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Assessment of current and future land sensitivity to degradation under climate change in the upstream Ouergha watershed (Morocco) using GIS and AHP method

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Abstract

Land degradation is a worldwide phenomenon that negatively affects the topsoil of agricultural land. The Mediterranean region is the hardest hit by this phenomenon, which is set to increase due to climate change. This study aims to assess the susceptibility of land to degradation under climate change, based on the calculation of the Land Degradation Sensitivity Index (LDI) in the upstream Ouergha catchment in in Northern Morocco (Southern Mediterranean), using Geographic Information Systems (GIS) and the Analytic hierarchy process (AHP) multi-criteria decision analysis (MCDM) method. In this study, 4 main criteria (climate, vegetation, soil and human environment) divided into 15 sub-criteria were used to assess soil sensitivity to degradation. The weight of each criterion was assigned using the AHP method. The degree of soil degradation was classified on a map based on four categories (low, moderate, high and critical). About 14.9% of land is not very sensitive to degradation, while 37.2% of land is highly sensitive to degradation. Vegetation and climate were identified as the main drivers of land degradation (37% and 28% respectively). Climate scenarios for model EC-Earth3-Veg (CMIP6) indicate a significant drop in precipitation in this region, which accelerates soil degradation. The result represents a planning tool that can help decision-makers to take the necessary measures to ensure sustainable soil management in the face of climate change.

1. Introduction

Land degradation is the most complex environmental problem, distributed differently on a global scale and subject to the influence of several natural and human factors depending on the different spatiotemporal variables [1-3]. Land degradation also has a number of economic, social and environmental impacts, particularly in relation to climate change [4,5]. The severity of degradation increases significantly in arid bioclimatic zones, which account for around 40% of land area [6] , because their resources are more vulnerable to over-exploitation due to the impact of climate change and human pressure [7,8]. Several criteria contribute to soil degradation, including the dry or semi-arid climate, low vegetation cover, unstable soils, the gravity of overgrazing, and incompatible human practices [9-11] . Climate change and the increase in human activity are exacerbating this degradation. The local population's exodus is a reflection of the ecological imbalance and barrier to social and economic stability this scenario causes [12]. The land degradation is therefore a threat to food and water security, given that 44% of cultivated areas are arid zones [13], a figure that is constantly rising due to the prolongation of drought years and the increase in human pressure. As a result, reducing degradation factors to ensure land productivity is becoming essential [14], especially as most of the impacts affect developing countries that are the most sensitive to climate change [15]. Several studies agree that land degradation is mainly linked to human activities, through excessive depletion of forest areas, intensive exploitation of water resources and heavy pressure on soils [16,17]. Research findings on climate change in the Mediterranean also point to a general decrease in annual rainfall rates, offset by an increase in average temperatures, resulting in high climate variability [18-21]. Climatic conditions, highly erodible environments, the reduction of forested areas and the decline in soil organic matter are therefore considered to be among the factors that impact on the susceptibility of land to degradation [22].

Morocco is one of the countries most vulnerable to the effects of climate change, with 90% of its territory classified as arid zones [23,24]. This is linked to its geographical location in the subtropical bioclimatic zone [25-27], since the arid and semi-arid climate accounts for 93% of the total surface area, while forest systems occupy 8%, but they are constantly threatened by human exploitation [7,28]. Degradation is intensifying with climate change, with repercussions due to the frequency of extreme climatic events, as persistent drought poses a real threat to the country's water and food security [29-31]. Most agricultural activities depend on rainfall, and the reduction in rainfall causes both quantitative and qualitative damage, reducing the productivity of the cultivated area and causing some farmers to migrate [32]. In addition, water erosion alters soil fertility in mountainous areas, accelerating the degradation process and weakening the land's production capacity [33]. Rehabilitating degraded land, or land that is susceptible to degradation, can help to stabilise local populations in fragile areas, such as the upstream Ouergha catchment in northern Morocco, by reducing the environmental degradation to which this area is exposed, in particular demographic pressure and the impact of climate change on vegetation cover.

The development of geospatial techniques, especially GIS and remote sensing, has made it possible to assess the vulnerability of land to degradation using alternative methods [34,35]. The Analytical Hierarchy Process (AHP) is used to estimate the weight of processes influencing land susceptibility to deterioration. A major advantage of this approach is its wide application by several researchers to assess the sensitivity to desertification in various regions [36,37], with good results in several studies. In addition, this method has the potential to be adapted and modified, allowing new sub-indicators to be added [38-40].

In this study, we have used quantitative measurement maps for various and differentiated indicators, through which we aim to learn about the natural and human influencing factors. In addition, we made some modifications to the model, selecting relevant indicators for the future evolution of the phenomenon, developing scenarios linked to climate change (SSP1-4.5 and SSP5-8.5), and to the increasing intensity of land use, within high population density and spatial mutations.

2. Materials and method

2.1. Study area

The study area occupies a large part of the eastern part of the Ouergha catchment, extending over an area of approximately 1182 km2, constituting 19% of its overall surface area. Topographically, the upstream part of the Ouergha catchment belongs to the Rif Mountain range, specifically to the central Rif zone (Figure 1). Its altitudes vary between 341m and 1875m, and its mountain peaks form a watershed between several sub-basins. It is bordered to the north by the Mediterranean Ghras basin, to the north-east by the Nkor basin and to the east by the Kert basin. To the south-east, it is bordered by the Msoun basin, which is a tributary of the Moulouya. To the south, it is bounded by tributaries of the Lebene and Inaouene basins, while to the west, it is bounded by the Guezzar basin [41]. Administratively, the basin partially covers the provinces of Taounate, Taza and Al Hoceima.

The upper Ouergha catchment is characterised by good water potential, most of which is superficial and linked to rainfall. The Oued Ouergha is the main watercourse, fed by several tributaries such as the Asfalou, Saghourt, Ras Ouergha and Amassine. As well as the Asfalou dam, whose capacity is estimated at around 320 million m^3 [42]. In addition, the basin has a large hydrographic network, with an estimated average drainage density of around $2km/km^2$ [42,43]. As for rainfall, it is characterised by extreme variability in its distribution, depending on the impact of climatic years and topographical features [44].

2.2. Data used

The study of the susceptibility of land to degradation requires an applied geographical approach, based on geographic information systems (GIS) and analytic hierarchical process (AHP), to identify the elements influencing the phenomenon, with a view to producing a map of the susceptibility of land to degradation at the upstream end of the Ouergha basin. To achieve this objective, emphasis was placed on several sources and data:

- Rock properties: We based our analysis on the 1:500,000 scale geological map of the Rif, which was used to obtain the characteristics of the bedrock.
- Soil characteristics: We used maps from the National Institute of Agricultural Research (1/100.000), and we also use data from reports carried out in the central Rif, such as the development plan and the fight against erosion in the Ouergha basin. Secondly, the report covered the study of the soil at 1:100,000 scale, which was of interest for agricultural development, and its data was used to obtain the texture and thickness of the soil.
- A series of rainfall and temperature data covering the period 1980-2020 was collected from the Sebou Basin Agency.
- Landsat OLI 8 image (15 September 2023), was downloaded from the USGS Earth Explorer website (http://eartheexplorer.usgs.gov/), and used to extract land use and land cover (LCLC).

- The 2020 forest inventory map, to determine the characteristics of forest formations (type of cover, cover rate, sensitivity of plants to fire and drought).

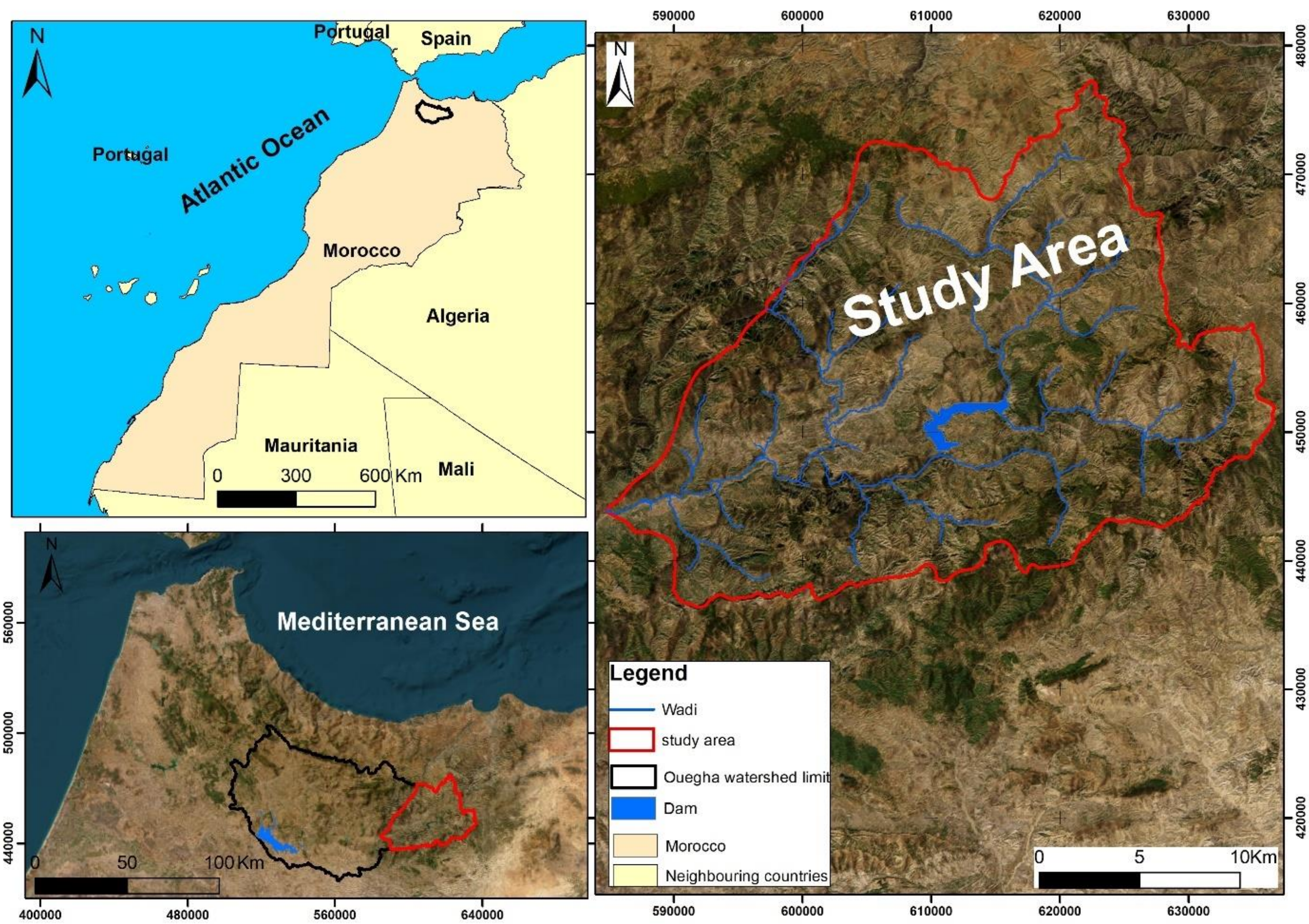

Figure 1. Situation of the study area

- A digital terrain model with a spatial resolution of 30 m (GDEM) was used to obtain the physiographic aspects (slopes and slope orientation);
- Population data has been extracted from the 2014 General Census of Population and Housing, available at https://www.hcp.ma.

2.3. Methodology

The methodology adopted in this study is inspired by the MEDALUS model commonly used to assess the sensitivity of land degradation in arid, semi-arid and sub-humid environments in the Mediterranean region. Four main criteria and 15 sub-criteria have been selected to classify the degree of sensitivity of land to degradation. The main criteria are soil, climate, vegetation cover and human pressure. Given that these criteria contribute to the degradation process in unequal proportions, the AHP method proposed by Saaty was applied to estimate the weight of each criterion Figure 2

The vegetation quality

Vegetation cover is a vital element in the sustainability of terrestrial ecosystems. Its presence protects land from erosion and improves structural stability [45-47]. The protective role is linked to the nature and rate of cover of plant formations, and their resistance to drought and fire. Forests enrich the soil in organic matter and form a barrier that protects it from the violence of precipitation, thus reducing run-off and favouring infiltration [34]. The vegetation quality index was calculated on the basis of four sub-criteria according to the following formula (Eq. 1):

$$VQ = (Ep \times Dr \times Fr \times Vc)^{1/4} \qquad \text{Eq. 1}$$

Where VQ is the vegetation quality, Ep is protection against erosion, Dr is resistance to drought, Fr is forest fires and Vc is the vegetation cover rate. The vegetation map from the national forest inventory was used to spatialise forest formations in the region. Vegetation cover was determined using the NDVI index [48] of Landsat images. Land protection against erosion was determined from the land use map and our field observations. The sensitivity of plant formations to fire and drought was classified with reference to the literature [49-51].

The climate quality

Climate is the most important factor in the process of land degradation [45]. Climatic variability, the succession of drought years and the frequency of heat waves make land more vulnerable to degradation, affecting the soil, plant cover and water resources, as well as the local ecosystem [7,46]. The climate quality is based on the following elements: annual rainfall, slope orientation and aridity index [38] according to the following formula (Eq. 1):

$$CQ = (P \times AI \times A)^{1/3} \quad \text{Eq. 2}$$

Where CQ is the climate quality, P is annual rainfall, AI is the aridity index according to Emberger's classification, and A is the orientation of the slopes.

Precipitation is the most important element influencing land degradation, as it controls the soil's capacity to drain water, thus stabilising plant formations [47]. Rainfall in the study area was spatialised on the map, based on climatic data provided by the Sebou ABH using the Kriging tool from spatial analysis in ArcGIS. The aridity index was assessed using the Emberger index, which is commonly used in the Mediterranean region to classify bioclimatic stages [48]. The aspect criterion also contributes to the soil degradation process, and reflects the position of the slopes in relation to the prevailing winds and insolation. The southern and eastern slopes are exposed to the Sirocco winds, which makes them hot and dry, accelerating the degradation process, while the northern and western slopes are considered wet and less sunny(Table 2). In this study, the exposure of the slopes is determined in relation to the four cardinal points, the reference to the north being the origin.

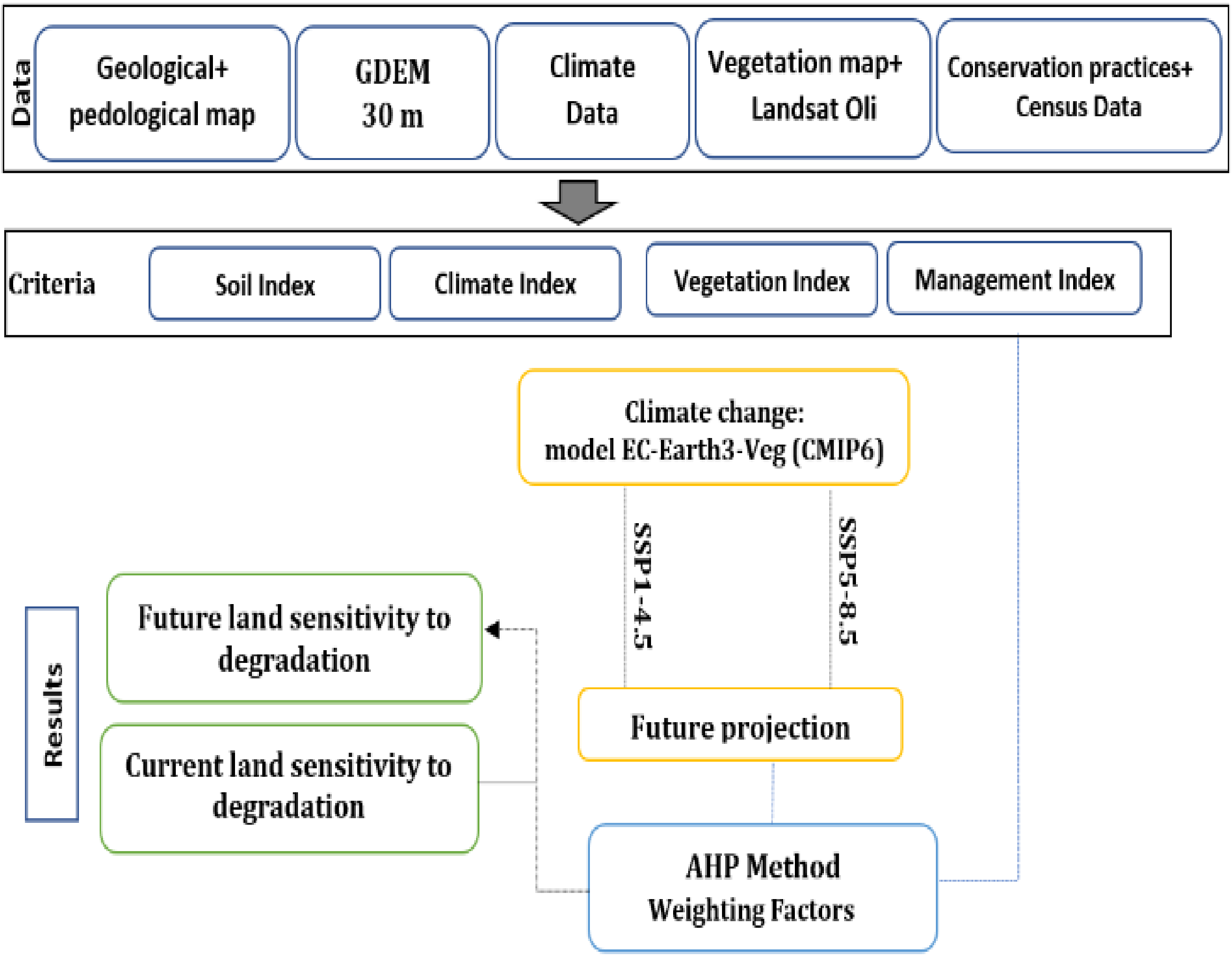

Figure 2: Flowchart methodology

The soil quality

Soil plays an important role in identifying the sustainability of agricultural activities, assessed through its fertility, its capacity to produce and its resilience to degradation factors, and then maintaining biological equilibrium [49]. The soil quality was determined on the basis of a combination of four sub-criteria according to the following formula (Eq. 1):

$$SQ = (Pm \times Dp \times T \times S)^{1/4} \quad \text{Eq. 3}$$

Where SQ is the soil quality, Pm is the rocky substrate, Dp is the soil thickness, T is the soil texture and S is the slope.

The substratum was determined from the 1:500,000 Rifan geological map, and then classified according to its water erosion resistance [50]. Soil texture and thickness were generated from physico-chemical analyses. The Surface and Reclassification spatial analysis tools available in ArcGIS were applied to generate and reclassify the slope (Table 2)

The management quality

Human practices have both positive and negative consequences for soil degradation [44]. Certain incompatible practices implemented locally, such as deforestation, overgrazing and successive ploughing, accelerate soil degradation through erosion [5,28]. On the other hand, appropriate human intervention, such as soil conservation, planting embankments, terracing and residue management, can mitigate the degradation process [51,52]. The management quality criteria was determined on the basis of three sub-criteria according to the following equation 4 (Eq.4):

$$MQ = (Pd \times Hp \ \times Mq)^{1/3} \qquad \text{Eq. 4}$$

Where Pd is population density, Hp is land use and Mq is spatial management. Population density was obtained from the general population and housing census (HCP, 2014). Tenure patterns and land management and conservation practices were generated based on the land use map and our field observations.

Table 1). Once the comparison matrix has been established, the eigenvalue of each parameter and the corresponding eigenvector are calculated. The

AHP method

As the criteria generating the land degradation process have different weight, the multi-criteria analysis (MCA) method is used to assess the influence of each criterion. This is a decision theory developed by Saaty [53]. It is a hierarchical process that reflects the relationships between parameters and possible alternatives in a hierarchical order [54,55]. Several studies have used this method to estimate the weight of criteria contributing to the land degradation process in the Mediterranean [34]. The AHP is based on a pairwise comparison of criteria at the same hierarchical level. The values attributed to the criteria are ranked using a numerical scale proposed by Saaty [53], ranging from 1 to 9 (1 = equal importance, 3 = moderately, 5 = strongly, 7 = very, 9 = extremely). The weight of each parameter is estimated on the basis of scientific literature [34,44] and also on the basis of our experience in the field. The most important criteria are climate, plant cover and soil (

consistency ratio (CR) is an important step in testing the consistency of the matrix calculation [54]. The CR is calculated using the equation proposed by Saaty [53].

Table 1. Pairwise comparison matrix for the 4 criteria used in this study

	VQ	CQ	SQ	MQ	Weight %
VQ	1	1	2	3	36.7
CQ	1	1	1	2	28
SQ	0.5	1	1	1	19.9
MQ	0.33	0.50	1	1	15

Where VQ: vegetation quality, CQ: Climate quality; SQ: Soil quality; MQ: Management quality.

Forecasting climate change

The expected consequences of climate change on land degradation were simulated using the regional climate model EC-Earth3-Veg, Coupled Model Intercomparison Project Phase 6 (CMIP6) with a spatial resolution of around 1 km [4]. Based on the reference period 1980-2020, a short-term period (2025-2049) was adopted [56]. Two scenarios were selected: the shared socio-economic trajectory SSP1-4.5 and SSP5-8.5. The Sixth Assessment Report (IPCC 2021) has adopted these scenarios. Recent studies have evaluated the performance of the EC-Earth3-Veg model in North Africa and have shown that this model gives a more accurate simulation of precipitation and temperature. These studies concluded that the data from this model are acceptable for simulating climate projections in this region. Recent studies have used data from this model to simulate the effects of future climate change [35].

3. Results And Discussion

3.1. Spatial assessment of quality indicators

The indicators used to assess the susceptibility of soils to degradation are presented in the

Table 3, and then mapped in Figure 3. Vegetation cover is the most important criterion for soil degradation, accounting for 36%. Several studies show that vegetation plays a key role in soil degradation or conservation in the Mediterranean region. For example, [34] used the fuzzy analytical hierarchy process to assess the risk of desertification in northwest Morocco and showed that the vegetation cover criteria is the most important in the degradation process with a proportion of 42.3%. The VQ assessment showed that low-quality areas account for around 31.9% of the total surface area (Figure 3-a), corresponding spatially to the eastern, north-eastern and south-eastern parts, characterised by the dominance of bare soil and fallow areas, which have limited soil protection, high water erosion, and are considered to be the most degraded in the basin. Areas of average quality cover around 39.8% and correspond to agricultural land (farms and areas planted with fruit trees such as olives, figs and almonds). Good quality land covers 28.3% of the total surface area of the basin. The distribution of this land corresponds to dense forests, more precisely on slopes that are well exposed to Atlantic disturbances (North and West).

The weight of the climate quality is 28%. The results for this criterion indicate a poor state of the land throughout the study area (Figure 3-b). There is a significant difference in quality, particularly in the north-eastern part of the study area. Areas of average climatic quality account for around 47.2% of the total surface area of the basin. Areas of low climatic quality occupy 41.4% of the total surface area and are concentrated in the centre of the basin, more specifically in the adrets and sheltered valleys that receive low rainfall. Land with a good climatic quality index represents 11.4% and is often located on the highest peaks, characterised by the predominance of a sub-humid bioclimatic stage and receiving rainfall in excess of 600 mm per year.

According to [37,38-49], soil quality criteria plays a key role in the land degradation process, with a weight of 19.9%. The soils in the study area are characterised by the predominance of crude mineral soils that are poorly developed, low in organic matter, thinner and highly vulnerable to degradation by erosion. Land with a low soil quality index, and therefore highly vulnerable to erosion, accounts for around 36.1% of the total surface area. These are steep slopes, prone to water erosion and run-off. This situation is exacerbated on fragile substrates (marl, clay and shale) and on soils that are poor in organic matter (

Table 3). Land with a good and average SQ occupies similar proportions, respectively 23.6% and 23.2% of the study area. They are located in the northern part of the basin and along depressions and valley bottoms, where slopes are gentle. The soil on this land is fertile and lies within or near wooded areas. Along the valleys, these areas are subject to the accumulation of sediment and rock formations from the uplands.

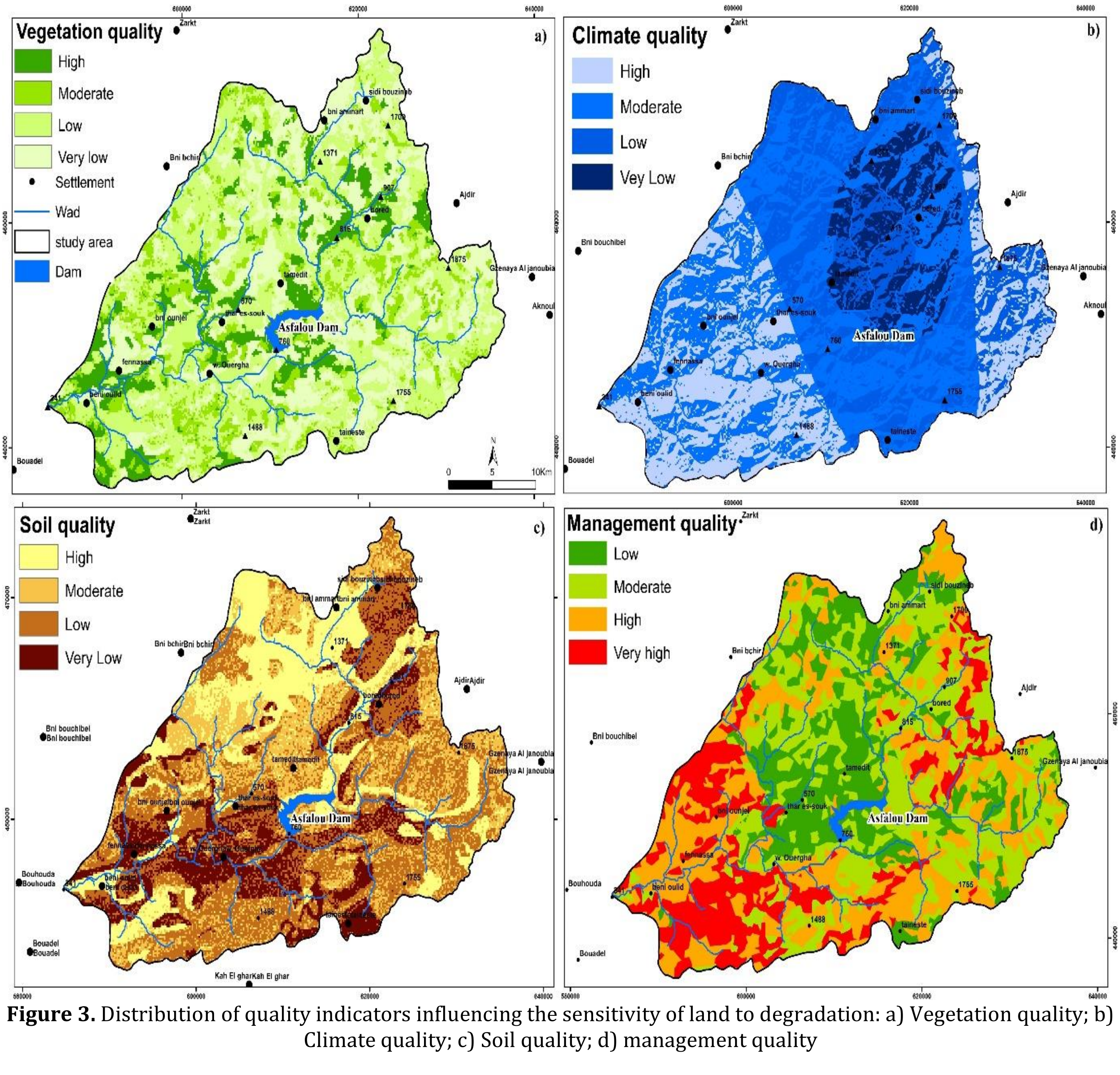

Figure 3. Distribution of quality indicators influencing the sensitivity of land to degradation: a) Vegetation quality; b) Climate quality; c) Soil quality; d) management quality

Table 2. The indicators and its parameters and scores in area study

Indicators	Parameters	Description	Proportion (%)	Scores
Vegetation quality	Erosion Protection	Natural and artificial forests	10,7	1
		Maquis and matorral	41,6	1,3
		Permanent agricultural crops, crops and arboriculture, vineyards	26,2	1,6
		Annual crops, annual grassland, bare land	21,5	2
	Drought Resistance	Natural and artificial forests, irrigated crops	2	1
		Tree farms, vines, scrubland, olive groves	28,9	1,3
		Grasslands, matorral	40,1	1,6
		Annual and seasonal crops, pastures, bare land	29	2
	Fire risk	Agricultural land use; dry and irrigated farming, crops and arboriculture, bare land	44,6	1
		Grasslands, scrubland, pastures, matorral	34,4	1,3
		Natural and artificial deciduous forests	20	1,6
		Pine forests	1	2
	Vegetation Cover (%)	High	9,4	1
		Low	84,3	1,5
		Very low	6,3	2
Climate quality	Aspect	NW/NE/N/W	54,1	1
		SE/SW/S/E	45,5	2
		Unclassified (flat)	0,4	--
	Precipitation	< 500 mm	19,9	2
		500-660 mm	46,6	1,5
		> 660 mm	33,5	1
	Aridity Index	lower semi arid	7,7	1,6
		Upper semi arid	54,4	1,3
		Sub humid	37,9	1
Soil quality	Soil Thickness (mm)	Thickness > 80 mm	25,1	1
		50<Thickness<80	48,7	1,5
		Thickness <50mm	26,2	2
	Soil Texture	Balanced	25	1
		Fine to medium	44,7	1,3
		Fine	26,1	1,6
		Gross	4,2	2
	Slopes (degree)	<6°	7,4	1
		6°<S<18°	41,9	1,3
		18°<S<35°	44,3	1,6
		>35°	6,4	2
	Parent materiel	Coherent: Limestone, dolomite, non-friable sandstone	5,1	1
		Moderately: Marl-limestone, friable sandstone, shale, Flysch, crusts	77,2	1,5
		Soft: Marl, clay, sandy formations, alluvium and colluvium	17,7	2
Management quality	Human pressure	Uncultivated land, forests, bare land	3,8	1
		Matorral, pastures, reforested areas	20,1	1,3
		Crops and arboriculture, olive trees, seasonal agricultural harvests	21,9	1,6
		Dry farming, irrigated perimeter, arboriculture, developed areas, annual agricultural harvests.	54,2	2
	Population density	PD < 50 hab. / km²	52,7	1
		50 hab. / km²< PD <90 hab. / km²	30,6	1,3
		90 hab. / km²< PD <130 hab. / km²	16,2	1,6
		PD >130 hab. / km²	0,5	2
	Management	Managed: Crops and managed arboriculture, annual agricultural harvests, dry farming, irrigated perimeter, dense managed arboriculture, reforested areas	33,9	1
		Average management: Crops under a forest stand, crops and forest, crops and matorral, seasonal agricultural harvests	44,2	1,5
		Undeveloped: Undeveloped land, forests, bare land, matorral, pastures, etc.	21,9	2

The human criteria has both positive and negative consequences for soil degradation. The weight of MQ criteria is the 15% and is calculated on the basis of three sub-criteria (population density, land use patterns and soil conservation management practices). The results show a significant variation in the quality of the MQ according to the spatial distribution of these sub-criteria (Figure 3-d). Land with a low MQ and which is therefore vulnerable and threatened by degradation represents around 47.2% of the total surface area and corresponds to land subject to high human pressure (more than 100 inhabitants/km^2), concentrated mainly in the south-west and west. Land with an average MQ occupies 32.2% of the total surface area and is distributed in the north, north-west and south-east of the basin, where population density varies from 90 to 50 inhabitants/km^2. The land with sensitivity low to degradation accounts for 20.6% of the total surface area, concentrated in the centre of the basin, in addition to certain parts in the north and south-east, which correspond to low-density populations (less than 50 inhabitants/km^2). In terms of intensity of land use, intensively occupied land covers 54.2% of the total surface area and includes agricultural areas of various types (dry and irrigated), areas devoted to arboriculture and developed areas. Moderately occupied land accounts for 21.9% of the total and includes areas devoted to seasonal agricultural crops, cultivation and arboriculture, as well as forestry crops. On the other hand, land with limited and very low occupation covers 23.9% of the total surface area and corresponds to natural areas such as forests, undeveloped land, bare land, matorral, pastures and reforested areas [44]. Indeed, 44.2% of land is moderately managed. On the other hand, 33.9% of land is adequately managed (
Table 3).

3.1. Distribution of land degradation

Four criteria were superimposed to generate the desertification map for the region studied. The weight of each criterion is determined using the hierarchical analytical process (AHP) matrix, based on literature and our field experience. The consistency ratio (CR) obtained is 0.03, indicating that the pair-wise comparison matrix is consistent, and the results are tolerable and acceptable. The final map was generated by integrating the normalized criteria weights using the weight overlay tool in ArcGIS 10.8, according to the following formula (Eq.5):

$$LDI = VQ \times 0.367 + CQ \times 0.28 + SQ \times 0.199 + MQ \times 0.15 \quad \text{Eq. 5}$$

Were LDI: Land sensitivity to degradation; VQ: vegetation quality; CQ: Climate quality; SQ: Soil quality; MQ: Management quality. These criteria have been classified into sub-criteria according to their contribution to the desertification process.

The land with a high and critical sensitivity to degradation covers 37.2% and 12.1% of the total surface area respectively (Figure 4). They extend over the southern and eastern slopes of the basin. Their degradation is linked to a combination of climatic and soil factors, as they receive less than 500 mm of rainfall per year and are underlain by fragile bedrock (marl, clay and shale), characterised by low permeability, resulting in low surface water recharge and underdeveloped vegetation during the dry period. Over-exploitation of the land by human activity has exacerbated the land degradation [45]. The impact of the steep slope has also contributed to the rapid evacuation of rainwater and a high concentration of surface runoff, due to the low vegetation cover and regression of the forest area by deforestation, resulting in high water erosion activity on the bare slopes, accompanied by an extension of the extent of degraded land and high intensity [57].

Table 3. Distribution of indicators and quantification of the respective zones

Indicators	Score range	Impact	Total area (%)
Vegetation	< 1, 2	High	28,3
	1,2 - 1,4	Moderate	39,8
	1,4 – 1,6	Low	29,1
	>1,6	Very low	2,8
Climate	1 - 1, 2	High	11,4
	1,2 - 1,4	Moderate	47,2
	1,4 – 1,6	Low	28,5
	>1,6	Very low	12,9
Soil	< 1, 2	High	23,3
	1,2 - 1,4	Moderate	23,6
	1,4 – 1,6	Low	36,1
	>1,6	Very low	17,1
Management	1 - 1, 2	High	20,6
	1,2 - 1,4	Moderate	32,2
	1,4 – 1,6	Low	30,5
	>1,6	Very low	6,7

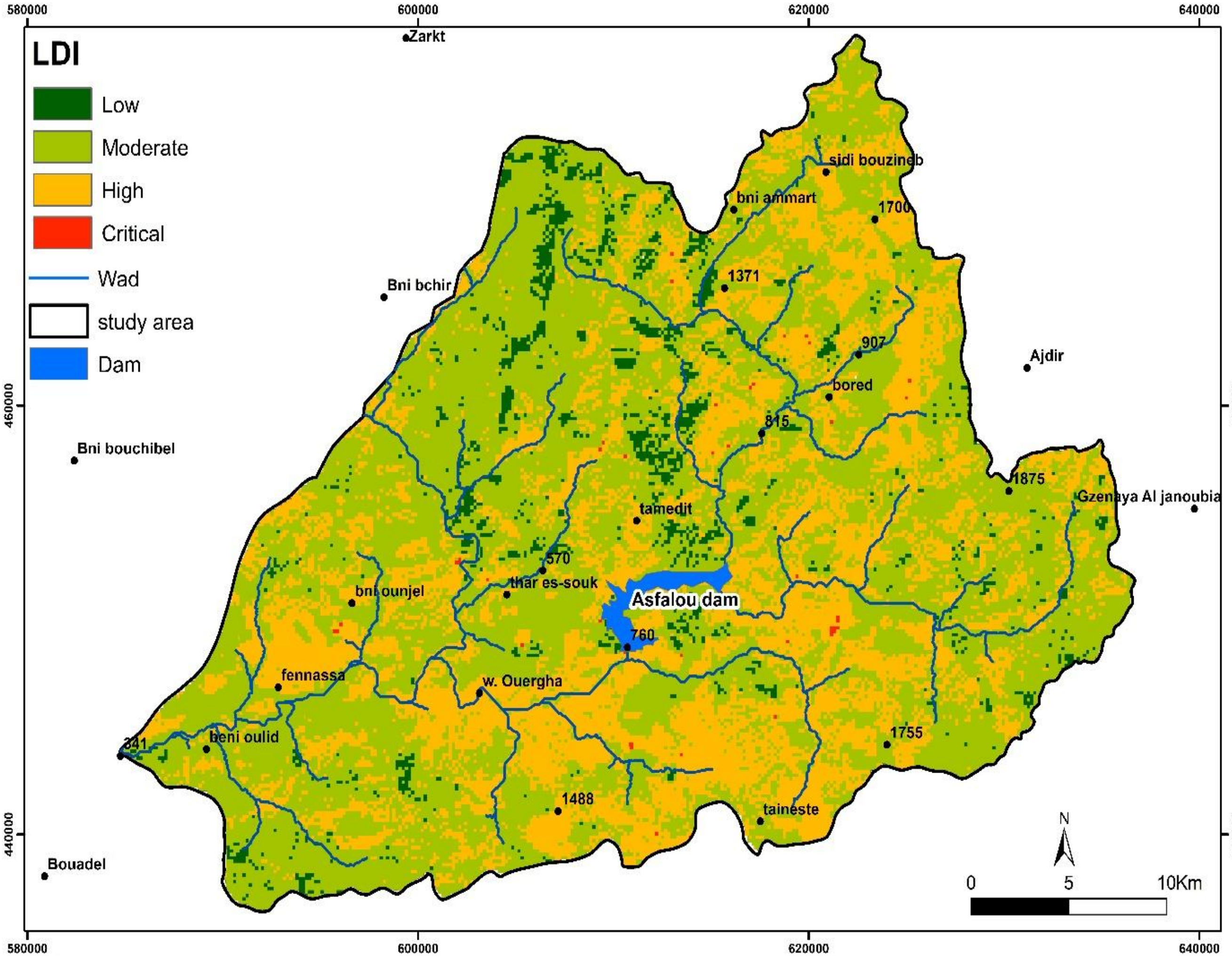

Figure 4. Current Distribution of land sensitivity to degradation in study area

Land at moderate risk of degradation accounts for 35.8% and covers a large area of the basin. It extends along the tributaries of the Oued Ouergha and the convergence zones, including the alluvial plains, as well as the moderately sloping areas below the mountain peaks. These areas are characterised by a moderate susceptibility to degradation, as a plant cover consisting of matorral and fruit trees such as olive, fig and almond protects them. In addition, the proximity of these lands to watercourses favours the supply of water for irrigation [58]. Land with a low susceptibility to degradation occupies 14.9% of the total surface area and generally extends across the northern part of the basin, with scattered islands in the south-east and west, corresponding to humid and sub-humid bioclimatic stages, as well as mountainous peaks, where the impact of precipitation is notable. They also correspond to areas of natural forest, which protect the land from water erosion [59]. The low-lying areas are distributed along the valleys, where alluvial and deep soils predominate, providing a water reserve in their moderately deep horizons. The fertility of these soils and their gentle slopes also make them suitable for a variety of agricultural activities, particularly irrigation. These soils are characterised by their high quality and their ability to resist degradation mechanisms, particularly water erosion and drought.

3.2. Assessing land degradation under climate change

To assess land degradation by 2049, all the parameters and classifications have been maintained, with the exception of the aridity index and precipitation, which have been replaced by the corresponding climate projections for 2049 based on two scenarios SSP1-4.5 and SSP5-8.5 (Table 4, figure. 5). As indicated by several studies in the Mediterranean region climate projections for the Rif region, where the study area is located, predict a significant decrease in rainfall and an increase in temperatures and extreme weather events, such as heat waves in summer [4,18,60,61]. This phenomenon will be more pronounced at higher altitudes, where precipitation and temperature will fall and rise sharply respectively. The optimistic scenario indicates that precipitation levels will fall by 5-10%, accompanied by a temperature rise of more than 1°C compared to the current situation [23], as well as the predominance of drought years. These changes will affect the distribution of bioclimatic stages, with an increase in the arid, semi-arid to the detriment of the sub-humid and humid. This result is in agreement with those found by several studies which have shown that climate change can cause an expansion of arid and semi-arid bioclimatic stages in Morocco [35].

The SSP1 4.5 scenario will lead to a moderate increase in the sensitivity of land to degradation in the study area compared to the current situation (Table 4) The pessimistic scenario of SSP5-8.5 predicts that precipitation will decrease by 25% for 2049, and that the temperature will rise by around 2°C. These changes will have a spatial impact, particularly on bioclimatic zones. The semi-arid bioclimatic zone will increase, to the detriment of the sub-humid bioclimatic zone, whose surface area will decrease to 4.8% (Figure 5). On the other hand, the high frequency of dry years will result in the appearance of an arid bioclimatic zone (15.7%) to the east of the study area. This climatic situation will lead to increased land degradation, with degraded and critical land expected to occupy 66.6% of the surface area, to the detriment of soils that are moderately and slightly sensitive to degradation. These results are consistent with several studies that have simulated the likely effects of climate change on soil degradation in Morocco. For example, [62,63] evaluated soil losses in the Haouz plain (Morocco) and found that climate change could increase land degradation.

Table 4. Current and future impact of climate criteria on land degradation according to the two scenarios, SSP1-4.5and SSP5-8.5 by 2049

Impact	Current impact	SSP1-4.5 (2049)	SSP5-8.5 (2049)
Low	11,4%	4%	2,6%
Moderate	47,2%	44,6%	30,8%
High	28,5%	36,6%	42,6%
Very high	12,9%	14,8%	24%

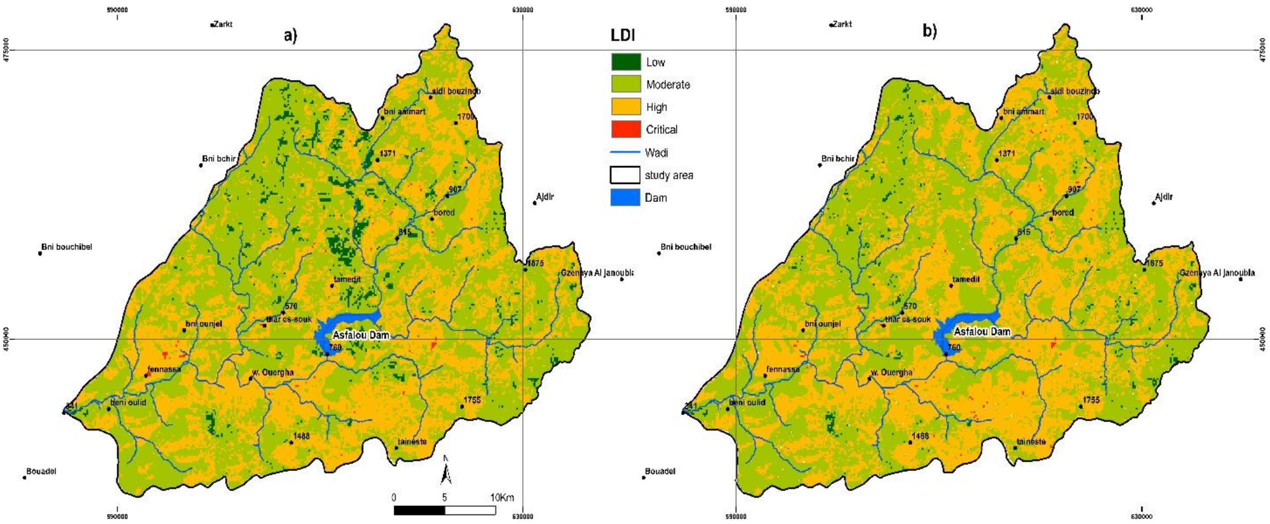

Figure 5. Effects of climate change on land sensitivity to degradation by 2049. a) SSP1-4.5 ; b) SSP5- 8.5

Conclusion

The results obtained in the upstream part of the Ouergha basin concluded that there is an overlap between the factors affecting the susceptibility of land to degradation (vegetation, climate, soil and human factors). However, vegetation cover (37%) and climate change (28%) have the greatest impact, represented by a decrease in the amount of rainfall, the duration of dry years compared with wet years, and therefore a decline in the water balance, accompanied by a rise in temperature and an increase in evaporation of surface water. The contraction of the forested area due to deforestation and fires has also led to a reduction in the proportion of plant cover and a high level of water erosion on bare slopes. The sovereignty of impermeable rocks is reflected in rapid surface drainage, reducing the soil's capacity to store enough water for longer, thus weakening the water table. This situation has led to an increasing demand for water resources by local residents, especially in summer, when many springs and wells dry up. The intensity has increased further with the expansion of cannabis cultivation, which has become dependent on intensive irrigation following the introduction of hybrid seeds.

The persistence of these environmental imbalances may lead to increasing sensitivity to land degradation in the basin, given that 49.3% of the total surface area is occupied by degraded to critical land. This proportion is set to increase in the future as a result of climate change (lower rainfall, higher temperatures), with arid bioclimatic stages expanding to the detriment of humid stages, and their environmental, social and economic impacts, which may constitute an obstacle to the development of rural communities, and hence the lack of economic and socio-spatial development. Consequently, it is necessary to reflect on the results obtained, in order to assess the current situation of the basin's natural and human potential, to make the most of territorial resources such as water, forest and soil, and to create development projects compatible with local specificities, particularly those aimed at combating various manifestations of spatial vulnerability.

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Author contributions

Mohamed Boutallaka: Conceptualization, Methodology, Software, Field study, writing**,** ***Miloud Talibi:*** Data curation, Software, Field study, ***Mohamed El Mazi:*** Methodology, Visualization, Investigation, Writing-Reviewing and Editing**, Mostafa Hmamouchi:** Visualization, Software, Field study, writing, **Khalid El Hairchi:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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