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Erosion Sensitivity Mapping Using a Multi-Criteria Approach under GIS Environment The Case of the Semiarid Hodna Basin in Central Algeria

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Abstract: The recent studies on the climate change vulnerability in the arid and semiarid regions show a trend to increase the aridity, which accelerates erosion. This complex and aleatory phenomenon is dependent in addition to the anthropogenic factor on some natural parameters, especially, the hydro-climatic forcing, the topography, the geology and the land use. This study aims to analyze and map the erosion sensitivity of Hodna basin in the central of Algeria with an area of 26000 km². It is the fifth basin of Algeria, located at 150 km to the south of the Mediterranean coast. The erosion sensitivity mapping approach is based on a multi-criteria method of the parameters of topography, the geology and the land use with a hydro-climatic forcing parameter represented by the precipitation. The analysis of the maps obtained under GIS environment for different criteria, shows that the findings vary from one criterion to another. However, taking all criteria into account, the obtained map shows that the areas with a high vulnerability to erosion are located in the south and the west of the basin, representing 25% of the total basin area.

Key words: Erosion sensitivity · GIS · Semiarid · Hodna · Algeria

INTRODUCTION

Algeria is among the most erodible regions in the world [1], the water erosion affects 28% of the land in northern Algeria; however, the Tellian steep mountains are the most affected with a rate of 45% representing 12 million hectares. The specific erosion varies between 2000 and 4000 t/km/yr [2]

The Hodna basin with drainage area of 26 000 km² is the fifth basin of Algeria. It is an interior basin, located at 150 km to the south of the Mediterranean coast (Golf of Bejaïa) (Figure 1). The erosion and sediment transport phenomenon is widely discussed [3, 4, 5 and 6]. A high values of erosion and sediment transport have been observed, the basin loses annually an average of 403 million m^3 of water and 11 million tons of sediment. Taking into a count the temporal variability, these yields can reach 860 million m^3 of water and 22 million tons of sediment. The sediment yield increases the terrain level of the Chott about 2 cm/year and the water yield is equivalent to a water depth of 74 cm on the whole region, which increases the risks of inundation, sediment deposition and spread of salinity. The specific erosion is between 500 to 1000 t/km²/yr. The only dam in Hodna basin, constructed in Ksob wadi, is almost silted up; it mobilizes less than 10 million m^3 of water from the total capacity of 50 million m^3.

This paper aims to map the sensitivity to water erosion of Hodna basin using a multi-criteria approach of the parameters of the topography, the geology and the land use with a hydro-climatic forcing parameter represented by the precipitation. Using a geographic information system GIS, we develop a sensitivity map for each erosion parameter and a final sensitivity map taking into account the obtained maps of the four studied parameters.

Study Area: The Hodna basin with a drainage area of 26 000 km² is the fifth basin of Algeria. It is an interior basin, located at 150 km to the south of the Mediterranean coast (Golf of Bejaïa) (Figure 1).

The altitude of the Hodna summits decreasing from east to west. They oscillate between 1900 and 1000 m, while in the south, only a few summits in the Saharan Atlas reach 1200 m. The situation of this basin between two sets of mountains at the north and the south, organizes it as an endorheic basin around an almost flat bowl at 400 m altitude. At the center of this latter region,

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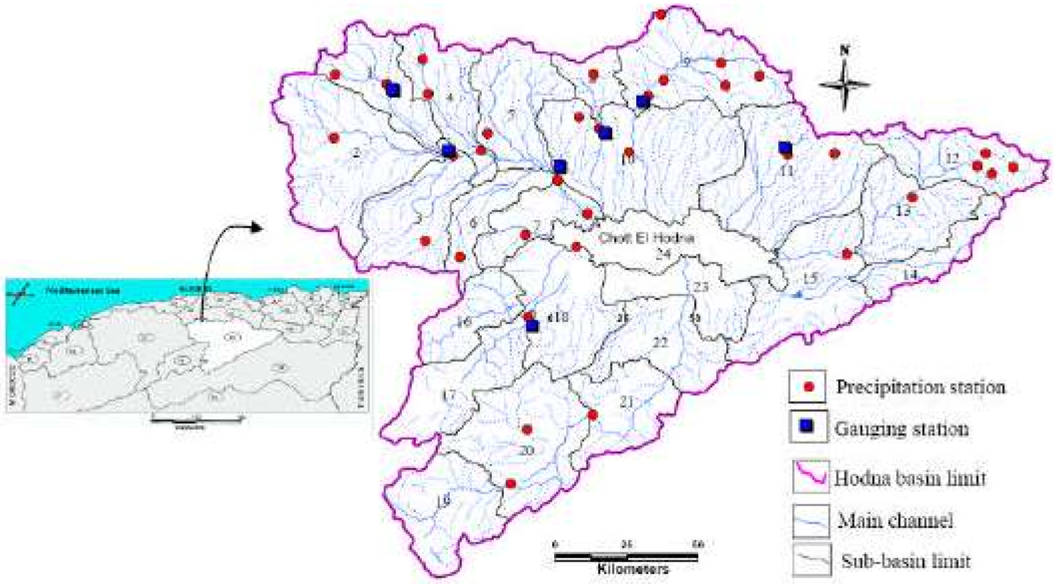

Fig. 1: Location of Hodna basin

Table 1: Morphometric Characteristics of the gauged sub-basins: wadi Soubella, wadi Elham, wadi K'sob

			Values		
Caractéristiques	Notation	Unit	Soubella sub-basin	El ham sub-basin	K'sob sub-basin
Area	A	km²	183.48	5605	1456
Perimeter watershed	P	km	76.18	360	202
Maximum altitude	Hmax	M	1886	1700	1860
Average altitude	Hmoy	M	1318.2	717.22	1120
Minimum altitude	Hmin	M	720	440	560
Circularity ratio	Kc	-	1.57	1.37	1.49
Average slope	I	%	18.3	41.39	14.12
Global slope index	Ig	%	1.96	3.64	31.68
length of the main wadi	Lp	km	34.45	104.6	89.70
Length of equivalent rectangle	L	km	32.5	126.52	84.25
width of equivalent rectangle	L	km	5.64	44.67	17.28
Drainage density	Dd	km/km^2	0.865	0.44	3.55

the dry salt lake named "Chott El Hodna" receives the water and the sediment yields of the whole wadis of the region. The center of this area is constituted by the Chott El Hodna (1150 km²). The basin has only one dam (Ksob) constructed in the 50s with an initial capacity of 29.50 km^3 and is located at the outlet of the Ksob sub-basin. According to the last bathymetry of the dam, realized by Algerian Agency of dams and Transfers (AADT), the silting rate of the dam is about 68%.

The Hodna basin is a typical semiarid climate, it is characterized by high temperature and low rainfall associated with a high spatiotemporally variability. The monthly average temperatures are between -3°C and 40°C, the warmest months are June, July and August and the coldest months are December, January and February. The annual rainfall is highly variable, ranging from 130 mm/year to 450 mm/year.

The Hodna basin is equipped with 07 gauging stations that are not all reliable. They were installed between 1966-1970 to measure the instantaneous liquid discharge and the suspended sediment concentrations. The examination of the available data shows that only data from three stations are reliable: Medjez station at wadi Ksob sub-basin, Sidi Ouadah station at wadi Soubella sub-basin and Rocade-sud at the outlet of wadi Elham sub-basin. The data of these later stations are used in several sediment transport studies [3-6]. The three above-mentioned stations control just 28% of the Hodna area; the rest of the surface is not gauged. The characteristics of their corresponding sub-basins are summarized in the table 1.

Methods and Discussion: To estimate the risk, the hazard and the sensitivity of the water erosion in the watersheds, several approaches exist based on quantitative or qualitative multicriteria analysis, this latter, permit to combine these criteria under a GIS environment. Like in the majority of the coupled models with GIS, the criteria (parameter) that directly influence the eroded sediment quantity are the principal criteria taken into a count in the determination of erosion sensitivity as: the topography, the slope, the geology, the land use and the climate (in this study we take only the maximum daily rainfall as climate parameter).

Examining the Hodna slope map generated from the Digital Terrain Model, shows that we can distinguish three classes:

- Class I (low sensitivity to water erosion) this class is characterized by a land slope from 0 to 5 % which represents the plain and the alluvial terrace.
- Class II (medium sensitivity to water erosion) this class is characterized by a land slope from 5 to 10 % which represents the grown thin soil.
- Class III (high sensitivity to water erosion) this class is characterized by a land slope from 10 to 20 % which represents the high piedmont.
- Class IV this class is characterized by a land slope from > 20 % which represents the mountain peaks.

The both classes III and IV constitute a single class of high sensitivity

The sensitivity map (Figure 2) realized with these four classes using GIS, shows that the north, the northeast, the west and some zones on the south of Hodna present a high erosion sensitivity. The rest of the Hodna surface oscillates between a medium to low sensitivity.

Regarding the geology, we can also define three classes of erosion sensitivity:

- Class I (rocks at low sensitivity) corresponds to the consolidated rock that resists to erosion as limestone, sandstone, dolomite, limestone marl and marl formations of limestone or sandstone.
- Class II (rocks at medium sensitivity) corresponds to the heterogeneous rocks such as marl and limestone formations, conglomerates breaches.
- Class III (rocks at High sensitivity) corresponds to the little cohesive rocks or friable as the shale, marl and the sedimentary rocks.

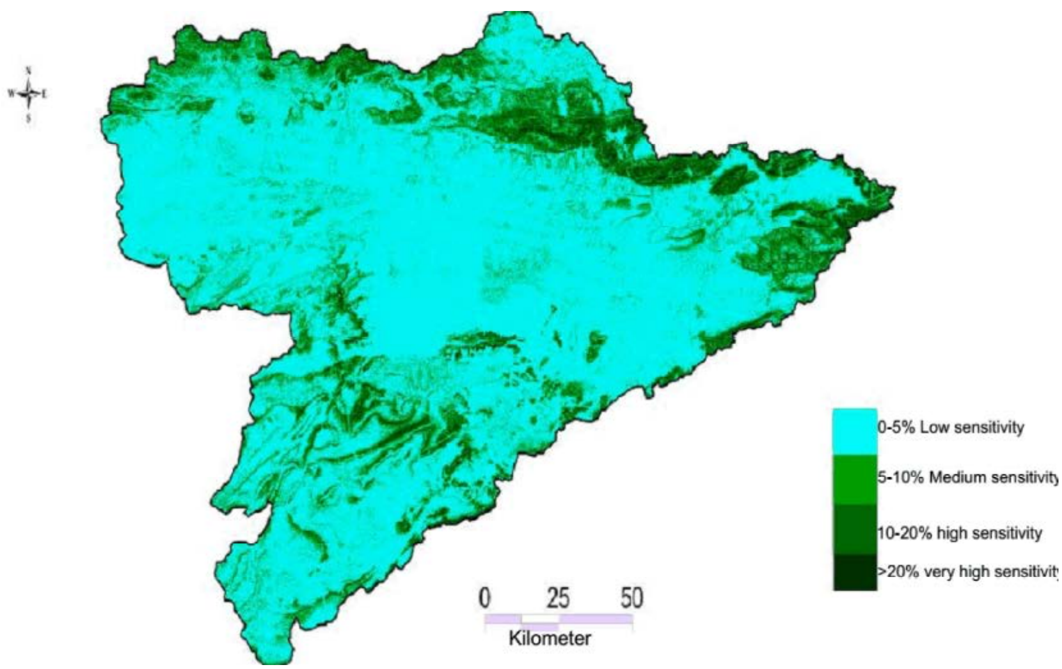

Fig. 2: Erosion sensibility of Hodna versus the Land slope (on %)

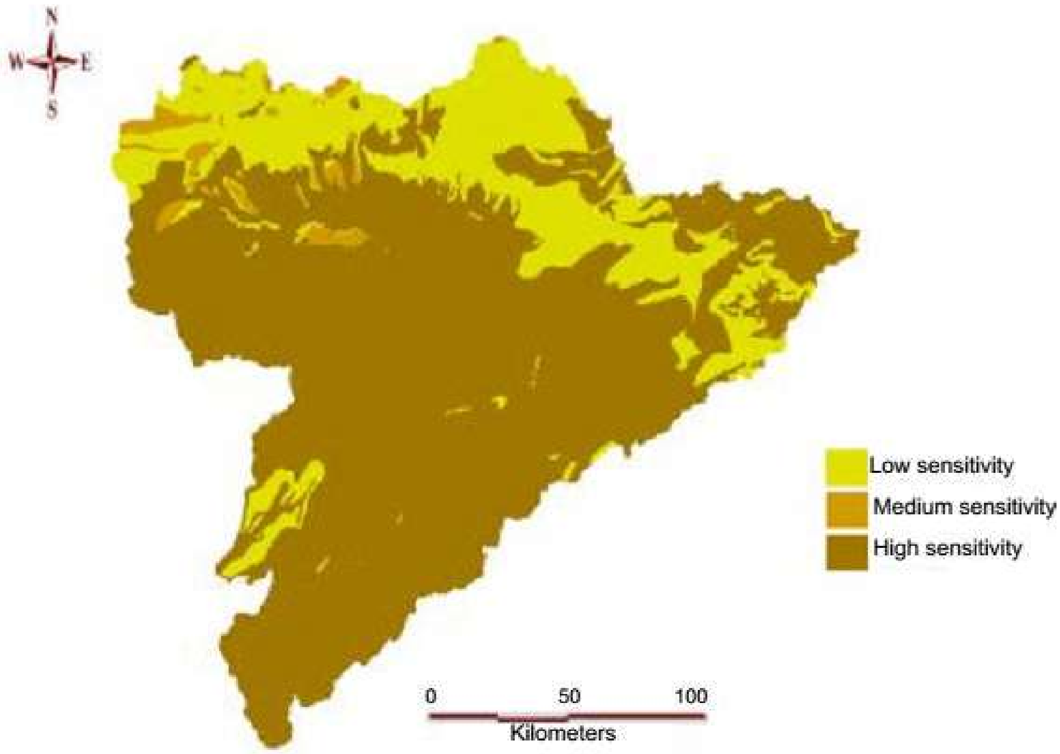

Fig. 3: Erosion sensibility of Ksob watershed versus the geology

Mapping of these three classes under the Hodna geologic map (Figure 3), shows that the low and the medium erodibility are located at the north of the basin, however, almost all the rest of the basin is at a high sensitivity to erosion.

The land use type has a different response to the water erosion, so, the most sensitive sectors are marked by the absence of the vegetal cover. In this study, we use a land use map generated from satellite photos provided by the forest agency of M'sila department. The classification of different types of land use allows the identification of four classes of sensitivity to water erosion:

- Class I (low sensitivity to water erosion) this class includes area that resists to erosion such as water bodies, roads, urban areas and deciduous forests.
- Class II (medium sensitivity to water erosion) this class includes areas that curb the runoff, especially the meadows and arable areas.
- Class III (high sensitivity to water erosion) this class includes the arable areas like the cereals, oilseeds and fodder because of the fertility of arable land.

Mapping of these three class under the Hodna land use map (Figure 4), shows that the majority of Honda area is classified between high and medium sensitivity to the water erosion. The low sensitivity is observed in the north and some southern regions of the basin.

The Hodna basin is equipped by several rainfall stations spread over its surface (Figure 1), among these stations, we use the data of 21 stations whose their data are exploitable. In fact, the rain accelerates the water erosion by its intensity. In this qualitative study, we use the maximum daily rainfall (R_{dmax}) as the representative parameter of the rainfall effect, which is also the most recorded parameter in the rainfall stations.

The maximum daily rainfall map generated by kriging method allows the identification of three class of the sensitivity to the water erosion by the rainfall

- Class I (low sensitivity to water erosion) for $R_{dmax} = 24$ mm
- Class II (medium sensitivity to water erosion) for $24 < R_{dmax} = 28$ mm
- Class III (high sensitivity to water erosion) for $R_{dmax} > 28$ mm

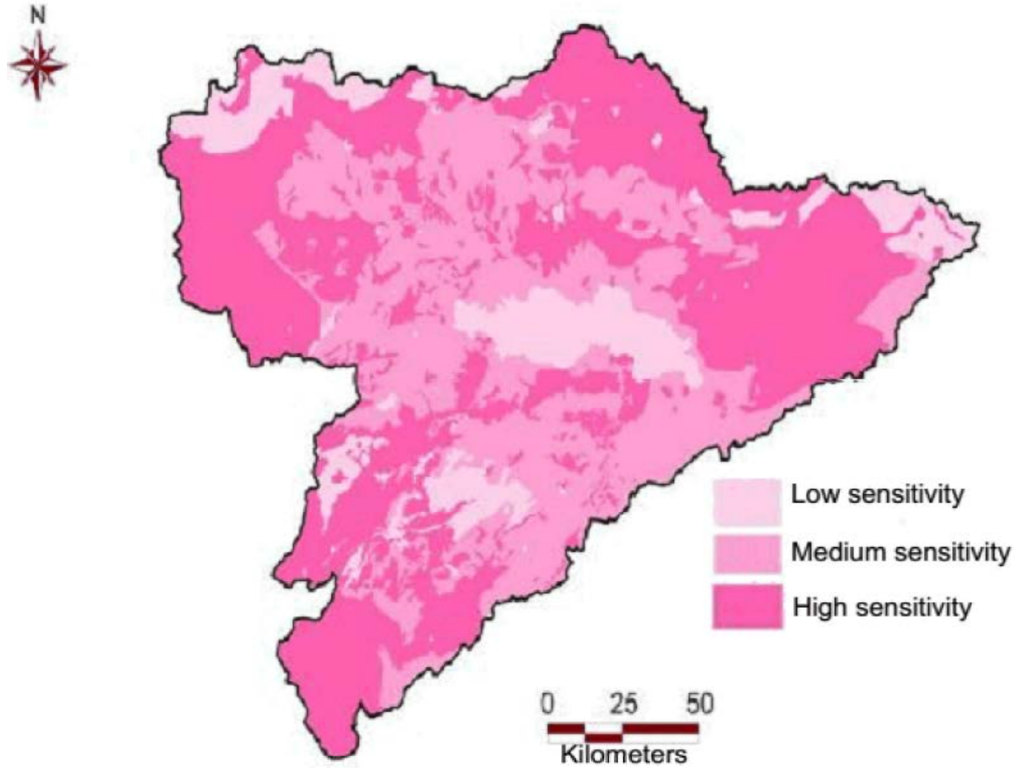

Fig. 4: Erosion sensibility of Ksob watershed versus the land use

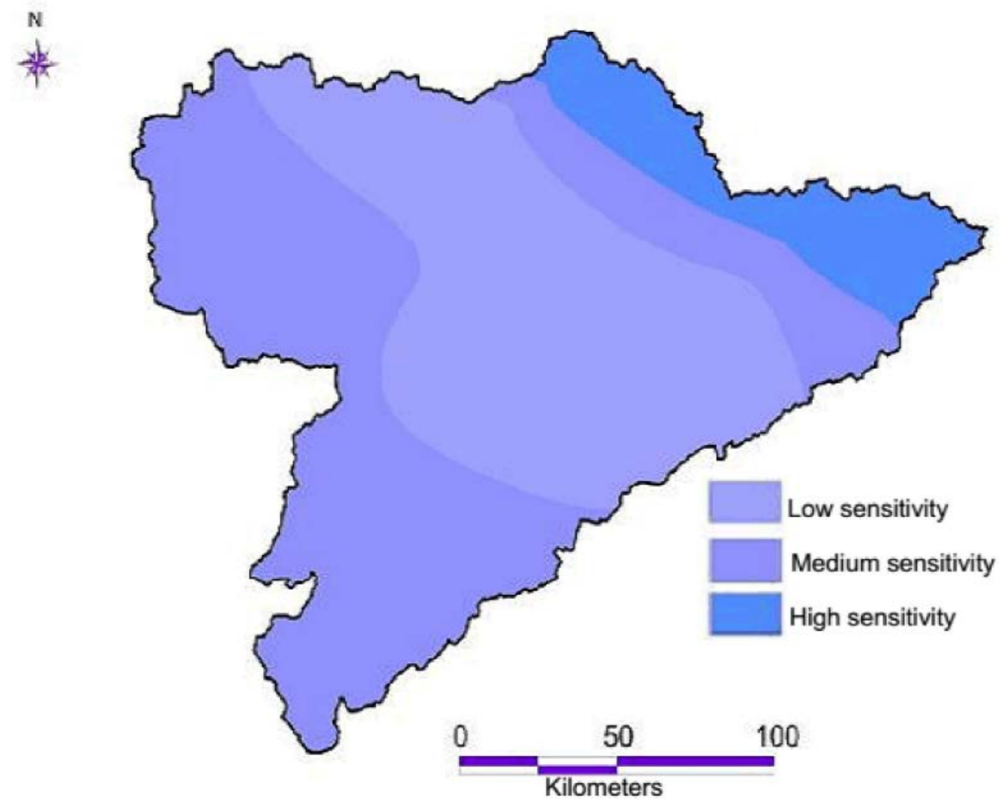

Fig. 5: Erosion sensibility of Hodna basin versus the maximum daily rainfall

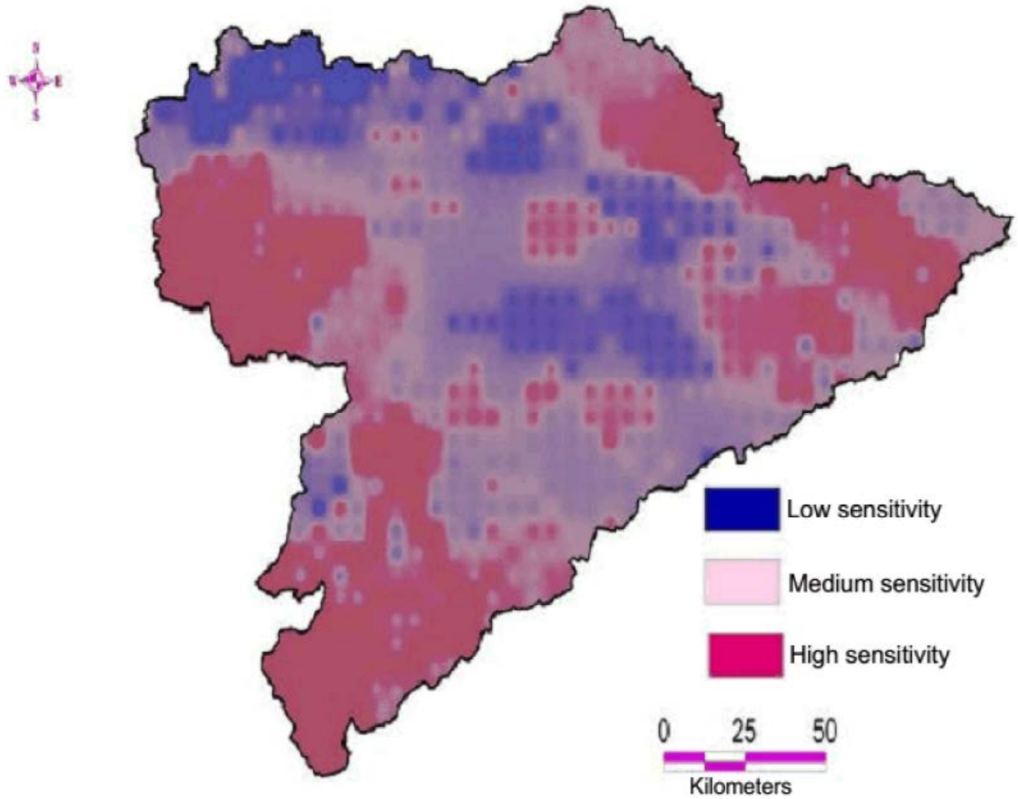

Fig. 6: Erosion sensibility of Hodna basin

Table 2: The index ISS Characteristics

Parameter	impact weight (IW)	Class	Systemic Sensitivity Index (ISS)
Land use	4	X	ISS= 4X
Geology	3	X	ISS= 3X
Rainfall	2	X	ISS= 2X
topography	1	X	ISS= 1X

Mapping of these three class (figure 5), shows the trend of precipitation increase with altitude. In both mountainous regions in the south and the north of the basin, it is more important involving a high sensitivity to water erosion. Contrariwise, in the center of Hodna (almost flat area), it is rather the contrary; the rainfall has a tendency to decline, which explains the low sensitivity.

To develop the sensitivity map of Hodna tacking into a count the four parameter (topography, geology, the land use and the rainfall), we propose divide the basin area in systematic units of about 3.50 square kilometers each, so that they serve as indicators of sensitivity.

We attribute to each studied parameter an impact weight (IW) from 1 to 4 according to its importance in the erosion process. According to scientific literatures, we can class the four parameters according their importance in the erosion process as: land use (IW =4), geology (IW = 3), rainfall (IW = 2) and the topography (IW = 1). By the multiplication of the weight (WI) by the class number (1: low sensitivity, 2: medium sensitivity and 3: high sensitivity), we can define the systemic sensitivity index (SSI) on each unit (Table 2).

ISS is considered as a hazard indicator of each unit to water erosion taking into account the four studied parameters. The mapping of ISS in the whole Hodna basin area allows the identification of three classes of sensitivity to water erosion.

For ISS > 30 the vulnerability to water erosion is very high and the hazard is also high. We classify these regions in the high sensitivity to water erosion

Similarly, we classify the regions with 20< ISS < 30 in the medium sensitivity to water erosion and those with ISS < 20 in low sensitivity to water erosion

The obtained map (Figure 6) shows that the most sensitive areas to erosion (almost 25 % of the Hodna surface) are located in the south to the east and at the north to the west in the mountain regions. The rest of the basin surface varies from low (about 17% of the surface) to medium sensitivity (about 58% of the surface).

CONCLUSION

In Algeria, the water erosion and the sediment transport present a great challenge to preserve the environment and the surface water resources. The mapping of the most vulnerable areas to erosion enables to better reduce and limit the dangers of this phenomenon. In this paper we have contribute to map the water erosion sensitivity of a large semi-arid basin of Hodna (26 000 km²) in the center of Algeria. We have used a qualitative approach based on multi-criteria method of the parameters of topography, the geology and the land use with a hydro-climatic forcing parameter represented by the precipitation.

The analysis of the maps obtained under GIS environment for different parameters, shows that the findings vary from one parameter to another; however, taking into account the all criteria, the obtained map shows that the areas with a high vulnerability to erosion are located in the south and the west of the basin, representing 25% of the basin area. The rest of the basin surface varies from low sensitivity (16.79%) to medium sensitivity (57.76%). This approach is of great interest for ungauged basins; it can be improved or verified by a quantitative approach in the gauged basin.

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