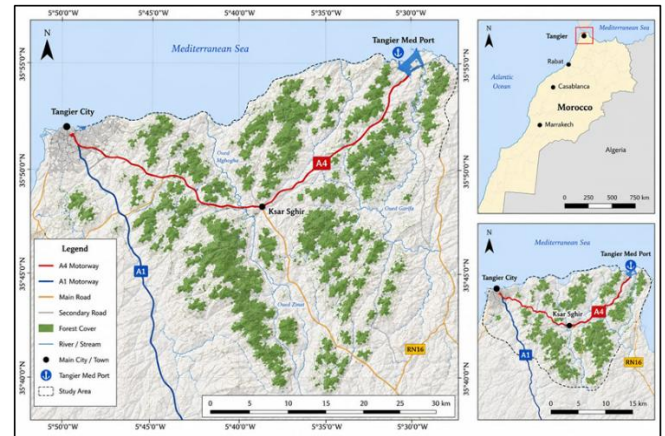


Figure 1. Location of the Study Area: A4 Motorway between Tangier City and Tangier Med Port, Northern Morocco

Source: OpenStreetMap contributors; ESA WorldCover (2021); Landsat Collection 2 (USGS); NASA SRTM DEM (30 m). Cartography by the author

1.2. The role of natural factors in vegetation and forest formation

A. Geological Characteristics

The study area lies within the Western Rif, which forms part of the Rif Mountain range in northern Morocco, and is characterised by a complex geological structure resulting from tectonic movements associated with the convergence of the African and Eurasian plates. This geodynamic evolution has produced a great diversity of rock formations and geological structures, which is reflected in the topographical and geomorphological characteristics of the region.

The geological foundation of the study area consists of a succession of rock units belonging primarily to the Outer Rif range, comprising sedimentary formations dating from the Cretaceous and Tertiary periods, consisting of marls, limestone, sandstone, and schist, in addition to Quaternary deposits concentrated in wadi beds and low-lying areas. (BEAUDET, 1982) These formations are characterised by varying degrees of resistance to weathering and erosion, which has contributed to the formation of a varied topography ranging from hills and slopes to wadis (Map 2).

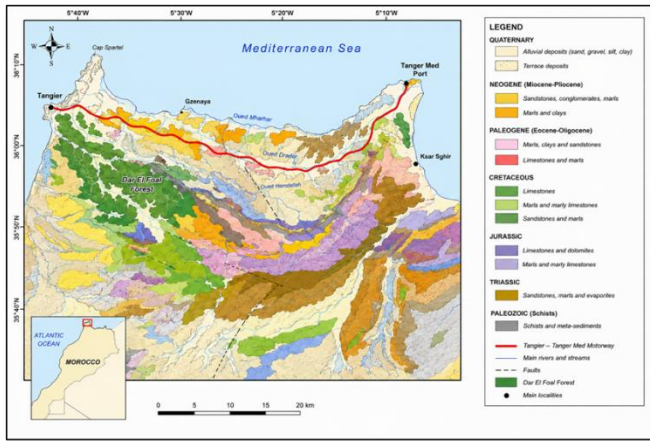


Figure 2. Geological Map of the Study Area: Tanger – Tanger Med Port Motorway corridor (Northern Morocco)

Source: Geological map of Tanger (1:50,000) and Ksar Sghir (1:50,000). Ministry of Energy, Mines and Environment, Department of Geology, Morocco.

Lithological characteristics play a key role in determining slope stability and soil behaviour, as marl and clay formations are among the geological units most susceptible to erosion and landslides, particularly during the construction of linear infrastructure projects that involve excavation, backfilling and slope cutting. These geological characteristics posed engineering and environmental challenges during the construction of the motorway, and also contributed to making certain sections more susceptible to environmental degradation and loss of vegetation cover.

This geological diversity has a direct impact on the distribution of soil and forest cover, as forest patches—particularly the Dar al-Fawal Forest—are associated with formations that provide suitable conditions for the growth of Mediterranean species, foremost among which is the Aleppo pine (*Pinus halepensis*). Therefore, understanding the geological characteristics of the study area is essential for explaining the spatial variation in the forest cover’s response to the changes resulting from the construction of the motorway.

B. Topographical characteristics

The study area is characterised by low-lying topography, comprising a group of small mountains, the most significant of which are ‘Jebel Dar al-Ruman’ (approximately 150 m high), ‘Jebel al-Khaladi’ (approximately 467 m high) and Jebel Tastouira (approximately 665 m high).

Furthermore, the slopes are generally steep, ranging between 25 and 40 per cent, which explains the prevalence of rugged

slopes where mountain torrents have carved a dense network of deep gullies, transforming them into distinct longitudinal features of varying significance, which generally terminate in convex foothills. Gentle gradients, on the other hand, are less than 15 per cent and are clearly concentrated at the mouths and along the beds of the wadis.

Topographical characteristics directly influence the distribution and diversity of forest vegetation cover in the area stretching along the Tanger–Tanger Mediterranean Port motorway, where a clear correlation is evident between topographical units and the distribution of forest stands; forest formations are particularly widespread on slopes and inclines, whilst they are less prevalent in flat areas and regions close to population centres and infrastructure. Topography therefore represents a determining factor in the structure of the forest landscape and influences its vulnerability to changes resulting from road development and urban expansion (Elgharbaoui A., 1981) (Figure 3).

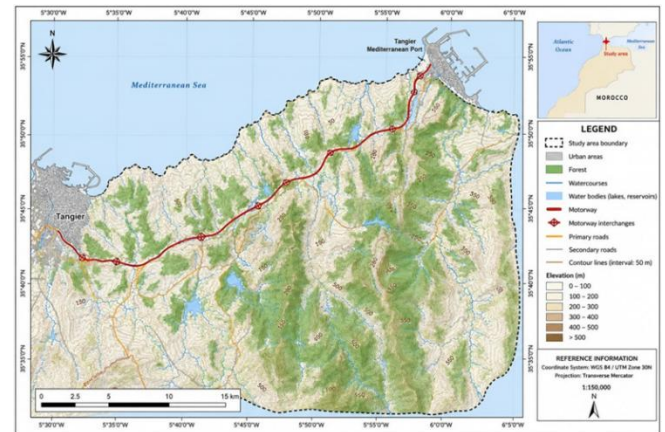


Figure 3. Topographic Map of the Study Area along the Tanger–Tanger Med Motorway (2023)

Source: Compiled by the author based on OpenStreetMap, Copernicus DEM (30 m), and Sentinel-2 satellite imagery (2023)

C. The Water Network

The water network is one of the key natural factors governing the distribution and development of forest vegetation cover, as watercourses and wadis provide the hydrological conditions necessary for the sustainability of forest ecosystems by regulating water availability, maintaining soil moisture and supporting biodiversity. This interdependence is clearly evident in the area stretching along the Tanger–Tanger Mediterranean Port motorway, where wadis and watercourses intertwine with forest formations, particularly in the hilly and mountainous regions of the Western Rif.

The wadis and areas adjacent to watercourses help to form **ecological corridors** that facilitate the dispersal of plant species and maintain the continuity of forest cover. Furthermore, the density of the water network and drainage patterns influence moisture distribution and soil development, which in turn accounts for the differences in the density and diversity of forest formations between the foothills and the low-lying areas. As for the hydrological units in the vicinity of the Port of Tangier-Mediterranean, these consist of seasonal, intermittent watercourses of a torrential nature, the most important of which are the coastal basins located between Al-Qasr al-Saghir and Tangier-Kouad Alian, and the Wadi al-Raml basin, which covers an area of approximately 47 km² characterised by an irregular yet powerful flow regime, Wadi Ghallala and Wadi Al-Qasr Al-Saghir.

2. Impact of the Tangier–Tangier Mediterranean Port motorway on forest resources

2.1. Characteristics of the vegetation cover in the study area

The study area is situated along the coastal strip between Al-Qasr Al-Saghir and the mouth of Wadi Al-Raml. This coastal strip is characterised by rocky and pebbly beaches, whilst the hinterland is characterised by coastal vegetation. The vegetation in this area is very dense, comprising plant communities typical of bioclimatic zones with a Mediterranean climate and a temperate climate.

The first level is characterised by the presence of thermophilic shrub formations (arar, olive, etc.), whilst the second level consists mainly of green oak and cork oak.

Consequently, the coastal zone surrounding the Mediterranean port of Tangier currently comprises a range of small-sized plants of both natural and cultivated origin. Among the most notable species that can be observed are dwarf palms, arar and saltbush... and a variety of plant species prevail along the entire length of the study area a range of plant species such as the pine forests of Al-Qasr al-Saghir, whilst cork oak forests predominate within the boundaries of the Meloussa area, as well as at Jebel Musa and the surrounding areas. However, generally speaking, we observe that the area surrounding the Port of Tangier-Med as a whole is dominated by riparian vegetation which are characterised by the presence of species found along watercourses and adapted to significant seasonal water flows. The most abundant plants are mostly trees, the majority of which consist of several species, the most important being the tamarisk and certain other species, which can be found both in the riverbeds and on their banks. These plant communities are clearly

evident in Wadi Karara, Wadi Lashba, Wadi al-Qasr al-Saghir and Wadi al-Raml, the latter being characterised by a significant concentration of African tamarisk (BENOITG and Comeau A, 2005).

Furthermore, natural factors in the Tangier region contribute to the enhancement of forest areas, lending them great significance; consequently, they occupy substantial areas around the Port of Tangier-Méditerranée and Tangier, totalling approximately 24,062 hectares, and are home to important plant and animal species, thereby forming a significant ecological system. Adjacent to the motorway linking the Port of Tangier-Med and the city of Tangier, the forest covers an area of approximately 950 hectares, comprising both native plant species (Figure 4) and introduced species.

Area of natural land units (ha)	Forest	Commune
787	- Tafoughalt - Ain Ansar	Melloussa
163	Dar Foual	Ksar Sghir

Figure 4. Main forest formations along the Tanger Med Port–Tangier motorway

Source: Provincial Directorate of Water, Forests and Desertification Control, Tangier

2.2. Impacts of the construction of the Tangier–Tangier Med Port motorway on forest areas

A. Degradation of forest areas along the motorway

Few people are aware of the importance of forests in maintaining ecological balance, given their close relationship with the atmospheric and biological spheres and their role in regulating the water cycle, not to mention their effective role in maintaining the stability of soils and surface formations.

Forests covering slopes – as is clearly evident in the study area, specifically the Dar al-Fawal and Meloussa forests – serve to limit erosion and the displacement of soil and solid formations composed not only of fine particles but also of larger elements (gravel, stones and even boulders), Nor can the aesthetic value of tree-covered areas be overlooked.

Despite the importance of forested areas as an economic and natural resource, they are undergoing an accelerating pace of human interventions that exceed the natural capacity of these forests.

The motorway linking the city of Tangier to the Port of Tangier-Méditerranée has been a strategic focal point amongst Morocco’s major infrastructure projects, as it has helped to strengthen logistical links between the port and the national transport network and to support economic development in the region. However, its construction through an area characterised by extensive Mediterranean forests, particularly in the Al-Fahs-Angera region, has brought about environmental and spatial changes that have affected the structure and functions of forest ecosystems.

The first of these impacts was the loss of parts of the forest cover as a result of tree felling and the construction of the roadbed and associated engineering structures, which led to a reduction in forest areas of approximately 10 per cent between 2018 and 2023 and a change in land-use patterns. The road has also contributed to forest fragmentation, dividing natural habitats into separate units, thereby weakening ecological connectivity and hindering the movement of numerous animal and plant species, and has increased edge effects, which lead to changes in microclimatic conditions at the forest edges and, consequently, to the degradation of the forest ecosystem (Figure 5).

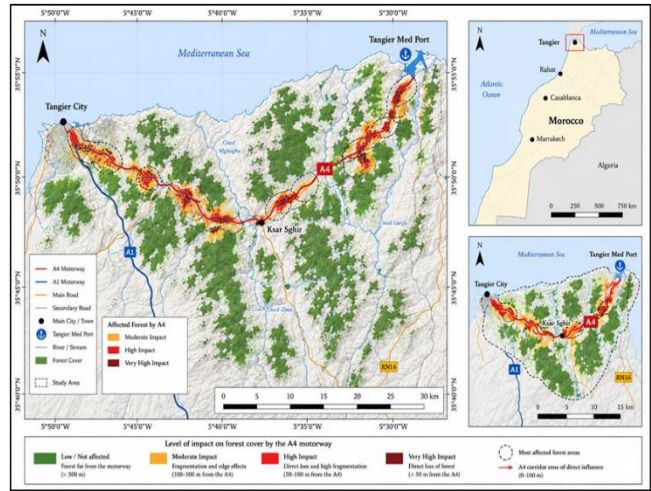


Figure 5. Spatial distribution of forest areas affected by the A4 motorway between Tangier City and Tangier Med Port, northern Morocco

Source: *OpenStreetMap* contributors; *ESA WorldCover* (2021); *Landsat Collection 2* (USGS); *NASA SRTM DEM* (30 m). Cartography by the author.

The Dar al-Fawal forest is a prime example of this type of degradation (Figures 6 and 7), as its area has decreased by approximately 50 hectares between 2018 and 2023, with the majority of felled trees being Aleppo pines, totalling 1,835 trees across three major phases (Figure 8).



Figures 6 and 7. Forest clearing in Dar El Foual Forest during the construction of the Tangier–Tanger Med Port Motorway

Number of Trees Removed	Cleared Forest Area	Affected Forest	Project Description
638	1 ha 05 a	Dar El Foual Forest	Tanger Med Port–Tangier Motorway
602	42.4 ha		
595	2 ha 20 a		

Figure 8. Assessing the Impact of the Tangier–Tanger Med Port Motorway on Dar El Foual Forest

B. The relationship between deforestation and erosion in the study area

The decline and degradation of forest areas within the study area, and the resulting loss of their importance, are among the key factors exacerbating the problem of erosion in the region, which has taken various forms depending on time and location.

Furthermore, the loss of vegetation cover on the surface—particularly on the rugged slopes composed of friable rock, which predominate in the region—has deprived the area of any protective cover. All of this makes the rocks more susceptible to weathering, which explains its significance in the study area (Figure 9), not to mention the activity of mass movements and landslides; these dynamics have had a particular impact on the environment.

Soil and natural vegetation form an integrated unit within the ecosystem; however, any disruption to this system leads to its degradation. The decline in vegetation cover in the study area, caused by human interventions involving the clearing of significant areas of this natural component, has inevitably affected the surface cover, particularly the soil, which has become susceptible to erosion, especially on the slopes.

The heavy rainfall received by the region exacerbates this degradation by breaking up and dispersing natural soil particles through the impact force that typically accompanies rainfall; in particular, torrential downpours allow runoff water on the slopes to carry away essential soil particles, which eventually end up at the foot of the slopes and in the wadi channels.

Furthermore, the prevalence of strong winds in the region, combined with the presence of poor-quality, thin soil layers in the study area, has accelerated erosion and the transport of fine soil particles, depending on the strength and speed of the winds, which control the deposition of these materials, leaving behind coarse materials and thus creating rough surfaces.

The gully erosion affecting the study area is prevalent on the slopes adjacent to the Tangier-Mediterranean Port–Tangier motorway, whether these slopes are bare or vegetated, as water gradually and slowly carves out its channels, depending on the nature of the friable rock formations, the steep gradient and the type of vegetation cover, and the watercourses. This phenomenon is particularly evident in the Melousa area, where it has affected significant areas, to the extent that some ploughed fields have lost a large portion—approximately one-fourth—of their surface soil cover.



Figure 9. Spatial Dynamics of Gully Erosion Along the Tangier–Tanger Med Port Motorway Corridor

Conclusion

This study concluded that the motorway linking Tangier to the Tangier-Med Port, despite its strategic role in enhancing logistical connectivity and supporting economic development in northern Morocco, has caused significant environmental and geomorphological changes in the forested area it traverses. The most significant of these impacts include the removal of parts of the forest cover, the fragmentation of natural habitats, the intensification of gully erosion and sediment transport, and increased slope instability, alongside changes in surface runoff patterns and increased human pressure on forest resources.

The study's findings highlight the importance of adopting an integrated approach to the planning and implementation of infrastructure projects, based on incorporating geomorphological and environmental data at various stages of the project, whilst strengthening mitigation measures such as reforestation, slope stabilisation, and the improvement of drainage networks, and the creation of ecological corridors to ensure the continuity of ecological connectivity.

This study confirms that the use of Geographic Information System (GIS) and remote sensing techniques, alongside field surveys, provides a robust scientific framework for assessing the environmental and geomorphological impacts of major transport projects, and helps to support decision-making and strike a balance between the requirements of economic development and the conservation of sustainable forest ecosystems in northern Morocco.

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