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Assessing human impacts on degradation of Maâmora forest (Morocco)

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ABSTRACT

The Maâmora forest, the world's largest contiguous cork oak (*Quercus suber*) ecosystem, plays a crucial role in protecting Morocco's Atlantic coastal region from desertification. However, rapid population growth, urban expansion, and overgrazing have significantly degraded this forest, reducing cork oak coverage from 60.71% in 1989 to 44.42% in 2022. Despite prior studies on land-use changes, the direct correlation between demographic expansion and forest degradation remains insufficiently explored. This study employed geographic information systems (GIS) to analyze the spatial relationship between population density and forest decline in the western Maâmora region. Using satellite imagery and spatial interpolation techniques, it was investigated how urban sprawl, rural settlement growth, and anthropogenic pressures accelerate deforestation, alter soil composition, and threaten the forest's regenerative capacity. The findings revealed a strong association between high population densities and intensified forest degradation, particularly near urban centers like Kenitra and Sidi Bouknadel. The obtained results demonstrate that unsustainable land use, coupled with the fragile sandy soils of Maâmora, exacerbates soil erosion and desertification risks. The study underscores the urgent need for sustainable land management strategies to mitigate further environmental degradation and preserve the ecological integrity of this vital forest ecosystem.

Keywords: geographic information system, Maâmora forest, cork oak, population, soil.

INTRODUCTION

The Maâmora forest, located along the Atlantic coast of Morocco, is recognized as the world's largest contiguous cork oak forest, covering an area of 133,000 hectares (Benabou et al., 2022; Laaribya et al., 2006). Of this, approximately 64,000 hectares are covered by cork oak (*Quercus suber*) (Mitique et al., 2025), a species known for its ecological, economic, and cultural value within its natural range (Laaribya et al., 2021). The Maâmora forest plays a critical role in protecting the region from desertification, particularly due to the presence of sandy soils that are highly prone to erosion (Aronson et al., 2009; Serrasolses et al., 2009). The cork oak (Quercus suber) ecosystem serves as a natural barrier against land degradation by stabilizing soil, reducing wind erosion, and maintaining soil moisture. However, rapid population growth has intensified deforestation and land-use changes, overgrazing, which have led to a decline in cork oak coverage from 60.71% in 1989 to 44.42% in 2022 (Ghouldan et al., 2024; Malki et al., 2022) and increased soil vulnerability. These changes have altered the forest composition and its capacity to provide essential ecosystem services, including biodiversity support and climate regulation. In recent years, several studies have highlighted the impacts of human activity on forest dynamics using GIS and satellite imagery (Khatri et al., 2019; Draoui et al., 2021). While existing research has focused on land-use changes and demographic trends, there is a limited understanding of the direct correlation between population density, human settlements, and forest degradation in the Maâmora region. Additionally, the specific effects of rural-locality expansion and urban encroachment on cork oak ecosystems remain underexplored.

This study aimed to bridge these gaps by analyzing the spatial distribution of population density and its impact on forest degradation, specifically focusing on the western region of the Maâmora forest. Using GIS-based spatial analysis and satellite imagery, the authors aimed to identify the correlation between demographic trends and forest cover loss, particularly in areas near urban centers such as Kenitra and Sidi Bouknadel, investigate the influence of population density on cork oak ecosystems and soil degradation and provide actionable insights into sustainable land management practices to mitigate further forest degradation. The primary hypothesis of this study was that higher population densities are strongly associated with increased forest degradation, particularly in terms of deforestation, overgrazing, and illegal logging. It was expected that the results would reveal clear patterns linking human settlement expansion to the decline of cork oak populations, providing valuable information for conservation and policy development.

MATERIAL AND METHODS

Study area

The Maâmora forest is situated in the northwest of Morocco, spanning up to 70 kilometers inland along the Atlantic Ocean between Rabat and Kenitra (Lemkimel et al., 2024). It is bordered to the south by the Bou Regreg valley and the foothills of the central plateau, and to the north by the Gharb plain (Boukbida et al., 2016; Mitique et al., 2025). Covering an area of 133,000 hectares, including 64,000 hectares of cork oak, this forest is recognized as the largest of its kind globally (Laaribya, 2006; Cherki, 2011). It serves various social, economic, environmental, and recreational purposes. For this study, the West Maâmora forest region was selected as the primary research area, encompassing an area of 475 square kilometers. Figure 1 illustrates the study area of the west Maâmora forest (Fig. 1).

The granulometric analysis method is employed to determine the soil texture, offering essential insights into its composition. This technique involves sieving the soil through a series of stacked sieves with varying mesh sizes (Figure 2), enabling the classification of particles based on their diameter (Table 1) (Vdović et al., 2010). As a result, it provides a detailed assessment of the soil's particle size distribution (Ballais et al., 2007; Mitique et al., 2024).

To determine the texture of a soil sample, the following procedure is performed: hydrogen peroxide is added to a soil sample in a beaker to remove organic matter. Next, hydrochloric acid (HCl) is added to dissolve limestone. The soil texture is then determined based on the percentages of clay, silt, and sand.

The study of the spatial distribution of population and habitats constitutes a central aspect of geographical analysis. Numerous studies have explored the most appropriate graphical and statistical representation techniques to model this

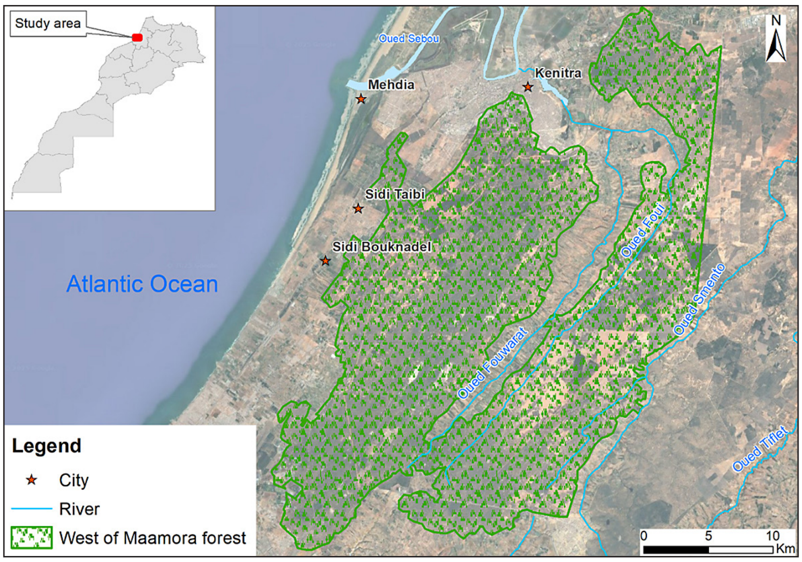

Figure 1. Situation map of the west Maâmora forest

Table 1. International classification of soil particles based on their diameters

Particles	Clay	Silt	Sand	Gravels	Rocks
Diameter (mm)	d<0.002	0.002 < d <0.05	0.05 < d < 2	2 < d < 20	d>20

phenomenon (Valle, 2004; Moukrim et al., 2022). The integration of GIS has enabled the analysis of the spatial distribution of population in the Maâmora forest. This analysis is based on satellite image acquisition, field data collection for validation, and the application of spatial analysis techniques to classify areas according to population density (Khatri et al., 2019; Draoui et al., 2021). It also allows for the assessment of the impact of anthropogenic activities such as deforestation, urbanization, and grazing pressure. Additionally, GIS provides advanced tools for processing and visualizing spatial data, facilitating the quantification of land cover variations at the forest scale. These tools enhance the understanding of demographic dynamics and the evolution of the forest ecosystem. The analyses have highlighted spatial patterns of population density and their correlation with vegetation cover degradation. Furthermore, the classification of population density using GIS enables the segmentation of continuous data into distinct categories, improving the visualization of geographical variations. By applying symbology tools, these categories are represented using a color gradient, making it easier to identify the areas of high and low population density. To enhance the spatial assessment of population pressures on forest degradation, this study utilized GIS-based interpolation techniques, including inverse distance weighting (IDW) and Kriging. Additionally, spatial interpolation methods and GIS were applied to map and evaluate the spatial distribution of soil texture in the Maâmora forest at various depths (0–20 cm, 20–40 cm, 40–60 cm, and 60–80 cm), particularly in the western part of the forest. The integration of digital maps through GIS has provided an effective means for storing and analyzing soil variation data.

Figure 2. Vibrating screen

Table 2 and Figure 3 provide an overview of the trends observed for each land cover class, along with the quantitative results obtained through supervised classification for the selected years between 1989 and 2022. Each vegetation class is accompanied by its corresponding area in hectares (ha) and its percentage share of the total study area (Ghouldan et al., 2024). The data show

Table 2. Evolution of the forest cover area of the Maâmora between 1989 and 2022 (Ghouldan et al., 2024)

Years	1989		1999		2009		2019		2022	
Classes	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area(ha)	%
Cork oak	80445.87	60.71	98564.85	74.38	78728.94	59.42	63989.55	48.30	58855.14	44.42
Eucalyptus	23999.76	18.11	25859.07	19.51	40680.54	30.70	53353.17	40.27	52085.79	39.32
Pine	22821.57	17.22	2092.5	1.58	3869.55	2.92	3735.9	2.82	6068.52	4.58
Acacia	3719.7	2.80	2711.61	2.04	314.91	0.24	400.95	0.30	31.05	0.02
Bare land	1270.62	0.95	2299.77	1.73	7779.87	5.87	10289.88	7.77	14360.67	10.84
Daya	74.88	0.05	548.91	0.41	437.49	0.33	191.88	0.14	447.57	0.34
Other	169.02	0.12	423.36	0.32	677.7	0.51	510.12	0.38	637.92	0.48
Total	132501.42	100	132500.07	100	132489	100	132471.45	100	132486.66	100

a significant decline in the area occupied by cork oak, decreasing from 60.71% in 1989 to 44.42% in 2022. Bare land (Figure 3) has experienced a continuous rise, especially after 2009. By 2022, the percentage of bare land reached a concerning level, indicating an acceleration of deforestation and soil degradation.

RESULTS AND DISCUSSION

Preliminary results indicate variations in population density across different regions of the Maâmora forest. Areas of high density are typically found in regions with favorable environmental conditions and minimal human interference. In contrast, low-density areas correspond to the zones affected by deforestation, overgrazing, and urban expansion. The study also reveals correlations between forest stand dynamics and environmental factors, such as soil composition and moisture levels. Additionally, the impact of anthropogenic activities on tree distribution is evident, emphasizing the need for conservation measures. Figure 4 compares forest degradation between 1990 and 2024, illustrating changes in vegetation cover, deforestation, and potentially land-use shifts. The 2024 image likely indicates

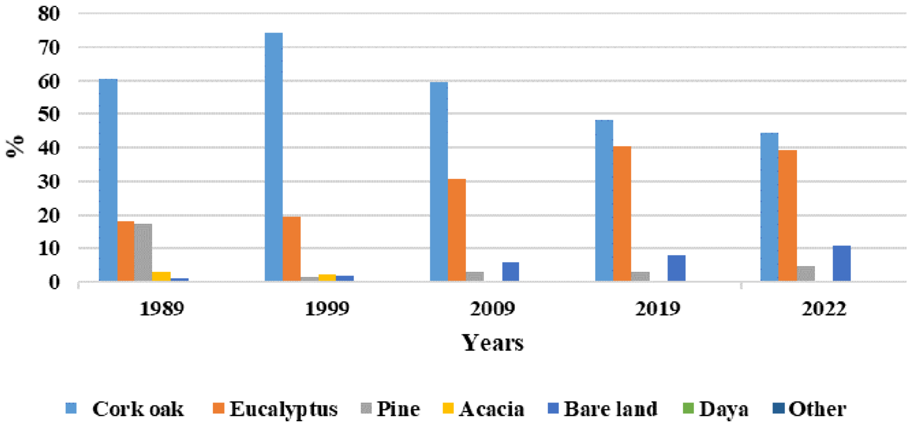

Figure 3. Evolution of the forest cover area of Maâmora between 1989 and 2022 (Ghouldan et al., 2024)

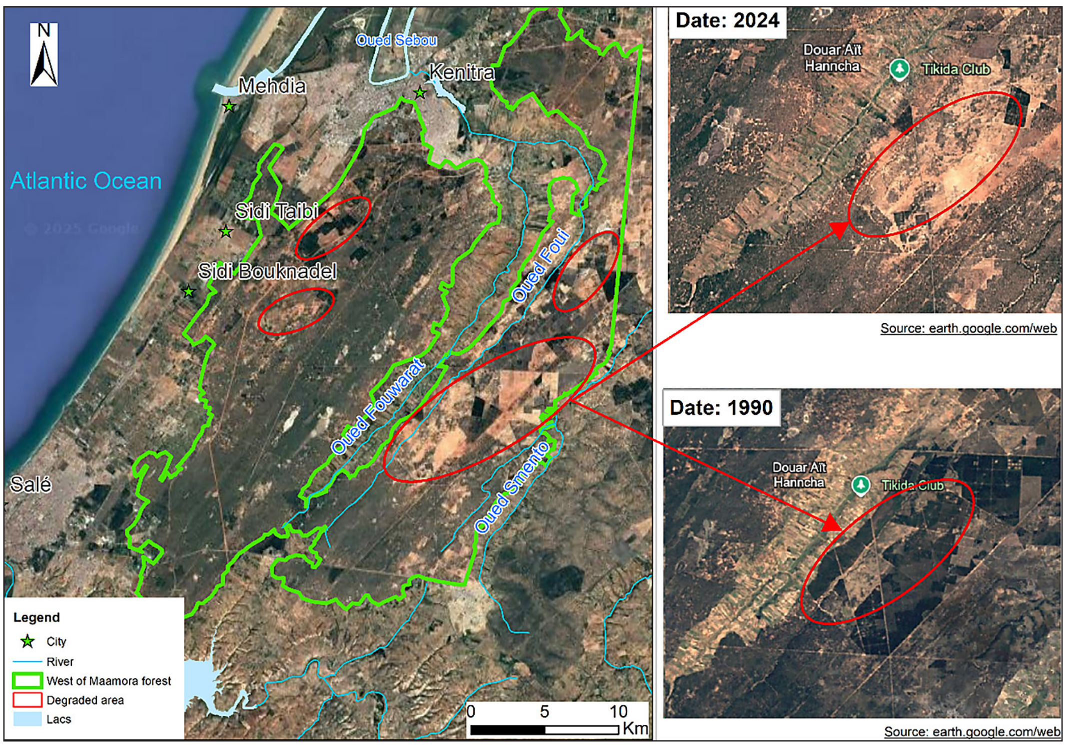

Figure 4. Illustrating and comparing the degradation of the Maâmora forest (Morocco) between 1990 and 2024

a reduction in dense forest areas relative to 1990. Deforestation could be attributed to urban expansion, agricultural activities, logging, climate-related factors. Smaller, isolated patches of forest suggest an increase in human activities and land-use changes. The expansion of urban or agricultural areas likely reflects land conversion for human purposes. Soil degradation and the loss of vegetation can result from heightened erosion and diminished water retention.

To assess demographic evolution, population distribution data from 2014 and 2024 were mapped and analyzed using GIS. The resulting maps illustrate variations in population density across municipalities surrounding the Maâmora forest, enabling a comparative evaluation of urban growth and spatial patterns. The analysis reveals a significant increase in population density from 2014 to 2024, particularly in municipalities adjacent to the Maâmora forest. The population distribution in 2014 (Figure 5) shows high densities concentrated in coastal cities and key inland settlements. By 2024 (Figure 6), significant demographic expansion is observed, with an increase in both the size and number of populated areas. Coastal cities exhibit notable growth, reflecting economic and infrastructural developments that attract migration.

Urban sprawl into previously undeveloped areas is evident in the 2024 map, with municipalities expanding towards the Maâmora forest. This trend suggests increasing pressure on natural

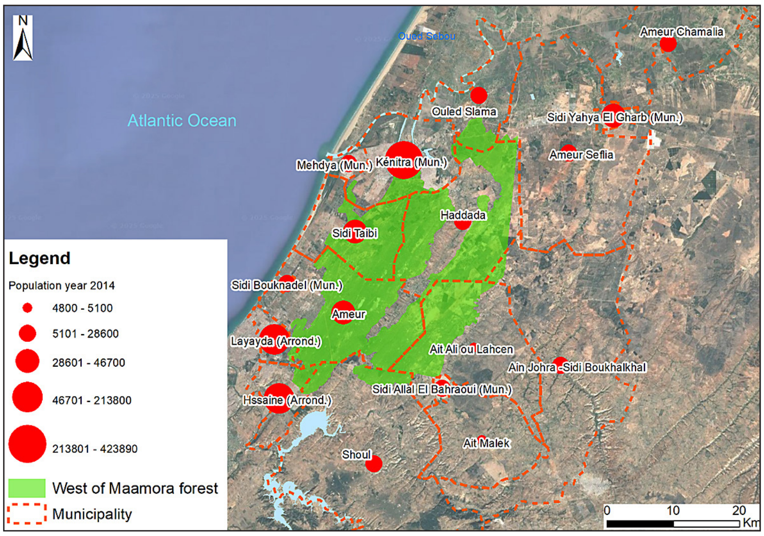

Figure 5. Distribution of the population in 2014 near the western Maâmora forest (Morocco)

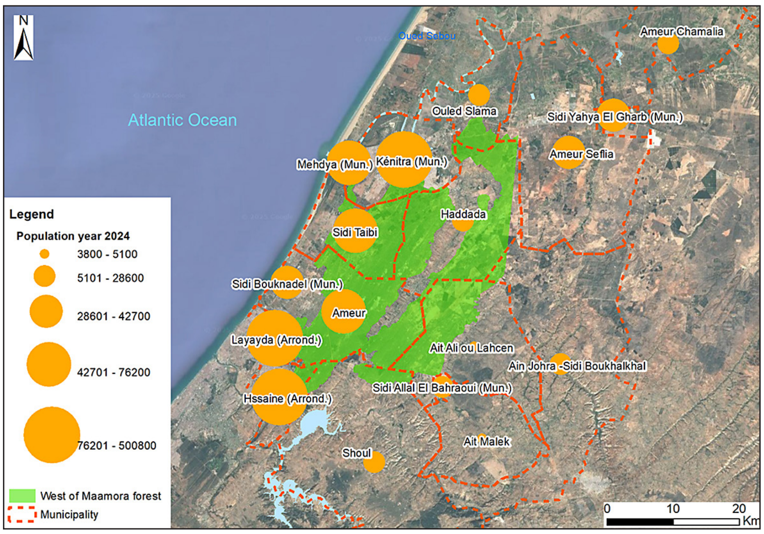

Figure 6. Distribution of the population in 2024 near the western Maâmora forest

resources, as forest lands may be converted to residential, or industrial. Such changes threaten biodiversity and ecosystem services provided by the forest. The increase in population density, as shown in Figure 6, is a contributing factor to the degradation of the Maâmora Forest. Higher population density has led to an increased demand for firewood, construction materials, and grazing land, resulting in the overexploitation of forest resources and illegal tree cutting. Among the affected species is the cork oak, a key component of the Maâmora ecosystem, the decline of which threatens the forest's regenerative capacity. Furthermore, the loss of tree cover exposes the soil to wind and water erosion, causing nutrient depletion and reduced land productivity. This degradation weakens the forest's ability to support biodiversity and sustain essential ecosystem services.

The density of rural localities is closely linked to forest degradation (Figure 7). The map indicates that the areas with higher population density in the western part of the Maâmora forest coincide with the regions of increased forest degradation. The presence of villages and human settlements within the forest contributes to deforestation through logging and fuelwood collection. The degradation of the cork oak ecosystem is particularly severe in densely populated zones, as human pressure reduces regeneration capacity and accelerates land conversion. The green boundary delineating the Maâmora Forest indicates that human settlements are primarily concentrated around its edges, although some inhabitant clusters exist within the forest itself. This pattern may be attributed to the demand for wood and grazing land, which leads to unsustainable resource extraction and further degradation. Cork oak stands are particularly vulnerable to uncontrolled human activity, grazing pressure, and soil degradation. The proximity of major urban centers significantly impacts forest degradation and the distribution of rural localities. Areas closer to cities, such as Kenitra and Sidi Bouknadel, experience greater population pressure, resulting in increased land-use changes and habitat fragmentation. The map suggests that rural density increases as forests degrade, underscoring the need for sustainable land management policies. The degradation of the Maâmora forest, particularly the decline of cork oak populations, is closely tied to rural locality expansion, and urban influence. The highest settlement densities are observed near degraded forest areas and urban centers, while intact forest regions remain sparsely populated.

Sandy soils in the Maâmora Forest, particularly in the western regions, pose a significant threat to ecosystem stability due to their susceptibility to wind erosion and desertification. Figure 8 illustrates the spatial interpolation of sand percentages in Maâmora forest soils at various depths (0–20 cm, 20–40 cm, 40–60 cm, and 60–80 cm). In the depth 0–20 cm, Sand content varies slightly across the region, with lower values (95–96%) observed in the western areas, while central and eastern regions exhibit higher percentages (97–98%). This indicates a predominantly sandy surface texture, with minor variations, likely influenced by local environmental factors or sediment inputs. At a depth of 20–40

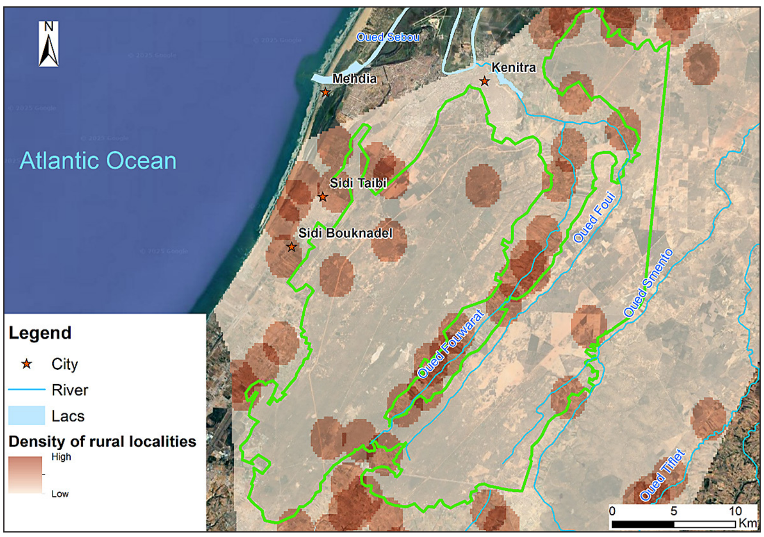

Figure 7. The density of rural localities near the western forest of Maâmora (Morocco)

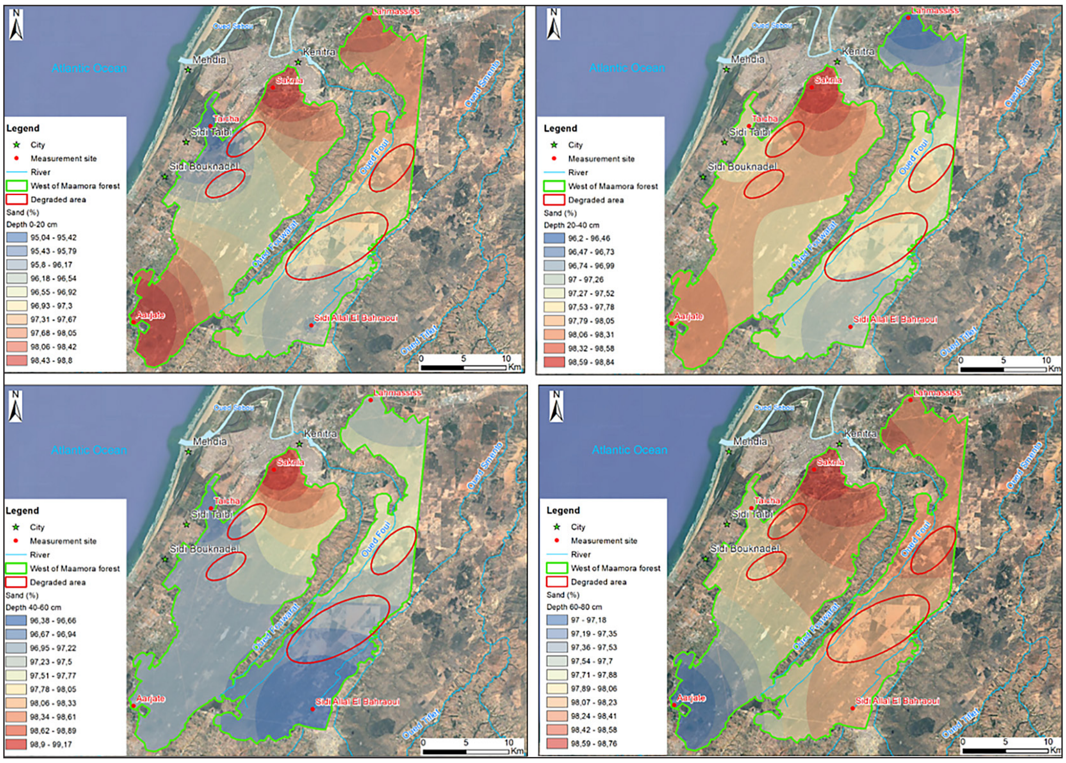

Figure 8. Spatial interpolation of sand percentages in Maâmora forest soils at different depths: 0–20 cm, 20–40 cm, 40–60 cm and 60–80 cm

cm, sand content generally increases compared to the surface. The southeastern areas, particularly around Sidi Allal El Bahraoui, reach maximum values (98–99%), indicating highly sandy soils. The northwest retains a slightly lower proportion but remains largely dominated by sand. At a depth of 40–60 cm, the soils become even sandier, with percentages approaching or exceeding 98% in most areas. A notable uniformity in sandy texture is observed in central and eastern regions, reflecting an increased prevalence of coarse particles at this depth. At a depth of 60–80 cm, the distribution remains highly sandy, with values consistently around 98–99% across most of the region. The southwestern and southeastern zones (notably Arjate and Sidi Allal El Bahraoui) exhibit slightly higher sand content, reinforcing the dominance of sandy soils throughout the profile. On this basis, it can be concluded that the studied soil is homogeneous within the depth range of 0–80 cm (Figure 9).

The degradation of cork oak (*Quercus suber*) forests accelerates this process, as these trees play a crucial role in maintaining soil structure and preventing sand encroachment. The deep and extensive root system of cork oak binds loose soil particles, reducing wind erosion and improving moisture retention, which is essential for sustaining vegetation cover. With continued deforestation and urban expansion, the absence of cork oak stands could lead to severe environmental consequences, including the encroachment of sand dunes toward nearby urban areas, such as Kenitra and Sidi Bouknadel. If the forest disappears, desertification will become a critical issue, threatening agricultural productivity, water resources, and biodiversity. This underscores the urgent need for conservation measures, including afforestation programs and sustainable land-use policies, to preserve the ecological balance of the Maâmora Forest and mitigate the advancing risk of desertification. To promote sustainable reforestation using drip irrigation, targeting the western Maâmora region (95–96% sand content) is suggested, as it offers better soil retention for young cork oak saplings, strengthening conservation policies to prevent further urban encroachment and overgrazing, integrating GIS-based suitability analysis to map potential reforestation zones more accurately. By applying drip irrigation strategically, reforestation efforts can enhance soil stability, restore cork oak populations, and combat desertification, ensuring long-term sustainability in the Maâmora forest.

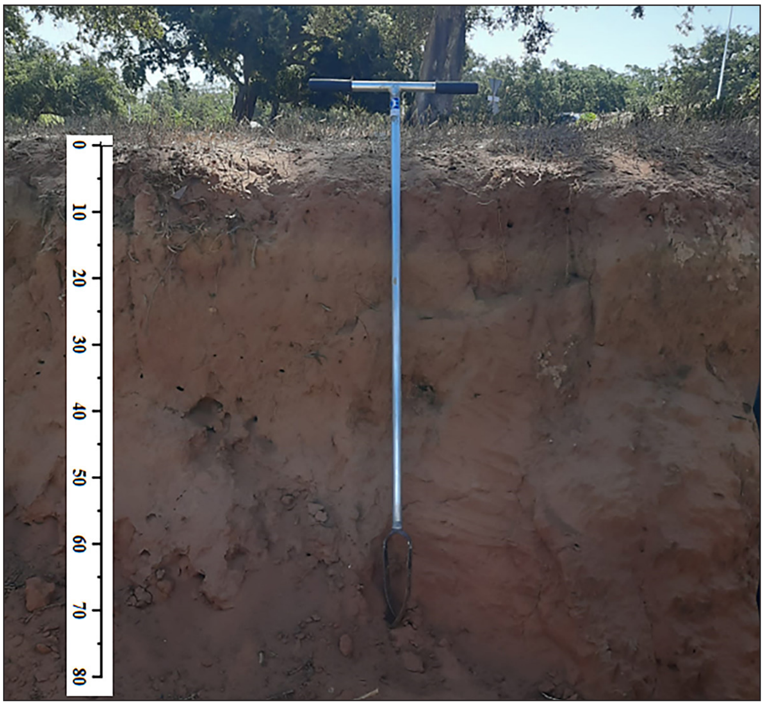

Figure 9. The sandy soil depth (0–80 cm) in the Maâmora forest (Morocco)

CONCLUSIONS

The findings of this study highlight the critical impact of demographic expansion on the degradation of the Maâmora forest, particularly in its western region. Using GIS-based spatial analysis, a clear correlation between increasing population density and forest cover loss was established. The results reveal that urban sprawl and unsustainable land use practices, such as overgrazing and illegal logging, have significantly contributed to the decline of cork oak (*Quercus suber*) populations. The reduction in forest cover from 60.71% in 1989 to 44.42% in 2022 underscores the urgency of implementing effective conservation strategies. Furthermore, the study demonstrated that the sandy soils of the Maâmora forest, particularly in its western regions, exacerbate environmental vulnerabilities, such as soil erosion and desertification. Without intervention, the continued loss of vegetation cover may lead to irreversible land degradation, threatening biodiversity, ecosystem stability, and local livelihoods. To mitigate further forest degradation, this research emphasized the necessity of sustainable land management strategies, including targeted afforestation efforts, improved land-use planning, and the integration of GIS-based decision-making tools for conservation. Reforestation programs using drip irrigation, particularly in the areas with better soil retention capacity, could enhance the resilience of cork oak ecosystems. Strengthening conservation policies to regulate urban expansion and prevent overgrazing is also essential.

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