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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)

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Abstract

The objective of this study is to contribute in assessing and monitoring drought's vulnerability by developing a GIS- based model to determine vulnerable areas to this natural hazard; the model utilizes a series of agricultural, statistical, meteorological and remotely sensed data, using GIS weighed ponderation and multicriteria analysis decision making, with the integration of three components: climatic sensibility, soil sensibility and socioeconomic sensibility. The result is a vulnerability map classified into five classes according to pixel values. Very Vulnerable class forms 19.46% of the study area, vulnerable class forms 32.81% and 21.37% of the area is not vulnerable, the study presents a modeling procedure of which the final results provide to researchers, users and decision makers important information on the environmental situation of the study area, for better prediction, and risk management.

Keywords: Drought; Modelling; GIS; Multi-criteria Analysis; Vulnerability

Introduction

Of all natural hazards drought is the most complex and least understood, it affects large numbers of people and results in significant economic, social and environmental impacts (Wilhite, 2005). It does not have a universal definition, but it can be said that drought is a deficit of water availability comparing to normal water supplies during a period of time (Layelmam, 2008), rainfall deficit may occur after a few days, weeks, months or even years which makes it is a very difficult hazard to monitor (Yasef, Saltani, 2009). Drought's intensity is also increased by the adverse human effect on the environment, like deforestation, gas emissions, livestock pressure, overgrazing and the overuse of natural resources (Safar Zitoun, 2006). Drought's evolvement is slow and does not present an instantaneous danger, it aggravates the stress on natural resources (soil and water reserves), and jeopardizes food and water security. The impacts of drought are observed over large area compared to other natural hazards such as floods, tropical storms, and earthquakes, which makes it particularly challenging to quantify the impact (Wilhite, 2005).

Four types of drought are distinguished; the most remarkable type is meteorological drought that which occurs when water deficiency spans an extended period of time (Wilhite, 2005). A hydrological drought is related to water supply diminution in soil and/or subsurface waters (i.e., stream flow, reservoir, lake) (Layelmam, 2008). An agricultural drought begins when the soil moisture available to plants drops to a level that adversely affects the crop yield and agricultural production (Martínez-Fernández, et al., 2015). A socioeconomic drought differs from other types in reflecting

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the disequilibrium between the supply and demand of certain natural resources (i.e, potable water) and economic goods (i.e., cereal) (WMO, 2006).

With global warming and the frequent occurrence of extreme events; concerns about global drought and its impacts have become more pronounced in recent years (Dai, 2011), particularly in arid and semi-arid regions where drought vulnerability is related mainly to climatic disturbances. The definition of vulnerability is the degree to which a system is susceptible to climate change and unable to cope with adverse effects (Houghton, et al., 2001).

In order to monitor and assess drought's impact, a series of indices and parameters have been developed to depict drought in different applications (Dracup, et al., 1980; Wilhite, Glantz, 1985). However, drought monitoring systems should be integrated and based on multiple physical and socioeconomic indicators to fully understand it's magnitude, spatial extent, and impacts (Wilhite, 2005). The present study seeks to identify the spatial extent of drought vulnerability in an arid region situated in central Algeria, a country that has experienced severe drought-related disasters during the last decades (Bensaid, 2006), the problem of Algerian arid regions' vulnerability made the project of several studies (Nichane, Khelil, 2014; Medjereb, Henia, 2011; Bensaid , 2006, Nadjraoui , 2011).

The methodology is based on developing a GIS model based on two previous regional drought assessing projects: the DMCSEE (drought monitoring center of southeastern Europe) model presented in 2012 to assess and monitor drought in southeast countries of Europe and the OSS (Sahara and Sahel Observatory) model presented in 2009 to put a classification of drought vulnerable areas of North African countries (Algeria, Morocco and Tunisia).

Methods and data

Study area

The study area is situated in central Algeria, in the El Hodna region, (4°90'4°351' N and 35°87'. 35°17' E). It spans the area of 1261.20 km² and extends over 6 sub-divisions (communes) of M'sila province: Maadhid, M'tarfa, M'sila, Souamaa, Ouled madhi and M'cif, (Figure 1), including the salt pan named "Chott El Hodna" (400 m above sea level).

According to Köppen's climate classification; this region has a steppe arid climate with cold winter (Bsk) (Urlike, et al., 1993). The study area is a typical North

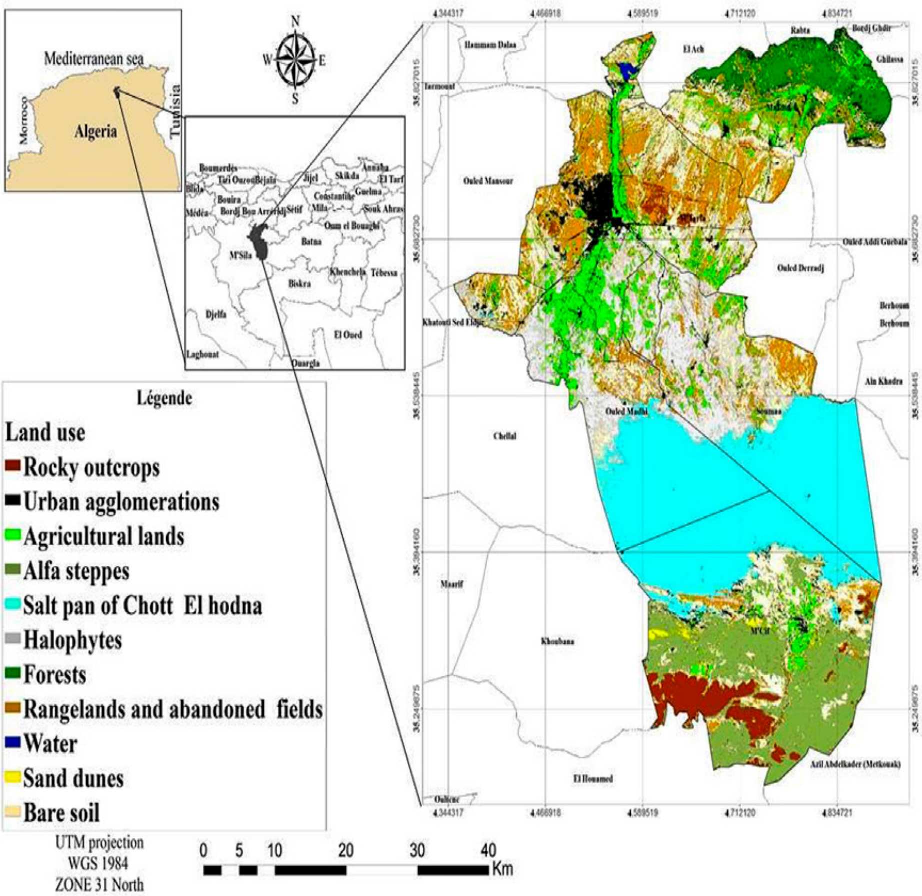

Figure 1. Geographic localization and the land use of the study area

African arid zone, characterized by a land use variability and heterogeneity; 12.25% of the study area is covered by rangelands reserved for grazing, 13% by halophytes surrounding the salt pan of Chott El hodna that constitutes 24.20% of the area, bare soil forms 19.24% and alfa (Stippa Tenacissima) forms 10.42%, where agricultural lands cover only 8.56% and forests cover 3.75% of the surface.

Data processing

Drought vulnerability mapping is generally based on calculated inputs that are obtained from thematic maps, remotely sensed images, climate and socioeconomic statistics. Our approach is based on using a series of drought related inputs to build a GIS-based model based on two existing experiences: OSS methodology (Observatory of Sahara and Sahel) and DMCEE methodology (Drought Management Centre for Southeastern Europe).

In 2009 the observatory of Sahara and Sahel (OSS) proposed a GIS model based on the overlay of several weighted factors for mapping drought vulnerability in North African countries (Table 1). This model used aridity, livestock pressure and soil sensibility as parameters to which weights have been assigned by experts according to the importance of each parameter in drought vulnerability (Safar Zitoun, 2006).

The Drought Management Centre for Southeastern Europe (DMCEE) proposed in 2012 a methodology for estimating and drought vulnerability mapping in southeast countries of Europe also based on the weighted overlay of several spatial layers (Table.2) to conduct an assessment of institutional capacity, including Meta data available by selecting and evaluating the most effective and reliable indices and indicators for drought assessment (Móring, et al., 2012).

Table 1. OSS vulnerability mapping parameters for North African countries

Parameter		Weight
Aridity		0.65
Livestock pressure		0.22
Soil sensibility	Water retention capacity	0.13
	Soil occupation	

Table 2. DMCEE vulnerability mapping parameters and weight for south Eastern Europe countries (2012)

Parameter	Weight
Slope	0.1623
Available groundwater	0.0518
Sunshine duration	0.3071
Precipitation	0.1180
Land use	0.0858
Soil type	0.2232
Irrigation	0.0518

The contribution of the present study is to propose a methodology based on the previously presented models, the essential objective is to conduct a drought vulnerability assessment by identifying three principal

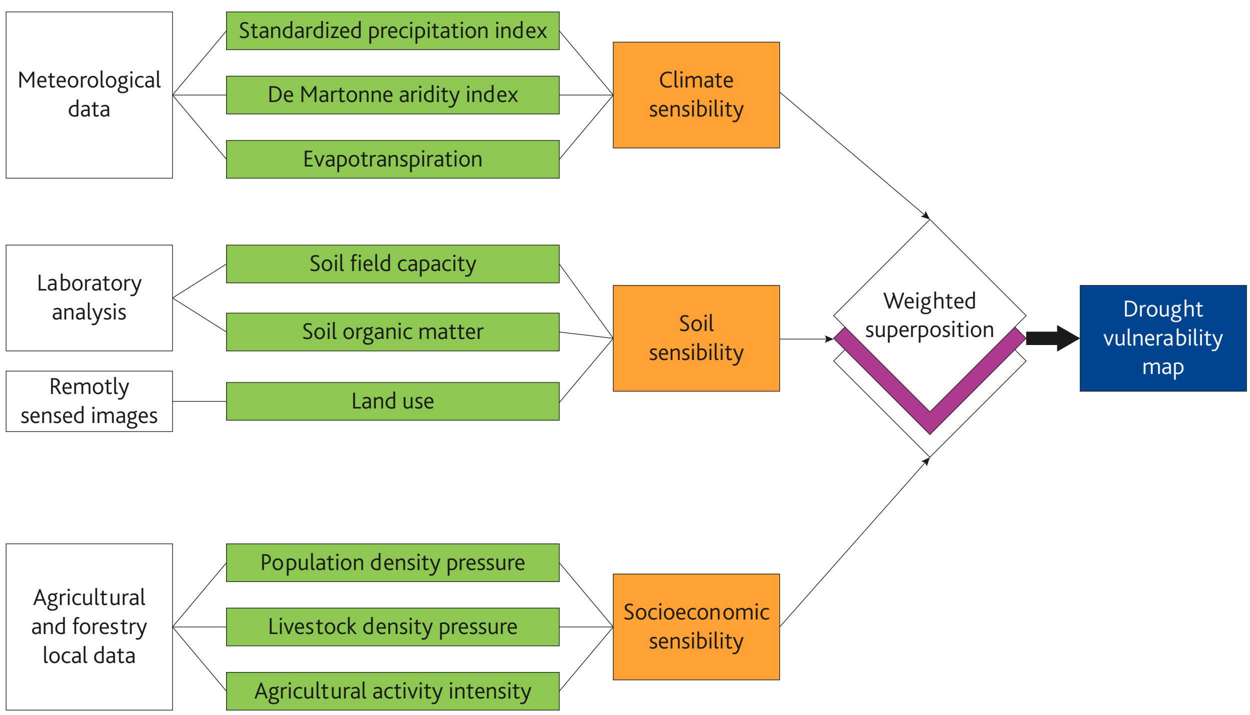

Figure 2. Methodology Chart of the drought vulnerability mapping in the study area

components that are related to drought : climate, soil and socioeconomic sensitivity using drought-related parameters and indices that are adapted to Mediterranean arid steppes of North Africa with the use of land management expertise weighting and multi-criteria decision making and GIS (Figure.2).

Creating thematic layers

Climate sensitivity mapping

The climate factor takes a major part in identifying vulnerable areas to drought, the climatic data used in this study is obtained from rainfall and temperature series provided by two meteorological stations (M'sila and Bousaada), in order to build a climate sensitivity, map we computed the following meteorological indices and parameters:

Standardized precipitation index SPI (Mckee, 1993):

$$SPI = \frac{\left(P_i - P_m\right)}{\sigma}$$

where: P: rainfall in mm per year, P_i: Precipitation of year i P_m: Average precipitation σ: Standard deviation.

De Martonne aridity index (De Martonne, 1926):

$$AI = \frac{P_i}{T_i} + 10$$

where AI = aridity index; P_i = monthly precipitation amount; T_i = monthly mean air temperature

Evapotranspiration (Thornthwaite, 1948):

$$ETP = 16 \quad \frac{10T}{I}^{\quad a}$$

where: T: temperature average over 1 year, I: annual thermic index, $a = 1.6{\cdot}(I/100) + 0.5$

Soil sensitivity mapping

Soil is one of the largest water storage parts of the climate system, therefore it is important to include it in the drought analysis (Gregorič, 2012). Soil quality has an important part in determining vegetation density and crops' health.

Because of the lack of historic soil maps of the area, the conduction of soil sensitivity layer needed laboratory analysis to define soil properties (water retention and organic matter), Soil samples were taken from randomized circles in 45 sampling points, after removing the litter layer from (0 - 20 cm depth). In laboratory, soil samples were sieved (<2 mm), then soil retention capacity (holding capacity) was determined from each sample using the "European" maximum water holding capacity, method where a soil sample is saturated with water in a cylinder that is placed on an absorbent membrane until the excess water is drawn away by gravity; once equilibrium is reached, the water holding capacity is calculated based on the weight of the water held in the sample comparing to the sample dry weight.

Organic matter was defined in laboratory using the Walkley-Black titration method (Walkley, Black, 1939). The analysis results were mapped using GIS (spatial interpolation tool) where data was interpolated spatially from each sample point using the IDW interpolation tool in ArcGIS 10.2.2 software.

The land use map is obtained after field sampling and observation followed by a using the ENVI 5.3 software for a supervised classification of a satellite image from Landsat Satellite (Oli Captor) of the date: 09 March 2016 provided by the USGS earth explorer.

Socioeconomic sensitivity mapping

Socioeconomic statistics are provided by forests conservation directorate and agricultural and rural development directorate of M'sila province. Data was processed and entered into a GIS database and interpolated spatially using the IDW interpolation tool in ArcGIS 10.2.2 software

Drought vulnerability final mapping

Sub criteria mapping and scores assigning

At first, all indices and parameters were mapped to form sub criteria layers that will enter in our final drought vulnerability assessment (Figure.3).

The next step is to reclassify each sub-criteria layer into value intervals using ArcGIS reclassifying tool (Table 3), then, scores from 1 to 7 were assigned to each class, where 1 stands for a favorable value class, for example entering 1 as a score for a class of values that range

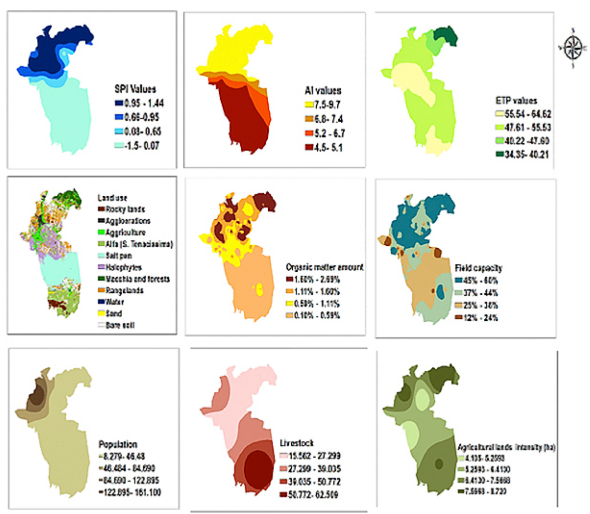

Figure3. Parameters and indices maps

Table3. Scores assigning

Factors	Parameters and indices	Values	Scores
Climate	Standardized precipitation index	0.95- 1.44	1
		0.66- 0.95	2
		0.08- 0.65	3
		- 1.5 - 0.07	4
	Demartonne Aridity index	7.5 - 9.7	1
		6.8 - 7.4	2
		5.2 - 6.7	3
		4.5 - 5.1	4
	Evapotranspiration	34.35 - 40.21	1
		40.22 - 47.60	2
		47.61 - 55.53	3
		55.54 - 64.62	4
Soil	Soil Field Capacity	12% - 24%	1
		25% - 36%	2
		37% - 44%	3
		45% - 60%	4
	Soil organic matter	1.60% - 2.69%	1
		1.11% - 1.60%	2
		0.59% - 1.11%	3
		0.10% - 0.59%	4
	Land use	Water	1
		Macchia and forests	2
		Agricultural lands	2
		Rocky outcrops	3
		Agglomerations	3
		Salt pan	4
		Alfa steppes	5
		Halophytes	6
		Rangelands	5
		Sand dunes	4
		Bare soil	7
Socioeconomic	Population Density pressure	8.279 - 46.48	1
		46.484 - 84.690	2
		84.690- 122.8956	3
		122.895- 161.100	4
	Livestock Density pressure	15.562 - 27.29	1
		27.299 - 39.035	2
		39.035 - 50.772	3
		50.772- 62.509	4
	Agricultural activity intensity	4.1056 - 5.2593	1
		5.2593 - 6.4130	2
		6.4130 - 7.5668	3
		7.5668 - 8.720	4

between 0.95 and 1.44 means that this class is more climatically suitable than the class where values range between 0.07 and -1.5 to which a score of 4 is given.

Multicriteria decision making

Multi-criteria decision-making method is a branch of a general class of operations research models that is suitable for addressing complex problems featuring high uncertainty, conflicting objectives, different forms of data and information, multi interests and perspectives, and the accounting for complex and evolving biophysical and socio-economic systems (Wang, et al., 2010).

This method was developed by Thomas Saaty in the 1970s and is based on mathematics and psychology (Saaty, 1980). It is used in managerial decision-making field, in summary, a decision-maker must "weigh" several options before deciding on one of them taking into account a series of criteria that he considers more or less essential to be respected (Cissokho, 2011).

The first step is to form a series of comparison by pairing these criteria according to their relative importance and their influence in drought hazard, we use a scale of numbers that indicate how many times more important or dominant one element is over another one, values of this scale range between 1 and 9 (Saaty, 1980). For example, entering 3 in the climate -soil position means that climate factor is three times more important and influencing drought in the study area than soil factor, and entering 1 in climate- socio-economic stress position means that both factors are equally important (Table 2).

Table 4. Assigned weight according to Saaty scale

Criterion	Climate	Socioeconomic stress	Soil
Climate	1	3	5
Socioeconomic pressure	1/3	1	3
Soil	1/5	1/3	1

The second step is to calculate the eigenvector (Vp) which is determined by calculating the geometric mean for each criterion, after that, the weighting coefficient for each criterion is deduced by dividing each eigenvector by their sum, the sum of the weighting coefficients must be equal to 1 (Table 3).

Table 5. Weighting coefficients

Criteria	Weight
Climate criterion	0.6333
Anthropic pressure criterion	0.1062
Soil criterion	0.2605
Sum	1

Results and discussion

Layer mapping

The final step is to aggregate and compile climate, soil and socioeconomic sensitivity layers to build the final vulnerability map using weighed sum method (Weighted sum tool in ArcgGIS 10.2.2) where each layer is divided by its calculated weight.

Climate sensitivity

Not sensitive areas form 37.61% of the study area, located mainly on Maadhid Mountains in the North (1,200 -1,900 m a.s.l), and on agricultural lands in M'sila and M'tarfa.

Slightly and moderately sensitive areas from respectively 2.66% and 35.70% located on the peripheries of the salt pan, where the altitudes vary between 400 and 440 m a.s.l.

Sensitive and very sensitive areas form 21.93 % and 2.08% mainly located on lower altitudes of the plains of M'cif and Souaamaa.

Soil sensitivity

Not sensitive areas constitute 22.55% of the total surface dominated by agricultural lands and mountainous regions covered by green oak stands, and Aleppo pine forests, the permanent irrigation of agricultural lands and the regular precipitation distribution on mountains provide a favorable soil quality for vegetation cover and crops in these areas.

Slightly and moderately sensitive areas form 16.10% and 23.27% respectively, distributed on rangelands, abandoned fields and Alfa steppes (stippa tencissima). Sensitive areas form 6.24% distributed on the salt pan surface, halophytes and spontaneous plants fields.

Very sensitive areas form 31.82% mainly located on bare and sandy soils where humidity and water retention is very low.

Socioeconomic sensitivity

The degree of socioeconomic sensitivity decreases away from urban agglomeration and industrial zones; not sensitive areas form 18.56% of the total surface, located on M'tarfa plains and on parts of the salt pan of El Hodna.

Slightly and moderately sensitive areas form respectively 39.91% and 32.11% located on the peripheries of urban agglomeration.

Sensitive and very sensitive areas form 3.21% and 6.10% are located on urban agglomerations mainly the city of M'sila (800,000 inhabitants).

Drought Vulnerability Mapping

Final drought mapping is also classified according to pixel values into five vulnerability classes (Figure 5).

Not vulnerable regions form 21.37% of the study area, located mainly on mountains (1,293m to 1,859m a.s.l) where the soil is humid and less exposed (Northern aspect), and on agricultural lands where the vegetation cover is denser and irrigated permanently, which makes of this region a favorable biotope, having the privilege of elevated rainfall rates, and also of being distant from human and livestock pressure, and road network (Figure 6)

Slightly vulnerable areas form 16.28% of the surface and located mainly on southern mountainsides

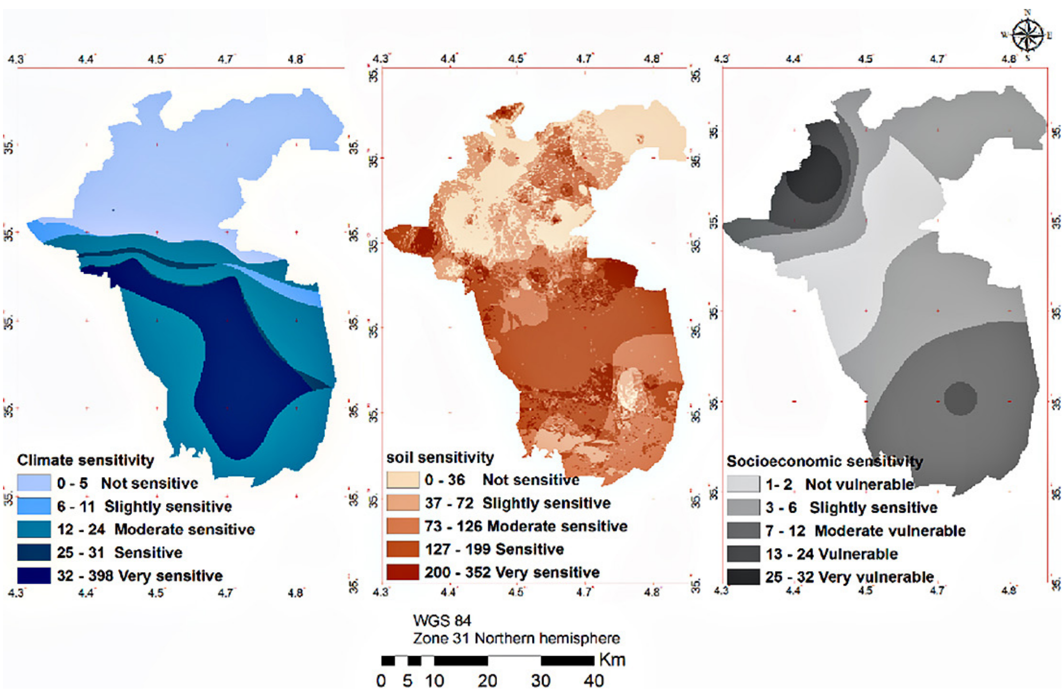

Figure 4. Climate, soil and socioeconomic sensitivity maps

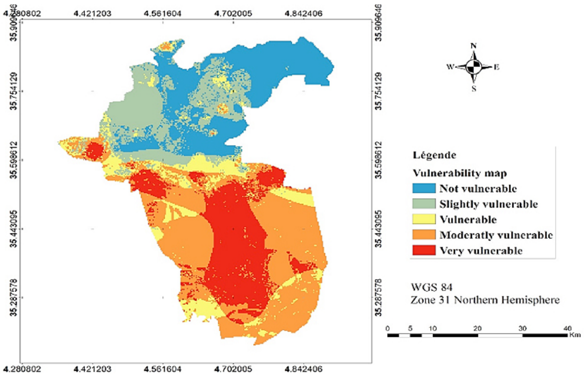

Figure 5. Final vulnerability map

and on the peripheries of agricultural that exigently require permanent water supplies which exacerbates the pressure and the overuse of water reserves.

Moderately vulnerable areas form 10.06% of surface and are located on rocky outcrops, rangelands and abandoned fields reserved for livestock grazing which leads to a land degradation (Figure 7).

Vulnerable and very vulnerable areas form respectively 32.81% and 19.46 % of the total surface, distributed on the rest of the study zone covering bare and sandy soils with southern aspect, and also the salt pan. The rainfall average in these areas is lower than 200 mm per year with sparse and rare vegetation cover (Figure 8).

The vast vulnerable and very vulnerable land surface notably in the south of the study area hypothecates that vulnerability situation will be aggravated in the future, especially with the decreasing of rainfall quantities and the tendency to scarcity reported by precipitation data of the last decades (Medjerab, Henia, 2011).

The combination of water supplies diminution with the poor quality of soil, the sparseness of vegetation cover, erosion, and the increasing of socioeconomic pressure; will exacerbate the drought vulnerability of the study area; areas that are classified as moderately vulnerable are tendentious to become vulnerable and/or very vulnerable. This tendency threatens the environmental situation of forests and agricultural lands leading to an overuse of water for irrigation which jeopardizes water and food security and transforming large steppes into bare soils.

In Algeria, arid and semi-arid environments' monitoring is based generally on thematic maps, field missions and classic methods, these operations take long durations of time, and absorb large disbursement especially in vast areas (Bensaid, 2006), many studies were conducted to assess environmental risks in arid lands such as erosion and desertification while drought still remains quit an unstudied hazard, studies were conducted on a regional scale such as Yasef and Saltani study (2009) (Sahara and Sahel observatory), or by reviewing climatic indices.

Bensaid (2006) and Bouzekri (2015), have conducted similar studies on others regions of Algerian arid steppes (the region of Naama and the Aures respectively) and they found that steppes reserved for grazing are more vulnerable to natural hazards such as desertification, sand invasion and wind erosion, in the case of our study agricultural lands are also potentially vulnerable besides steppes and rangelands.

After building the vulnerability final map, field missions were performed to validate the results and to verify the adequacy of our methodology as well as to identify and propose appropriate management plans and solution for drought mitigation.

Several management plans may be considered for application in this area to alleviate the impact of drought, such as planting trees around farms and agricultural lands to form natural barriers against wind erosion and sand storms. Other ways to alleviate the impact include planting shrubs and turf to limit soil evaporation and moisture loss

Drought mitigation is strongly related to the preservation of water resources (dams, reservoirs, underground water), also collecting precipitation water for immediate or eventual use in irrigation or domestic activities may be considered as a solution to minimize the pressure on underground water.

Due to the use of saline water for irrigation, salt levels are very elevated in agricultural lands and appear as a white layer on the surface (Figure 7); and for this, land reclamation is required to minimize salt amount in these soils. Reducing the salt amount is accomplished by disposing the accumulated salt on the surfaces, and improving chemical and biological soil properties through leaching and drainage operations with adding amendments and calcium supplies to reduce salt concentration in soil depths which will allow plants' roots to grow, also it is important to select salt-tolerant crops at the beginning of reclamation.

Figure 6. Not affected area region of Maadhid mountains

Figure 7. Agricultural lands of the region of M'sila

Figure 8. Rangelands and abondoned fields

Conclusions

Vulnerability mapping of different natural hazards is very important to both predict and prepare for a natural disaster's response, it allows to decision makers and users to have spatiotemporal information about the extent and the duration of different natural hazards. This study presented a contribution to drought vulnerability mapping, the aim of this study is to compile climate, soil and socioeconomic data using a GIS-based model adapted to dry lands and developed from two previous drought assessment models: a DMCSEE model (drought management center of southeastern Europe) and an OSS model (Observatory of Sahara and Sahel), with the integration of multicriteria analysis tool for decision making. This methodology uses available and simple data to facilitate drought assessment and monitoring to users and researchers.

The results show that very vulnerable and vulnerable areas form respectively 19.46 % and 32.81% of the total surface, slightly vulnerable form 16.28%, moderately vulnerable form 10.06% and not vulnerable areas form 21.37%, the decreasing of water supplies and rainfall rates with the increasing of socioeconomic pressure may exacerbate the vulnerability situation and cause the expanding of vulnerable and very vulnerable areas.

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