

Original Research Paper

Using GIS and AHP techniques to evaluate the forest site quality in the Ouled Yagoub National Forest (North-East, Algeria)

Chaouki CHAFAI ^{*1}, Abdallah BENTOUATI ¹, Khellaf RABHI ², Tahar SGHAIER ³, Abdelkrim ARAR ⁴, Abdelkrim SI BACHIR ⁴,

¹ Department of Agronomic Sciences, Institute of Veterinary and Agronomic Sciences, University of Batna 1, Batna, Algeria;

² Department of Agronomic Sciences, Faculty of Biological and Agronomic Sciences, University of Tizi Ouzou, Algeria;

³ Institut National de Recherches en Génie Rural, Eaux et Forêts, Ariana, Tunisia;

⁴ Department of Ecology and Environment, Faculty of Naturel and Life Sciences, University of Batna 2, Batna, Algeria.

***Corresponding Author:** Chaouki Chafai, Institute of Veterinary and Agronomic Sciences, University of Batna 1, Batna, Algeria; **Email:** chaouki.chafai@univ-batna.dz

Article history: Received: 30 January 2023; Revised: June 11th 2023; Accepted: June 17th 2023

Abstract

For better forest management, it is very important to evaluate rationally the forest site quality. In this context, the study was carried out in the Ouled Yagoub National Park (North-East Algeria), a semi-arid natural evergreen coniferous and oak forest protected area. A set of 8 indicators were selected from two dimensions (topography and soil conditions), to formulate a forest site quality evaluation index system based on the technique of the Analytical Hierarchy Process (AHP). The results showed that the dominant quality of forest sites was medium (30%), with some variability between places. The range of forest site quality index (FSQI) in the study area ranged between 1.640 and 3.148, with a mean value of 2.555 ± 0.257 SD. The forest site quality grades were mainly second and third grade. The higher-grade forest site quality was mainly distributed in the northern high mountain regions. The lower-grade forest site quality was mainly distributed in the southern low-mountain regions. Our results highlight the spatial attributes of studied forest sites and can provide a scientific basis and methodological reference for logic and reasonable formulation of a forest management plan.

Keywords: GIS-AHP method, forest, site quality, topography, soil, management.

المخلص

من أجل إدارة أفضل للغابات، من المهم جدًا إجراء تقييم عقلاني لجودة موقع الغابة. في هذا السياق، أجريت هذه الدراسة في غابة الدولة لأولاد يعقوب (شمال شرق الجزائر)، وهي منطقة محمية طبيعية شبه جافة ذات أشجار صنوبر دائمة الخضرة وغابات البلوط الاخضر. تم اختيار مجموعة من 8 مؤشرات من عاملين (الطوبوغرافيا وظروف التربة)، لصياغة نظام مؤشر تقييم جودة موقع الغابة بناءً على تقنية عملية التسلسل الهرمي التحليلي (AHP). أظهرت النتائج أن الجودة السائدة لمواقع الغابات كانت متوسطة (30%)، مع بعض التباين بين الأماكن. تراوح نطاق مؤشر جودة موقع الغابات (FSQI) في منطقة الدراسة بين 1.640 و 3.148، بمتوسط قيمة 2.555 ± 0.257 . كانت درجات جودة موقع الغابة في الدرجة الثانية والثالثة بشكل أساسي. تم توزيع جودة مواقع الغابات عالية الجودة بشكل أساسي في المناطق الجبلية العالية الشمالية. تم توزيع جودة مواقع الغابات ذات الدرجة المنخفضة بشكل أساسي في المناطق الجنوبية للجبال المنخفضة. تسلط نتائجنا الضوء على السمات المكانية لمواقع الغابات المدروسة ويمكن أن توفر أساساً علمياً ومرجعاً منهجياً للصياغة المعقولة لخطط إدارة الغابات وتثبيتها.

Introduction

Currently, one of the main reasons for the decline and erosion of biodiversity is the degradation of forest ecosystems. The equilibrium of these ecosystems is threatened by the rapid expansion of natural plant landscapes in bordering arid areas. In 2017, the United Nations General Assembly adopted the United Nations Strategic Plan for Forests (2017–2030), which proposes a global action plan for each country, in order to manage various forest land resources sustainably and improve forest land quality (U.N.G.A., 2017).

In the North African region, Algeria's semi-arid forests are an essential portion, contributing as a barrier to stopping the sand movement, and the extension of the desertification phenomenon (Benmessaoud 2009). Algeria is a huge territory with a diversified and difficult topography. The

large latitudinal difference between the north and south boundaries has resulted in a rich and diverse climate scales and physical geography, fostering forest resources with a diverse range of biological species and vegetation types (D.G.F. 2018). Algeria is a country with habited forest area and one of the countries with the highest danger of forest fires due to climatic conditions of drought. Indeed, forest fires accounted for 994 555 ha between 2008 and 2021 corresponding to 24% of the total forest area in Algeria, primarily in the western and central forest areas (D.G.F. 2018; E.F.F.I.S. 2022).

In the northeast, the Ouled Yagoub national forest is one of the most important forests in North Africa and has recently been designated as a national park. The forestland of this vast region represents a significant ecological function reserve, that contains the Atlas Cedar (*Cedrus atlantica* (Endl.) Manetti ex Carrière 1855) species endemic to North Africa; the Aleppo Pine (*Pinus halepensis* Miller 1768); the Evergreen Oak (*Quercus ilex* Linné 1753); the Prickly Juniper (*Juniperus oxycedrus* Linné 1753); and the Wild Ash (*Fraxinus dimorpha* Cosson, Durieu 1855) (B.N.E.D.E.R. 2008). The forest formations contain dense and clear cedar formations, mixed formations of cedar and oak, Aleppo pine forests, scrubland oak, and Prickly juniper, scrubland of oak and wild ash, lawns, and pasture of mountains (Beghami et al. 2012).

The Ouled Yagoub forest shelters a rich plant diversity, and also represents a habitat of choice for an original and diversified fauna but undergoes multiple pressures, both natural and anthropogenic (Schoenenberger 1970a-1970b; Abdessemed, 1981-1984- 1985; Kadik 1987; Ramade 1997; Beghami et al. 2007; Benmesaoud et al. 2009). In addition to the traditional causes of degradation, the recurrent forest fires in the pine forest and dieback in the cedar forest would constitute the main causes of the current degradation of the Ouled Yagoub forest (Abdessemed 1984-1985; Bentouati & Bariteau 2006; Bentouati 2008; Meddour-Sahar, Derridj 2012; Rahmani & Benmessaoud 2019). The magnitude of this situation, which cause not only significant environmental degradation but also societal and economic losses (Bedia et al. 2014), has been little studied, particularly using modern techniques and tools (Geographic Information System analysis with QGIS 2.8 and remote sensing).

In this last context, the status and condition of the land are reflected in forest site quality (Chen et al 1998). The kind of forestland and its combined characteristics determine forest site quality, which is a composite of numerous qualities (Yu et al. 2009). The forest site quality refers to its inherent ability to produce biomass. It is the composite expression of a variety of physical and chemical attributes of a forested area (Chung 1978; Zhang et al. 2017).

The widespread use of computing and "3S" technology (Global Positioning Systems (GPS), Remote Sensing (RS), and Geographic Information Systems (GIS) have led to the development of more quality of forests, ranging from simple qualitative descriptions to quantitative analysis (Wang et al. 2021). These tools are frequently combined with statistical approaches for the assessment of the quality of forest sites, among others, The weight of entropy (EW), fuzzy evaluation, analytical hierarchy process (AHP), and gray correlation analysis (Wang et al. 2021) are now the most widely used approaches. EW objectively distributes weights according to the physical properties of data (Ye 2010). When dealing with high-dimensional data, fuzzy evaluation, and gray correlation analysis are less stable (Xia et al. 2016; Wang et al. 2011). Lyu et al (2015), used the model of an integrated index to assess forest land quality by selecting topography and soil fertility variables using Delphi.

In calculating index weights, the AHP is more subjective and less complex (Kumar 2006). Also, this method aims to help decision-making in order to bring out the best alternative among all the possibilities in the presence of multiple priorities (Chandio et al 2013). Thus, the impact of land use change on the physicochemical quality of forest soils was studied by Bonilla-Bedoya et al. (2017). The AHP multi-criteria analysis method was used by researchers in Algeria and North Africa, for choosing the best decisions to be made in the assessment and management of environmental situations such as the monitoring of drought and desertification (Mihi et al. 2022; Boultif &

Benmessaoud 2017), human impact on the ecosystem (Bouzekri & Benmessaoud 2016), and development of a land suitability model for cereals (Koull et al. 2022).

This study aims to evaluate the quality of forests and examine the grades distribution of sites quality in the Ouled Yagoub national forest using a new approach (GIS-AHP) which is applied, to our knowledge, for the first time in the arid North African forests, which are characterized by binding conditions. To this end, we construct a forest site quality comprehensive evaluation indicator system related to topography and edaphic conditions, using 8 environmental indicators, including elevation, slope, aspects, soil organic matter, soil layer thickness, soil texture, soil pH and land degradation. We used the AHP model to build an assessment model to evaluate forest site quality. The grades of forest site quality ensuing can be used by forest services to elaborate the management plans for these forestlands.

Materials and Methods

Presentation of the study area

The Ouled Yagoub National Forest area is part of the Aures Forest massif; it is located in northern Algeria, specifically in the province of Khenchela. The spatial arrangement of this forest reveals a very distinct topography, exhibiting a mountainous aspect characterized by a series of narrow and discontinuous ridges. It is part of a rectangle 13.5 km long and 6.5 km broad, 17 km away from the Chelia Cedar Forest, and is aligned in the same SW-NE direction (Fig. 1).

The study area has been classified into three distinct bioclimatic stages, semi-arid with cool winters at low elevations, and humid and sub-humid with cold winters at high and mid-elevations. The average monthly rainfall for this area starts with 11 mm in the driest month (August) up to 57 mm in the wettest month (March). The seasonal rainfall pattern is "Spring. Winter. Autumn. Summer" type. (B.N.E.D.E.R. 2010).

According to B.N.E.D.E.R. (2008), the national forest of Ouled Yacoub is composed of 81% forest proper and 19% scrub and wooded scrub. The forest itself is divided into ancient forests of Atlas cedars and holm oaks; old dense forests of cedars with holm oaks and wild ash trees, forests of evergreen holm oaks, dense and open high forests of Aleppo pines, young open high forests of Aleppo pines and holm oaks and burnt forests of Aleppo pines.

The choice of this area was mainly based on the continuity of previous forest management studies, which is an old management study that included compartments, some of them for the production of wood and others for protection. In addition, we note the specific and diversified floristic composition dominated by the cedar grove and the diversified topographic characteristics of the land.

Data collection and Processing

Various types of data were used in this work, namely: data related to topography and edaphic data.

1- A spatial division of the forest as compartments were obtained from the forest department services (BNEF 1984). The study area is divided into 16 compartments, which constitute a unit of forest stand and coherent management, considered in this work as the study unit on which the statistics were made. Each compartment is subdivided into 30 m resolution pixels on which measurements and calculations were made. In addition, the administrative division map was acquired from the National Institute of Mapping and Remote Sensing (I.N.C.T. Algiers) in 2014.

2- The data related to the topography were obtained from the exploitation of DTMs, namely: the slope (%), the exposure, and the elevation (m), The DTM with a resolution of 30 m was obtained from the ALOS Global Digital Surface Model database "ALOS World 3D – 30 m (AW3D30)", whose data is hosted in the site "https://www.eorc.jaxa.jp/ALOS/en/dataset/aw3d30/aw3d30_e.htm" (ALOS 2021)

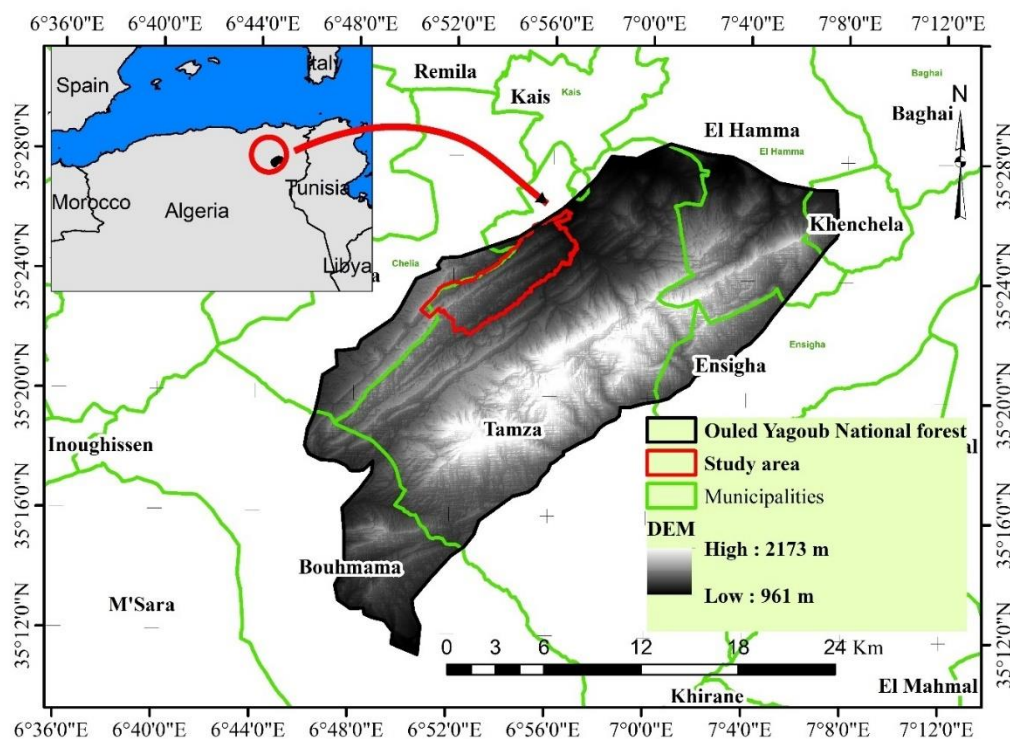


Figure 1. Location of the study area inside the Khenchela Province (Algeria) with a virtual elevation map (D.E.M.).

3- Five edaphic factors were selected to run the model, namely: soil depth (m), soil texture (%), soil carbon concentration g/kg, soil PH and soil degradation. Soil data were obtained from the African database “field-level soil map for Africa” whose link is “<https://www.isda-africa.com/isdasoil/>” (ISDA 2021).

We had not taken into account climatic factors, which are considered globally homogeneous in the 16 compartments.

The data obtained went through a preparation phase and finalization using the free GIS software Quantum GIS 2.8 in order to classify, standardize and homogenize them in terms of file format, resolution and alignment of pixels and their spatial extent.

To reduce the impact of the evaluation indicator scale, the indicators were assessed and scores were provided based on their impact on the quality of the forest area. The indicator grade is used to determine the indicator score that is proposed by Wang et al. (2021) and modified in this study for the study area’s data ranges of each indicator. The higher score is, the better the forest site quality (Table 1) (Fig. 2).

Indicator evaluation system

To elaborate an evaluation system of the indicators of the forest quality sites, eight factors were used belonging to the two groups of factors chosen, namely, topographic and edaphic. Therefore, eight layers of the previously explained factors were used as criteria controlling the quality of forest sites using the AHP method. It is a multi-criteria process that requires going through several successive stages according to Saaty (1980), namely:

Table 1. The grading standards for forest site quality evaluation indicators and their classes.

Criteria Layer	Indicator Layer	Code	Classes				
			5	4	3	2	1
Topography	Elevation/m	C6	<200	[200-800[	[800-1400[	[1400-2000[	> 2000
	Slope (%)	C7	<5	[5-15[	[15-25[	[25-35[	≥ 35
	Aspects	C8	North	East	West		South
Soil conditions (Predicted mean at 0-20 cm depth)	Soil depth/cm	C1	≥ 80		[40-80[		< 40
	Soil texture	C2	Loamy		Loamy sandy, sandy loam		Clay, sandy clay
	Soil organic matter/(g/kg)	C3	≥40	[30-40[	[20-30[	[10-20[	< 10
	Soil pH	C4	[6.0 -7.9[	[5.5 – 6.0[or [7.9 - 8.5[	[5.0 to 5.5[or [8.5 to 9.0[	[4.5 - 5.0[	< 4.5 or ≥ 9.0
	Land degradation	C5	None	Light	Moderate	Intense	Hight intensity

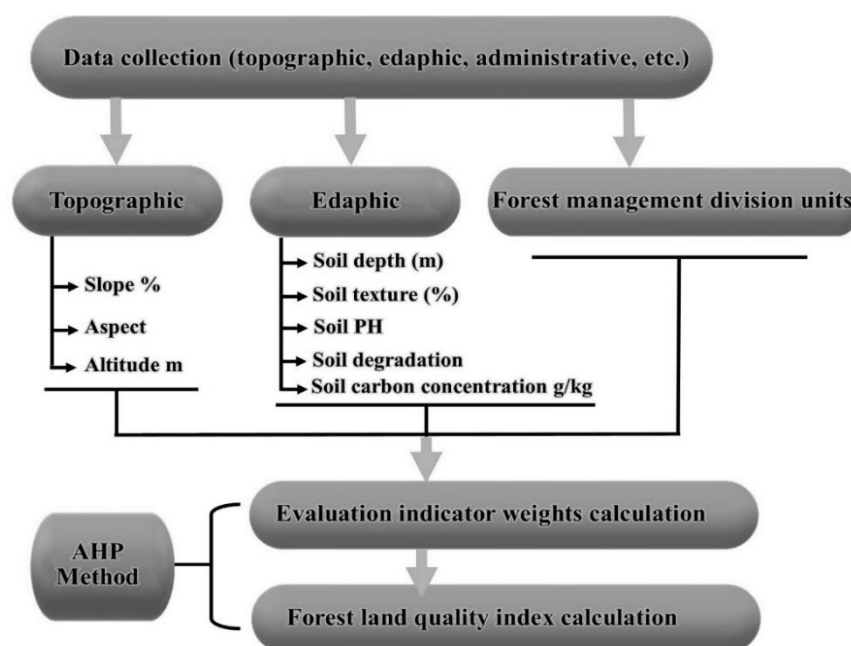


Figure 2. The process of evaluation index system construction. (AHP: Analytical Hierarchy Process)

After determining the problem to be structured into a hierarchy, we establish a pairwise comparison matrix, which is a criteria comparison matrix in pairs that consists of structuring into a decision hierarchy. The latter is established through the construction of a model to identify the criteria and the relevant alternatives (DE FSM Russo et al 2015). This means that the comparison is between each factor of a higher level, which is to be compared to a factor of a lower level relative to it, through a scale to show "how many times an element is more important or dominant than another element with respect to the criterion or property against which they are compared?" (Saaty 2008). This scale varies from 1 (the two elements are of equal importance) to 9 (means more important than). The preferred criterion cell in the array (eg, comparing C1 with C5) takes the actual value, and the same backward comparison in the other cell (eg, comparing C5 with C1) takes the reverse value (1/value) (Table 2). The strength of this method is its ability to determine a relative weight to all the factors of the problem to be studied and to prioritize their relative relevance (DE FSM Russo et al 2015).

Table 2. Matrix of weighting pairwise criteria using the AHP model for evaluating the forest site quality. (C1 to C8: criteria or ecological parameters)

Criterion Code	C1	C2	C3	C4	C5	C6	C7	C8
C1	1.00	0.66	0.33	0.50	2.00	1.00	2.00	0.50
C2	1.50	1.00	0.50	0.75	3.00	1.50	3.00	0.75
C3	3.00	2.00	1.00	1.50	6.00	3.00	6.00	1.50
C4	2.00	1.33	0.66	1.00	4.00	2.00	4.00	1.00
C5	0.50	0.33	0.16	0.25	1.00	0.50	1.00	0.25
C6	1.00	0.66	0.33	0.50	2.00	1.00	2.00	0.50
C7	0.50	0.33	0.16	0.25	1.00	0.50	1.00	0.25
C8	2.00	1.33	0.66	1.00	4.00	2.00	4.00	1.00

To validate the AHP results, the coherence rate (CR) is determined using the formula: $CR = CI/RI$ (Where: CR – refers to Consistency Ratio; CI – indicates Consistency Index; RI – refers to Random Consistency Index).

The consistency index (CI) is assessed using the formula: $CI = (\lambda_{\max} - n)/(n-1)$

Where: $\lambda_{\max}$ – refers to the maximum eigenvalue of the pairwise comparison matrix; n – refers to the number of compared elements.

The dimension of the matrix determines the value of RI (Golden, Wang 1990), in this case with 8 dimensions, RI is approximately 1.3952. The $\lambda_{\max}$ is equal to 8.019. Then, the coherence index (CI) is equal to 0.003. Note that a consistency ratio of less than 0.10 indicates that the comparison results are acceptable. In this case, the consistency ratio (CR) is 0.002, which indicates the acceptability of the comparison results.

Calculating the eigenvector of the comparison matrix in pairs is required to estimate the weighting coefficient. The geometric mean of these eigenvectors is calculated by averaging each criterion to determine their values. The weighting coefficient for each criterion is calculated by dividing each eigenvector by its sum after normalizing it. Assume that the sum of the weighting coefficients equals 1 (Table 3).

Table 3. Weight values for each criterion used for evaluating forest quality.

Indicator Layer	Code	Weight
Soil depth (cm)	C1	0.087
Soil texture	C2	0.123
Soil organic matter (g/kg)	C3	0.273
Soil pH	C4	0.172
Land degradation	C5	0.043
Elevation (m)	C6	0.087
Slope (%)	C7	0.043
Aspects	C8	0.172

Aggregation criteria

The selected criteria layers are then combined using the weighted sum approach based on their weights, which involves multiplying each standardized factor layer by its respective weight coefficient (Koull et al 2022), allowing us to map the forest site quality using the raster calculator tool in QGIS 2.8 with the syntax:

“("C1@1" * 0.087) + ("C2@1" * 0.123) + ("C3@1" * 0.273) + ("C4@1" * 0.172) + ("C5@1" * 0.043) + ("C6@1" * 0.087) + ("C7@1" * 0.043) + ("C8@1" * 0.172)”

The FSQI raster map is then overlaid with the vector map of the compartments, and then the individual pixel numeric values along with the compartment numbers are exported as a textual data file (.csv). Using the tool (XLstat 2016) these last data were subjected to a one-way ANOVA to study the

differences between the compartments in terms of FSQI values. An ad-hoc test (Newman-Keuls) of compartments based on FSQI values at the significance level of 0.05 was realized to identify homogeneous groups of compartments.

Results

Variation of index quality according to the spatial distribution

The forest site quality index (FSQI) ranged from 1.640 to 3.148, with an average index of 2.555 ± 0.257 , indicating that overall forest site quality is moderate, according to a scale from 1 to 5. The FSQI is higher in the central and western sections of the studied forest and lower in the northeastern and southern parts (Fig. 3).

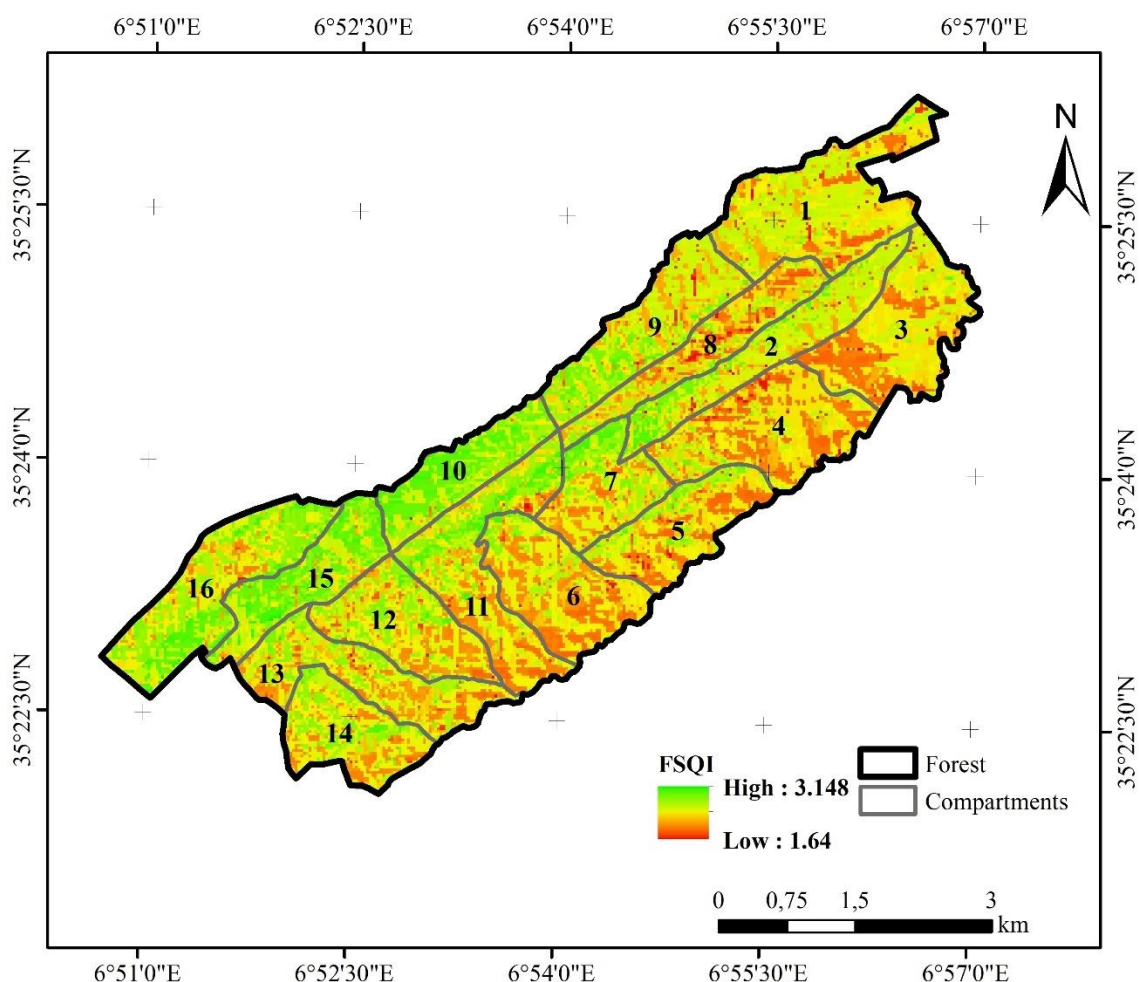


Figure 3. Forest site quality index (FSQI) with spatial distribution In Ouled Yagoub National Forest. (1 to 16 : forest compartments code).

There is some heterogeneity in the mean values of FSQI in different compartments, according to the statistical parameters of FSQI calculated for the studied compartments. According to the coefficient of variation, the FSQI in compartment 12 changed the most, while the FSQI in compartment 10 fluctuated the least (Table 4).

The result of ANOVA analysis shows that the difference in FSQI between compartments is highly significant. The P-value is <0.0001 at the significance level of 0.05, according to the analysis of variance (Table 5).

Table 4. Values of forest site quality index (FSQI) of forest compartments in Ouled Yagoub National Forest with statistical analysis.

Compartments	Area (ha)	minimum	maximum	Mean± SD
1	244	1.80	3.03	2.51± 0.20
2	152	1.80	3.06	2.65± 0.21
3	195	1.64	3.03	2.43± 0.20
4	204	1.84	3.06	2.40± 0.21
5	141	1.80	3.06	2.47± 0.25
6	170	1.86	3.06	2.43± 0.23
7	119	1.93	3.06	2.59± 0.26
8	129	1.86	3.06	2.44± 0.24
9	174	1.80	3.06	2.61± 0.23
10	122	1.91	3.06	2.83± 0.19
11	201	1.86	3.06	2.56± 0.27
12	149	1.90	3.15	2.54± 0.24
13	165	1.73	3.15	2.52± 0.23
14	134	1.93	3.06	2.56± 0.23
15	132	1.97	3.15	2.79± 0.22
16	205	1.93	3.15	2.70± 0.23

Table 5. Results of the ANOVA applied to testing the variation between compartments of forest site quality index (FSQI)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean of Squares	F-value	P
Model	15	402.061	26.804	512.045	< 0.0001
Residual	29232	1530.210	0.052		
Total	29247	1932.271			

Table 6. Ad-hoc test of forest compartments based on the values of forest site quality index FSQI at the significance level of 0.05 (test of Newman-Keuls)

Compartments	Estimated means	Standard Error	Lower limit (95%)	Upper limit (95%)	Groups
4	2.405	0.005	2.395	2.414	A
3	2.428	0.005	2.418	2.438	B
6	2.429	0.005	2.419	2.439	B
8	2.454	0.006	2.442	2.465	C
5	2.456	0.006	2.445	2.467	C
1	2.515	0.004	2.506	2.524	D
13	2.518	0.005	2.508	2.529	D
12	2.538	0.006	2.527	2.549	E
14	2.559	0.006	2.548	2.571	F
11	2.563	0.005	2.553	2.572	F
7	2.588	0.006	2.575	2.600	G
9	2.612	0.005	2.602	2.622	H
2	2.639	0.006	2.629	2.650	I
16	2.703	0.005	2.694	2.712	J
15	2.787	0.006	2.776	2.799	K
10	2.827	0.006	2.814	2.839	L

Spatial distribution of grades evaluation

The FSQI mean values in compartments 2, 9, 10, 15, and 16 are relatively high (Groups I, J, K, and L), but the FSQI mean values in compartments 3, 4, 5, 6, and 8 are comparatively low (groups A, B and C). The FSQI mean values are moderate in compartments 1, 7, 11, 12, 13, and 14 (groups D, E, F and G) (Table 6).

In the study area, the forest site quality is divided into five grades, according to the natural breakpoint method: first to fifth grade, with areas of 446.42, 721.21, 786.81, 339.31 and 337.33 ha, respectively. The biggest area of third-grade forest site quality is 29.9%, while the smallest area of the fifth grade is 12.8%. The distribution of the forest site quality grades showed that the area of the first-grade forest site quality is weak (17%), the majority of them being concentrated on the northern slopes of the forest. The area of the second-grade forest site quality was more important (27%), with most of them located near first-grade forest site quality at the bottom of the northern slopes. The third-grade forest site quality, mainly distributed on the South and East exposures, adjacent to the second-grade forest site quality, occupied a larger area than the other forest site quality grades (30%). The fourth-grade forest site quality, mainly on south-eastern exposures, adjacent to the third- and second-grade forest sites, occupied a smaller area than the other forest site quality grades. The fifth-grade forest sites quality had the smallest area and were mainly near fourth-grade forest sites in the bottoms of the South-western Mountains (Fig. 4).

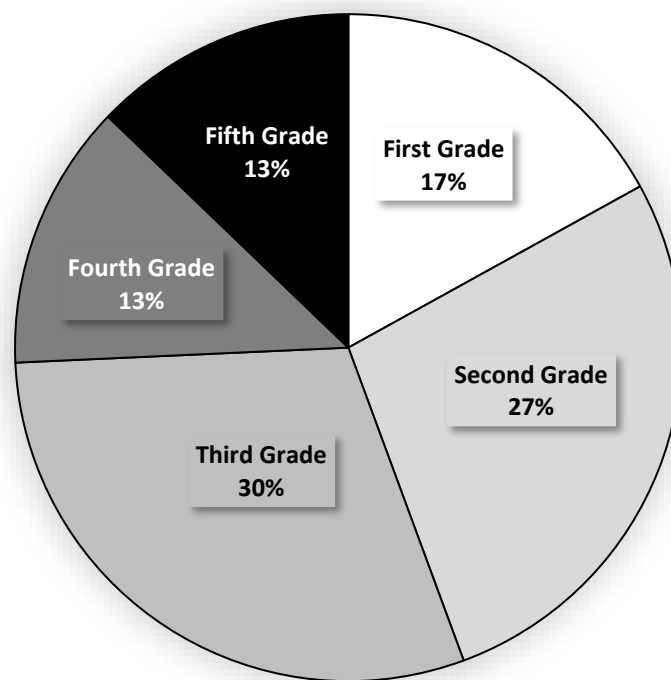


Figure 4. Percentages of areas according to forest site quality index grades in Ouled Yagoub National Forest.

As a result, there is some heterogeneity in the quality of forest sites at the average scale of the compartments (Table 7). With an area of 18.15%, 14.61%, 14.33%, and 10.58%, respectively, and a total area of 64.6%, high-quality forest sites have primarily been located at the level of compartments 16, 10, 15, and 11. Compartments 1, 2 and 9 had the most second-grade forest site quality, accounting for 15.72%, 11.08%, and 10.81% of the overall area, for a total area of 37.61%. Compartments 4, 3 and 6 had the most third-grade forest site quality, accounting for 12.29%, 10.82%, and 8.77%, respectively. Compartments 6, 13, 1 and 12 had the most fourth-grade forest site, accounting for 10.95%, 10.73%, 10.20%, and 10.18% of the total land area, respectively. Compartments 4, 3, 5, and 6 had the most fifth-grade forest site quality, accounting for 17.95%, 16.19%, 11.49%, and 10.35%, respectively (Table 7).

Table 7. Area and areas percentages of forest compartments in Ouled Yagoub national forest according to the forest site quality grades.

Compartments	Area (ha)	First Grade		Second Grade		Third Grade		Fourth Grade		Fifth Grade	
		Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
1	244	4	0.85	113	15.72	65	8.25	29	8.53	33	9.73
2	152	27	6.11	80	11.08	20	2.59	19	5.57	5	1.63
3	195	1	0.12	43	5.98	85	10.82	12	3.50	55	16.19
4	204	5	1.17	24	3.33	97	12.29	18	5.19	61	17.95
5	141	8	1.83	30	4.09	54	6.83	10	2.94	39	11.49
6	170	9	1.95	20	2.82	69	8.77	37	10.95	35	10.35
7	119	26	5.92	28	3.88	36	4.54	19	5.49	10	2.99
8	129	7	1.61	29	4.06	45	5.75	20	5.75	27	8.13
9	174	31	6.97	78	10.81	30	3.75	29	8.51	7	2.11
10	122	65	14.61	42	5.79	11	1.42	3	0.93	1	0.19
11	201	47	10.58	36	5.05	61	7.69	35	10.20	23	6.69
12	149	26	5.88	33	4.52	45	5.69	35	10.18	10	3.04
13	165	21	4.67	39	5.45	52	6.64	36	10.73	15	4.48
14	134	23	5.24	30	4.19	48	6.11	19	5.67	11	3.25
15	132	64	14.33	44	6.09	17	2.11	6	1.80	1	0.43
16	205	81	18.15	51	7.14	53	6.74	14	4.06	5	1.36

The overall quality of the forest sites is higher in compartments 10, 15, and 16. The forest sites on compartments 4, 8, 6, 3 and 5 were mostly of poor quality (Fig. 5).

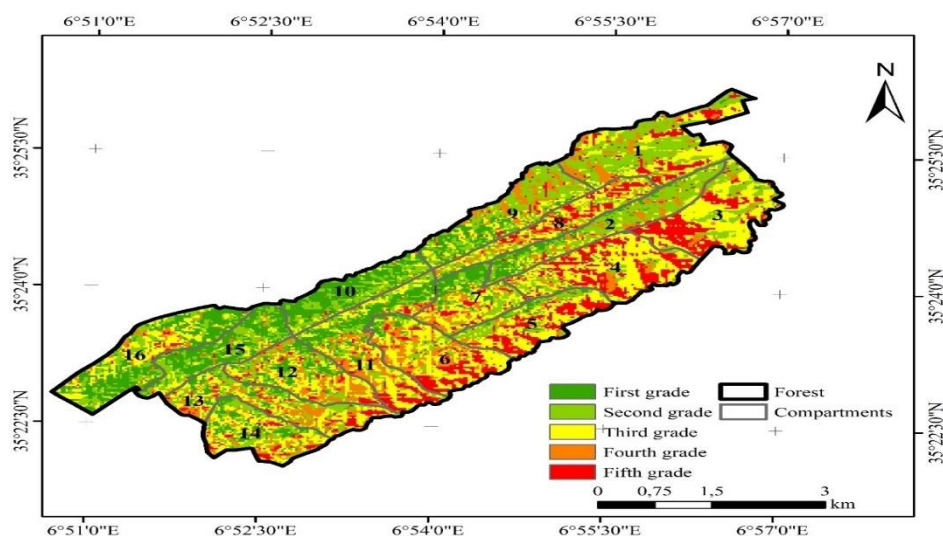


Figure 5. Spatial distribution of forest site quality grades in Ouled Yagoub National Forest.

Discussion

The AHP model was used in this work to investigate novel techniques for evaluating forest site quality never been studied before in binding ecological conditions, namely the semi-arid North African forests.

When evaluating the forest site quality in Ouled Yagoub national forest by the AHP model, we combined the characteristics of the study area represented by eight ecological indicators: topography (elevation, slope, aspect) and soil parameters (depth, texture, Ph, organic matter, and land degradation). The developed model has shown 5 grades of forest site quality:

- (1) For the first-grade areas of the FSQI, the ecological conditions of the forest sites are the most favorable. The topography is slightly rugged and soil conditions are favorable. It had a sandy-clay-loam texture, a deep layer, a high concentration of organic matter, and therefore nutrients in the soil. These forest stations with the best quality are also favored by a cooler climate through their high altitude. As a result, the excellent ecological conditions of the area have ensured the stability and high quality of the forest sites.
- (2) About the second-grade areas of FSQI, the topography has altered the quality of these forest sites to some extent (low elevations). The ecological conditions were also better, with a favorable climate on more watered northern slopes, a short slope, a sandy-clay-loam soil type, a soil layer thickness very thick, a soil organic matter content of medium to high, and a neutral pH.
- (3) In the areas with the third-grade FSQI, the slope is average, the altitude is often average and the soil quality is low. Due to the location of these places, the thickness of the soil layer is thinner, the rate of soil organic matter is lower, soil degradation is more severe, and grazing is more intense in these places. As a result, the quality of forest sites in these areas is moderate and topography is the main limiting factor.
- (4) At the fourth-grade areas of FSQI, the slope is very low and the elevation is often low to moderate. The total organic matter of the soil is low, soil degradation is more severe (high stone content) and grazing is more intense in these areas. As a result, the quality of such forest sites is low and topographic position and low soil quality were the main limiting factors.
- (5) The areas of the fifth-grade FSQI are at a low altitude, with low slopes, low vegetation cover, and therefore significant soil erosion. Topography and soil were the main factors limiting the quality of forest sites in these places.

On a large regional scale, the zones of the high mountain had the best forestland quality, followed by zones of medium mountain, zones of a medium and low mountain, and zones of a low mountain. It is demonstrated that the quality of forest sites is directly related to the topography, which contradicted the spatial model of forest site quality.

Furthermore, at the compartment's mesoscale, altitude and exposure, which reflect essential topographic characteristics, have significant effects on the climate and the physical and chemical soil qualities. The impact of elevation on precipitation, effective soil nutrients, and soil pH is significant. As the altitude rises, precipitation rises, the vegetation becomes denser, soil nutrients increase, and soil pH increases, this has a greater impact on the growth of forest trees and improves the quality of forest sites (Merabtene et al. 2021). The slope has a significant impact on the thickness of the soil, the amount of water in the soil, nutrient conditions, as well as tree growth (Lyu et al. 2015). The higher the quality of the forest area, the more beneficial the growth of forest trees on a smaller slope.

The Ouled Yagoub forests are located in the north-south climate transition zone, it is a climate change hotspot. The frequency of droughts and floods in this region has grown since the twentieth century (Kherchouche et al. 2012). The primary locations of excessive temperature in the Ouled Yagoub pine forest in the last years, according to NASA-PCDM (2021), were located in the south and west, however, the extreme precipitation indicators in the vast Aures region discovered that excessive precipitation is concentrated in the Northern aspects and high elevations. The overall quality of forestland in Ouled Yagoub National Forest is medium, but there were differences between compartments, and low-quality forestland is primarily distributed in the Southern and western aspects regions, with aspects, elevation, and soil conditions serving as limiting factors, which is consistent with previous studies (Abdessemed 1984; Benmessaoud 2009).

Furthermore, because data access is limited, forest site quality evaluation is a complex system project, and the evaluation indicator system and evaluation criteria created in this work are susceptible to additional in-depth study and validation. Further research could combine remote sensing data and observed data as technology advances to uncover more appropriate and relevant markers for evaluating forest site conditions.

The high-grade forest site quality is primarily found in the northern high mountain areas, with the topography serving as the primary restraint. The low-grade forest area is mostly found in the southern low zones, where geography and soil fertility were all major factors.

More research is needed to determine how successful management and construction can be implemented in the later stages of forestland protection, as well as how the zoning–scale–management trinity can be realized in a forestland protection system.

The spatial features of forest site quality can be incorporated into the construction of forest protection zoning schemes, thereby expanding the scope of this form of zoning for classified areas as a National Park of Chelia-Ouled Yagoub forests. To establish forest zoning protection, the quantity of forest land must still be considered and we suggest:

- (1) To make the most of this type of forest site, rational forest management must be increased through the reduction of the density of stands to have better quality wood.
- (2) To make the most of this type of forest station, forest management such as protection forests must be put in place, to control the degradation of the soil of these places and the gradual loss of forest cover.
- (3) In addition, forest fires were more frequent in the region and the ecological degradation of forests is more severe, resulting in a greater influence on the quality of forest sites (Rahmani, Benmessaoud 2019). To maintain ecological stability in this delicate environment, avoid the ecological degradation of forest sites, and increase soil fertility through the introduction of resistant and fixing plant species, strict management and protection measures for these forest sites must be implemented.

Conclusion

The GIS is used to investigate the spatial distribution of forest site quality at the compartment scale, using the forest site quality index as a spatial variable, based on the scientific evaluation of forest site quality in Ouled Yagoub National Forest (Aures, Algeria) based on the multicriteria AHP model, which combined topographic factors and soil conditions to evaluate the spatial distribution of forest site quality.

The range of the forest site quality index in Ouled Yagoub National Forest is 1.64–3.148, with a mean value of 2.555 ± 0.257 SD), indicating that the overall forest site quality is medium, but there were some variances among compartments, according to this study. The high-grade forest site quality is primarily found in the northern high mountain areas, with the topography serving as the primary restraint. The low-grade forest area is mostly found in the southern low zones, where geography and soil fertility were all major factors.

The spatial features of forest site quality can be incorporated into the construction of forest protection zoning schemes, thereby expanding the scope of this form of zoning for all the areas classified as a National Parc of Chelia and Ouled Yagoub forests. To establish forest zoning protection, the quantity of forest land must still be considered. More research is needed to determine how successful management and construction can be implemented in the later stages of forest land protection, as well as how the zoning–scale–management trinity can be realized in a forest land protection system.

Acknowledgement

We would like to express our deepest gratitude to the conservation of Khenchela forests staff for their help in the research process and the data supports.

Funding Information

This research was funded by the ministry of higher education and scientific research of the People's Democratic Republic of Algeria (university-training research projects)—Ecophysiological analysis and plant production for the rehabilitation and enhancement of degraded ecosystems in the Aurès region (No. D00L02UN050220220001).

Author's Contributions

Funding acquisition, C. C.; conceptualization, C.C., A.B., T.S. and K.R.; methodology, C.C., A.B., T.S. and A.A.; investigation, C.C.; writing—original draft preparation, C.C., K.R., A.S.B. and A.A.; writing—review and editing, C.C., K.R. and A.A. All authors have read and agreed to the published version of the manuscript.

References

- Abdessemed K. (1981):** Le cèdre de l'Atlas (*Cedrus atlantica* (Endl.) Manetti ex Carrière 1855) dans les massifs de l'Aurès et Belezma (Algérie): Étude phytosociologique et problèmes de conservation et d'aménagement. [PhD. Thesis.] Marseille, Université Aix-Marseille.
- Abdessemed K. (1984):** Les problèmes de dégradation des formations végétales dans l'Aurès (Algérie). 1. La dégradation, ses origines et ses conséquences. Forêts Méditerranéennes, 6 (1) : 19-26.
- Abdessemed K. (1985):** Les problèmes de la dégradation des formations végétales dans l'Aurès (Algérie) – les mesures à prendre. Forêt Méditerranéenne, 7 (1) : 43-51.
- B.N.E.D.E.R. (2008):** Rapport sur la caractérisation des formations forestières de la Wilaya de Khenchela. Alger, BNEDER: 25. (in French)
- B.N.E.D.E.R. (2010):** Etude de classement de la cédraie de Beni Oudjana et d'Ouled Yagoub en parc national - Phase II : ANALYSE DE L'ETAT DES LIEUX. Alger, Bureau National d'Etudes pour le Développement Rural: 230. (in French)
- Bedia J., Camia A., Moreno J.M., Gutierrez Herrera S. (2014):** Forest fire danger projections in the Mediterranean using ensembles regional climate change scenarios. Climatic Change, 122 : 185–199. <http://dx.doi.org/10.1007/s10584-013-1005-z>
- Beghami Y., De Bélair G., Véla E. (2007):** Les groupements végétaux de la cédraie du massif de Chelia, “Aurès” (Algérie). Actes du colloque géoflore. Bulletin de l'Association des Botanistes Lorrains, Numéro Spécial 1 : 153-159.
- Beghami Y., Kalla M., Thion M., Benmessaoud H. (2012):** Spatiotemporal Dynamics of Forest and Mountain Formations in Aurès Area, Algeria. Journal of Life Sciences, 6: 663-669.
- Benmessaoud H., Kalla M., Dridi H. (2009):** Evaluation de l'occupation des sols et désertification dans le Sud des Aurès (Algérie). M@ppemonde, 94 (2) : 1-11. Available at: <http://mappemonde-archive.mgm.fr/num22/articles/art09206.pdf>
- Benmessaoud H. (2009):** Etude de la vulnérabilité à la désertification par des méthodes quantitatives numériques dans le massif des Aures (Algérie). [PhD. Thesis.] Batna, Université de Batna.
- Bentouati A. (2008):** La situation du cèdre de l'Atlas dans les Aurès (Algérie). Forêt Méditerranéenne, 29, 203-208.
- Bentouati A., Bariteau M., (2006):** Réflexions sur le dépérissement du cèdre de l'Atlas des Aurès (Algérie). Forêt Méditerranéenne, 27 (4) : 317-322.
- Bonilla-Bedoya S., Herrera-Machuca M.A., Lopez-Ulloa M., Vanwalleggem T. (2017):** Effects of land use change on soil quality indicators in forest landscapes of the Western Amazon. Soil science, 182 (4): 128-136.
- Boultif M., Benmessaoud H. (2017):** Using climate-soil-socioeconomic parameters for a drought vulnerability assessment in a semi-arid region: Application at the region of El Hodna, (M'sila,

- Algeria). *Geographica Pannonica*, 21: 142-150.
<http://dx.doi.org/10.5937/GeoPan1703142B>
- Bouzekri A., Benmessaoud H. (2016):** Using multi-criteria analysis for the study of human impact on agro-forestry-pastoral ecosystem in the region of Khenchela (Algeria). *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLI-B8: 779-783.
<http://dx.doi.org/10.5194/isprs-archives-XLI-B8-779-2016>
- Chandio, I. A., Matori, A. N. B., WanYusof, K. B., Talpur, M. A. H., Balogun, A. L., & Lawal, D. U. (2013) :** GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. *Arabian Journal of Geosciences*, 6(8), 3059-3066.
<http://dx.doi.org/10.1007/s12517-012-0568-8>
- Chen L., Chen X., Shi G., Nzai W.L. (1998):** Study on improving the quality of forest land of larch plantations. *Journal of Northeast Forestry University*, 26(3): 6-11.
- Chung I.K. (1978):** Quantitative Forest land productivity survey and the result: Forest land capability classification in South Korea. *Japanese Journal of Forest Environment*, 19: 31–35.
- DE FSM Russo, R., & Camanho, R. (2015) :** Criteria in AHP: a systematic review of literature. *Procedia Computer Science*, 55, 1123-1132. <http://dx.doi.org/10.1016/j.procs.2015.07.081>
- D.G.F. (2018):** Les feux de forêts en Algérie - Analyse et perspectives. Alger, Direction Générale des Forêts DGF: 46. (in French).
- E.F.F.I.S. (2022):** <https://effis.jrc.ec.europa.eu/apps/effis.statistics/estimates/DZA/>, accessed on 13/02/2022.
- Golden B. L., Wang Q. (1990):** An Alternative Measure of Consistency. In: Golden B. L., Wasil A., Harker P.T., (eds): *Analytic Hierarchy Process: Applications and Studies*. New York, Springer Verlag: 68-81. <http://dx.doi.org/10.1007/978-3-642-50244-6>
- Kadik B. (1987) :** Contribution à l'étude du pin d'Alep (*Pinus halepensis* Mill.) en Algérie : Ecologie dendrométrie morphologie. Alger, OPU: 580. (in French)
- Kherchouche D., Kalla M., Gutiérrez E.M., Attalah S., Bouzghaia M. (2012):** Impact of Droughts on *Cedrus atlantica* Forests Dieback in the Aures (Algeria). *Journal of Life Sciences*, 6: 1262-1269.
- Koull N., Helimi S., Mihoub A., Mokhtari S., Kherraze M. E., Hani Amir Aouissi H. A. (2022):** Developing a Land Suitability Model for Cereals in the Algerian Sahara Using GIS and Hierarchical Multicriteria Analysis. *International Journal of Agriculture and Natural Resources*, 49(1): 36-50.
- Kumar V.S. (2006):** Analytic hierarchy process: An overview of applications. *European Journal of Operational Research*, 48: 77–80.
- Lyu F.Z., Luo H.J., Lyu Y. (2015):** Study on forestland quality indexes and their application. *Journal of Forest and Environment*, 35: 87–91.
- Meddour-Sahar, O., & Derridj, A. (2012) :** Bilan des feux de forêts en Algérie Analyse spatiotemporelle et cartographie du risque (période 1985-2010). *Sécheresse*, 23, 133-141.
- Merabtene M.D., Faraoun F., Mlih R., Djellouli R., Latreche A., Bol R. (2021):** Forest Soil Organic Carbon Stocks of Tessala Mount in North-West Algeria – Preliminary Estimates. *Frontiers in Environmental Science*, 8 (520284): 1-9. <https://doi.org/10.3389/fenvs.2020.520284>
- Mihi A., Ghazela R., Wissal D. (2022) :** Mapping potential desertification-prone areas in North-Eastern Algeria using logistic regression model, GIS, and remote sensing techniques. *Environ Earth Sci* 81, 385. <https://doi.org/10.1007/s12665-022-10513-7>
- Rahmani S., Benmessaoud H. (2019):** Modélisation et cartographie du risque incendie de forêt dans la partie orientale des Aures (Algérie). *Forêt méditerranéenne*, T. XL (4) : 435-446.

- Ramade F. (1997):** Conservation des écosystèmes Méditerranéens : Enjeux et perspectives. Les fascicules du plan bleu 3. Rome, Programme des Nations Unies Pour L'environnement, Economica: 189. (in French)
- Saaty T.L. (1980):** The Analytic Hierarchy Process: Planning, Priority Setting, Resources Allocation. 2nd Edition. London, McGraw-Hill: 287.
- Saaty, T. L. (2008) :** Decision making with the analytic hierarchy process. International journal of services sciences, 1(1), 83-98. <https://doi.org/10.1504/IJSSCI.2008.017590>
- Schoenenberger (1970a):** Catalogue des espèces vasculaires des massifs forestiers des Beni-Imlou, Chélia, Belezma et S'gag (Aurès). 1st Edition. Alger, CRBT/ONRS: 30. (in French)
- Schoenenberger (1970b):** Etude du couvert forestier de l'Aurès oriental : Tendance évolutive de ce peuplement. 1st Edition. Constantine, F.A.O. Projet Algérie 15: 42. (in French)
- U.N.G.A. (2017) :** United Nations strategic plan for forests 2017-2030 and quadrennial programme of work of the United Nations Forum on Forests for the period 2017-2020. United Nations General Assembly New York, USA.
- Wang Z., Li K.W., Xu J. (2011):** A Mathematical programming approach to multi-attribute decision making with interval-valued intuitionistic fuzzy assessment information. Expert Systems with Applications, 38: 12462–12469. <https://doi.org/10.1016/j.eswa.2011.04.027>
- Wang L., Zhou Y., Li Q., Zuo Q., Gao H., Liu J., Tian Y. (2021):** Forest Land Quality Evaluation and the Protection Zoning of Subtropical Humid Evergreen Broadleaf Forest Region Based on the PSO-TOPSIS Model and the Local Indicator of Spatial Association: A Case Study of Hefeng County, Hubei Province, China. Forests, 12(325): 1-25. <https://doi.org/10.3390/f12030325>
- Xia X., Sun Y., Wu K., Jiang Q. (2016):** Optimization of a straw ring-die briquetting process combined analytic hierarchy process and grey correlation analysis method. Fuel Processing Technology, 152: 303–309. <https://doi.org/10.1016/j.fuproc.2016.06.018>
- Ye J. (2010):** Multicriteria fuzzy decision-making method using entropy weights-based correlation coefficients of interval-valued intuitionistic fuzzy sets. Applied Mathematical Modelling, 34: 3864–3870. <https://doi.org/10.1016/j.apm.2010.03.025>
- Yu K.Y., Liu J., Lai R.W., Yang Z.Q., Wei Q.G. (2009):** Chinese fir commercial forests forestland productivity in Minjiang watershed based on 3S technologies. Journal of Forest and Environment, 29: 326–331.
- Zhang Z.Y., Liu P.J., Tang X.M. (2017):** Evaluation of forest land quality based on rough set and C5.0 decision tree. Journal of Northwest A & F University - Natural Science Edition, 45: 96–102.

Other sources:

1. AL.O.S. (2021): <https://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm/>, accessed on 13/11/2021.
2. I.S.D.A. (2021): <https://isda-africa.com/isdasoil/>, accessed on 13/11/2021.
3. NASA-PCDM(2021): <https://power.larc.nasa.gov/data-access-viewer/>, accessed on 13/11/2021.
4. I.N.C.T. Algiers (L'Institut national de cartographie et de télédétection) 2014
5. ISDA : Innovative Solutions for Decision Agriculture