

## MAPPING OF SOIL WATER EROSION BY REMOTE SENSING AND GIS: CASE OF THE WADI BOUMESSAOUD WATERSHED (NW-ALGERIA)

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### Abstract:

Like other semi-arid regions, the north of Algeria undergoes the impact of a strong erosive potential especially in the denuded lands of steep slopes. The climate with all its hazards favored the occurrence of intense downpours and torrential floods, thus generating several environmental damages such as the loss of agricultural land, the siltation of dams and water pollution. The identification of areas at risk of water erosion is therefore necessary, this leads us to resort to cartographic approaches using various digital data which will be subjected to a multifactorial analysis via the computer tool of the GIS. The methodology adopted is that which is inspired by qualitative models using a crossing of parameters representative of the determining factors in erosion in the form of logical combinations. First of all, the factors intrinsic to the soil (relief, type of soil and vegetation cover) are combined with each other to obtain an index identifying the potential sensitivity of soils to erosion, and then a cross-referencing is carried out with the climate factor by the effect of precipitation erosivity. The study applied to the Wadi Boumessaoud watershed (118 km<sup>2</sup>) located in the northwest of Algeria, enabled us to draw up a map describing four classes of multifactorial risk of soils to water erosion: low (26%), medium (35%), strong (28%) and very strong (11%). The results indicate that the basin is subject to strong and moderate erosion affecting more than 60% of the total surface, where the erosion factors combine with each other: steep slopes exceeding 15°, degraded plant cover and soils characterized by particularly soft and strongly erodible outcrops undergoing extensive agriculture. The study could constitute a reference document for the forecasting of floods and the protection of irrigated perimeters or any other anti-erosion development project to be planned.

**Keywords:** Water erosion, Watershed, Erosion risk, Mapping, GIS

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## INTRODUCTION

Algeria, a Mediterranean country whose climate tends towards semi-aridity and where the risks of desertification remain very high, has experienced significant episodes of periodic and frequent droughts, the duration of which can exceed three successive years (Meddi and Hubert, 2003; Khaldi, 2005; Baba Hamed, 2007; Baghdadli, 2014; Djellouli, 2017; Otmame, 2019). Natural disasters appear and trigger floods and torrential floods resulting in considerable material and human damage. Soil erosion is one of the consequences of these extreme phenomena that mark the Mediterranean basin, it causes the loss of soil productivity, the siltation of dams and water pollution. Inappropriate farming practices, deforestation, overgrazing and human activities are all causes that accentuate soil erosion in the Maghreb (FAO, 1980, PAP/RAC, 1998; Boukheir et al., 2001, Achite et al., 2006; Touabia et al., 2010). The decrease in annual water reserves by sediment deposition in reservoirs in Algeria has been estimated at 40 million m<sup>3</sup> (Remini, 2009; Rémini, 2010).

Various forms of soil degradation (badlands, landslides, solifluction) are emerging over vast areas, particularly sloping clay soils devoid of vegetation. According to Roose et al. (2012) in the low Mediterranean mountains with slopes varying between 10 and 40%, gully erosion largely dominates tillage erosion and sheet erosion. In this context, one of the sub-basins of northwestern Algeria in a semi-arid climate, namely the Boumessaoud wadi, has been targeted in order to identify the zones vulnerable to erosion according to a certain number of factors triggering. These have been adopted by several authors and include the soil by its erodibility or its capping, the plant cover by its protective effect, the topography by the slope of the land and the climate by the erosivity of the rains (Moussa et al., 2002; Le Bissounais et al., 2004; Mazour, 2004; Souchère et al., 2005; El Garouani et al., 2008; Aké et al., 2012; Boughalem et al., 2013; Bouguerra, 2018).

In fact, rainwater runs off sloping land, carrying sedimentary particles and promoting the formation of slaking crusts. In addition, crop residues and vegetation litter protect the soil from the impact of raindrops, absorb a large amount of runoff energy and allow better infiltration. The soil intervenes by its erodibility in the sense that it undergoes the effects of other erosive factors and reacts according to its nature which itself depends on the characteristic properties of the soil such as its texture, its mineralogy and its structural stability (Roose, 1994; Le Bissonnais et al., 2002; Boughalem et al., 2013). The methodology undertaken in this study aims to exploit remote sensing data and satellite images relating to erosion parameters for multifactorial mapping of areas exposed to water erosion after

integrating and analyzing them in a GIS environment. Thus, an evaluation of the qualitative erosion is established thanks to various crossings of the thematic maps between them. The results of this approach will provide information on the degrees of soil degradation in the basin and allow the implementation of an erosion prevention strategy.

## MATERIAL AND METHODS

### Study Area

The watershed of the Boumessaoud wadi is part of the large Tafna basin which extends to the northwest of Algeria. Located between longitudes 1° 19' 15" W and 1° 28' 30" W and latitudes 34° 49' 30" N and 34° 58' 55" N (Fig.1), it covers an area of 118 km<sup>2</sup> for a perimeter of 60 km. Elongated in shape, it occupies an area of 118 km<sup>2</sup> with a perimeter of 59 km. In the southern part of the basin, the slopes are steep (> 20%) and the altitudes reach 1150 m. The hypsometric curve indicates that 80% of the surface is between 900 and 200 m with a median altitude equal to 630 m.

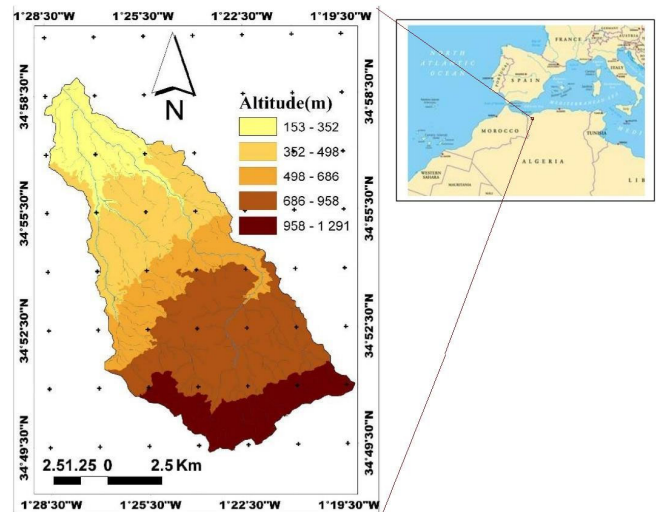


Fig. 1 Study area

From upstream to downstream, we find Jurassic carbonate formations which characterize the south of the basin, while in the center marl and sandstone formations of the Tertiary predominate and towards the north there are outcrops of marls from the lower Miocene and recent alluvium (Bouanani, 2004). The climate in this region is semi-arid, the average temperature is 16.3°C. The rainfall regime is very irregular and the basin receives an average of 382 mm annually. Two climatic periods characterize the hydrological year: a period corresponding to the

dry months of the year (June, July, August), and another for the remaining nine months in which the months of November to March are considered the rainiest in the year.

## Methodology

Different empirical models (quantitative and qualitative) have been adapted to predict, characterize and understand the phenomenon of water erosion and highlight the factors that come into play throughout this process (Wischmeier *et al.*, 1978; Renard *et al.*, 1997; Cerdan *et al.*, 2006; El Garouani *et al.*, 2007). Water erosion depends on active (precipitation intensity) and passive (soil texture, vegetation cover, slope, etc.) characteristics. In terms of risk, active characters can be assimilated to hazard and passive characters to part of the vulnerability that can be grouped under the name of potential sensitivity to erosion (El Hage Hassan, 2013). Thus, risk can be defined by the intersection of two dimensions: hazard  $\times$  vulnerability.

For our work, the source data focused on four main factors which are now the subject of a consensus and include soil, land use, relief and climate (more precisely precipitation). The following remote sensing and satellite image data are used using ArcGIS software to produce maps of erosion factors:

- world erosivity map at a resolution of 30 arc seconds (~1 km) which is available on the site of the European Soil Data Center (<https://esdac.jrc.ec.europa.eu/content/global-rainfall-erosivity>): its processing makes it possible to extract the erosivity map of the basin of study.

- world erodibility map from the site relating to the harmonized database of soils of the world which is the result of a collaboration between FAO, ISRIC-World Soil Information, the Institute of Soil Sciences, the Chinese Academy of Sciences (ISSCAS), and the Joint Research Center of the European Commission (<https://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/>): its use provides us with the erodibility map.

- The Shuttle Radar Topography Mission (SRTM) image at coordinates SRTM1N34W002V3 and SRTM1N35W002V3, July 10, 2014, from the TERRA satellite downloaded from

the EarthExplorer-USGS site (<https://earthexplorer.usgs.gov/>): its processing made it possible to extract the slope map.

- The Landsat ETM+ 2007 image was used to extract the map from the NDVI (Normalised-Difference Vegetation Index): its use led to the characterization of land cover.

The mapping approach adopted is inspired by the qualitative model of the expert system type, such as MESALES, the model for the spatial evaluation of the hazard of soil erosion, i.e. a model using a crossing of determining parameters in erosion in the form of logical combinations whose weight must be weighted based on current knowledge of the different types of erosive functioning (Le Bissonnais *et al.*, 2004). The unanimously recognized role of vegetation against water erosion has led us to retain a higher weighting coefficient for plant cover. The approach consists of assigning coded classes to each erosion factor in order to reflect the influence of each in the estimation of vulnerability at the spatial scale. The classification of the various factors according to their involvement in erosion was established taking into account field observations and bibliographical knowledge (Bou Kheir *et al.*, 2001; N'dri *et al.*, 2008). The integration of cartographic and descriptive data of the factors influencing the water erosion process was carried out in a GIS. Finally, the synthetic map of water erosion risk distribution was produced from the combination of the previous thematic maps, applying the qualitative approach (of the expert system type).

## RESULTS AND DISCUSSION

### Rainfall erosivity factor (R)

The noted precipitation erosivity factor (R) is obtained for all given periods by summing - for each rainstorm - the product of the total energy of the storm ( $E_c$ ) by the maximum rain intensity in 30 minutes (I30):  $R = E_c * I30$  (Wischmeier *et al.*, 1978). Unfortunately, this data is not available at standard weather stations. For our case, the basin rainfall erosivity map (**Fig. 2a**) was obtained by the ArcGIS software using downloaded cartographic data on the erosivity factor R, in this case the world erosivity map which is available on the European Soil Data Center website. With values varying between 349 and 487 MJ.mm/ha.h.year, the map

shows low and medium erosivity in the center of the basin, while the north and south experience an increase in the R factor.

### Soil erodibility factor (K)

According to Wischmeier *et al.* (1971), the K factor depends on several soil properties (soil texture, organic matter content, soil structure and permeability). The acquisition of the world erodibility map (in addition to a file on the granulometric and organic properties of the soils) was made from the availability of data from the site relating to the harmonized database of soils of the world which is the result of collaboration between FAO and other state bodies such as the Joint Research Center of the European Commission. Note that the erodibility factor K was calculated according to the formula established by Williams (1995) and which is the product of four parameters which take into account the texture and organic matter of the soil. Using the GIS tool, we were then able to process all this data to produce the map of the erodibility factor relating to the study catchment area (**Fig.2b**). Four classes of outcropping materials were identified (resistant, moderately resistant, vulnerable and very vulnerable). The middle class is the most frequent where the soils are the most resistant and the most stable (brown calcareous soils, little evolved soils and association of marls and sandstones) with a K factor equal to 0.20, it occupies a large central part with more than 70% of the pool surface. Friable outcrops (K=0.3-0.4) are less resistant and more vulnerable found in the north (Miocene marl and silty alluvium) and south (sodium vertisols and Jurassic marl-limestone) with more than 20% of the total surface of the bowl. The erodibility values found indicate a clear fragility of the soils increasing the erosive potential of the watershed.

### Topographic Factor (S)

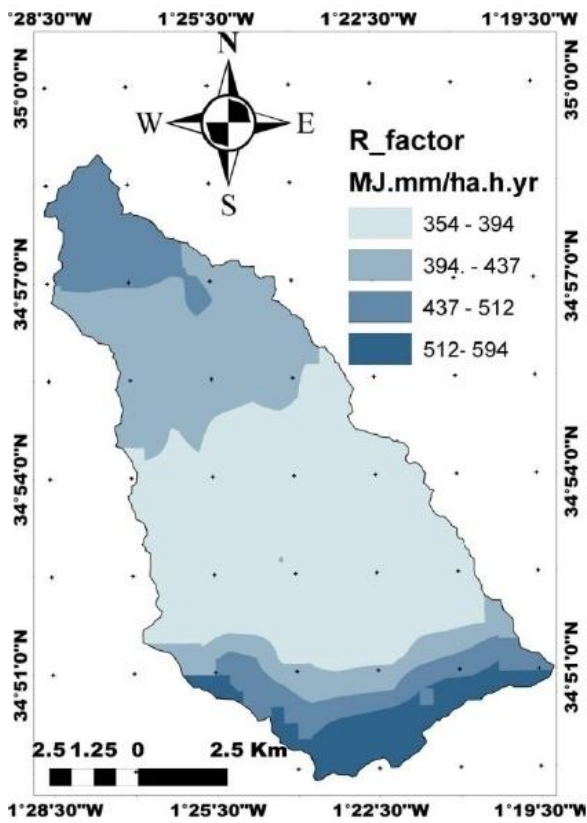
Topographic Factor has two components: Slope (S) and Slope Length (L). This has more uncertain effects in the Mediterranean regions (Roose, 1994; Boukheir, 2002), it was not taken into account in this study. The digital terrain model (DTM) derived

from satellite maps (SRTM) enabled us to establish the map of the slopes via the ArcGIS software (**Fig. 2c**). In the figure, the steepest strong and very steep slopes are mainly concentrated in the upstream part of the watershed characterized by a mountainous relief where the slope exceeds 15°. The moderate slopes as well as the low to very low slopes (< 10°) are distributed much further downstream and to the south-east of the basin. We ordered and mapped the slopes into four classes (**Fig. 2c**).

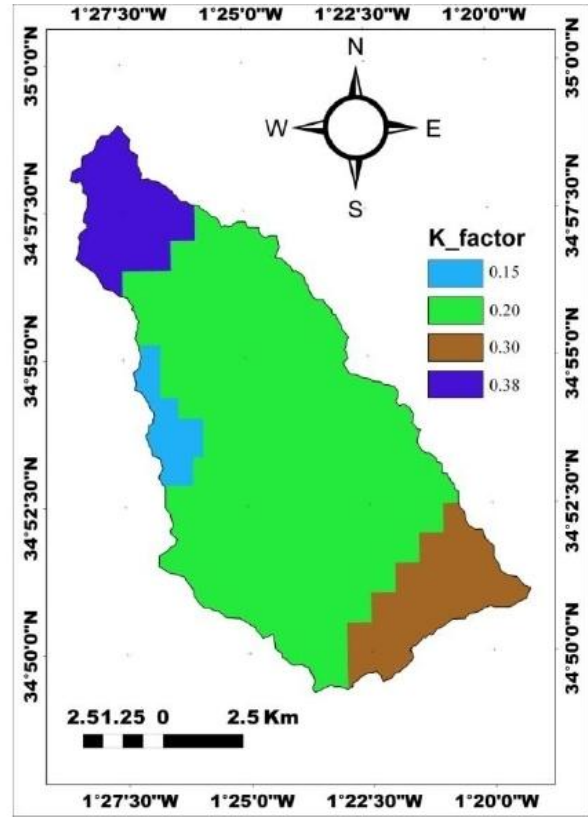
### Vegetation cover factor (C)

Vegetation cover is after topography the second most important factor that controls the risk of soil erosion. It provides information on the degree of protection of the floor. Indeed the roots of trees and plants fix the soil improving its structural stability and thus promoting infiltration. Falling plant leaves are transformed into organic matter, which promotes biological activity and biomass formation, which enhances the physicochemical properties of the soil and contributes to its cohesion (Roose *et al.*, 2012). Soil that is well covered by vegetation slows down the flow of water, while bare soil is more prone to erosion.

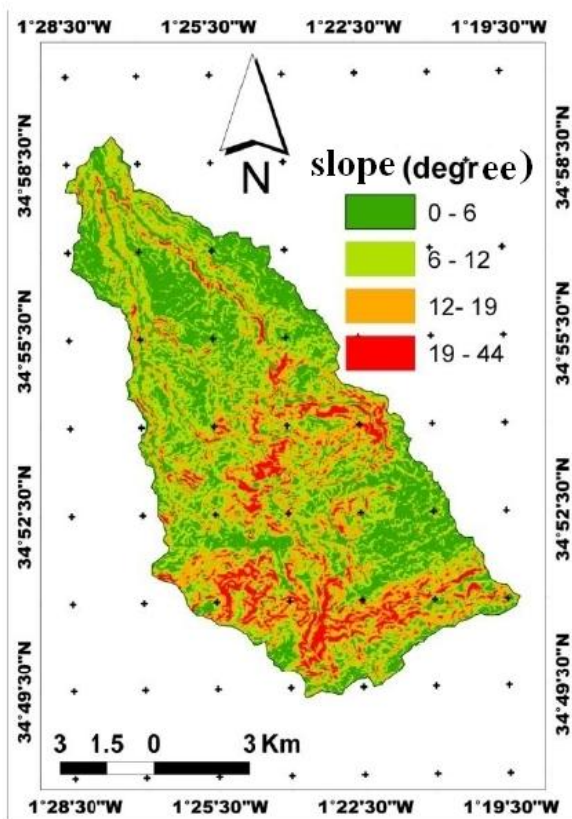
Using ArcGis software, the combination of several spectral bands from the ETM+2007 Landsat image was used to extract the map from the NDVI (Normalised Difference Vegetation Index), the most widely used indicator of vegetation growth in remote sensing. Thus, by drawing on methods put forward by many authors who have worked on regions with a Mediterranean climate and by adopting appropriate correlations between NDVI and vegetation properties (Van Der Knijff *et al.*, 2000; Roose *et al.*, 2012), expert (C) values were assigned to different vegetation types in our watershed, while taking into account field observations (**Fig. 2d**). Four classes of vegetation cover were defined: very dense vegetation (C = 0.01), sparse or medium-density vegetation (C = 0.25), cultivated land (C = 0.4) and bare land (C = 0.8). Each class is assigned a value between 1 and 4, with 1 assigned to the least vulnerable class and 4 to the most vulnerable class.



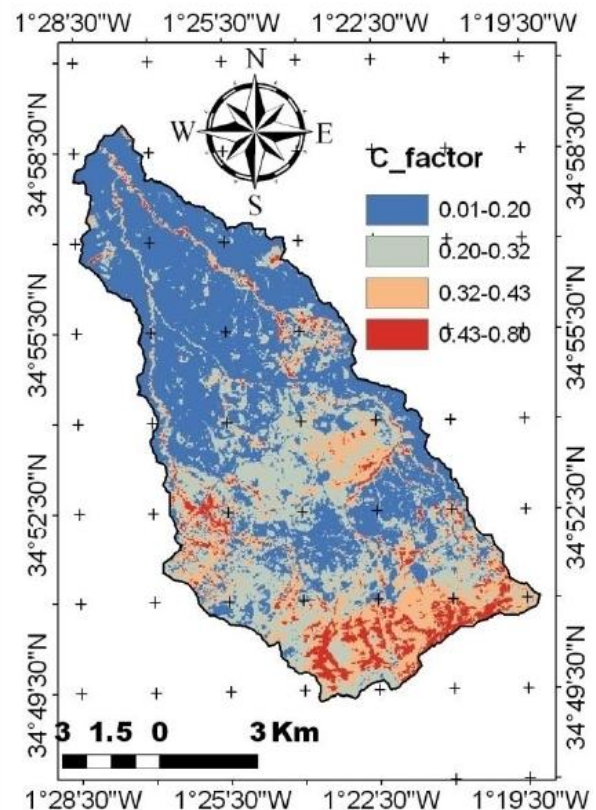
(a)



(b)



(c)



(d)

Fig.2 Erosion factors: (a) erosivity, (b) erodibility, (c) slope, (d) vegetation cover.

**Table 1** summarizes for each factor, the classes coded in ways to reflect the influence of each in the estimation of vulnerability. The weighting coefficients inspired by the knowledge of the terrain and the general principles used by Le Bissonnais (Le Bissonnais et al., 2004): 1 (for the erodibility of the terrain), 2 (for the topography), 3 (for vegetation cover), the erosivity factor being constant.

**Table 1.** Classification of the factors of soil water erosion in the study basin.

Erosion Factor	Weighting coefficient	Rank (MJ.mm/ha.h.an)	Vulnerability to Water erosion	code
Rainfall Erosivity (R)	/	354 - 394	low	1
		394 - 437	medium	2
		437 - 512	strong	3
		512 - 594	very strong	4
Soil typology factor (K)	1	stony lithosols: K=0.1 limestone shell, sandstone	Low	1
		brown calcareous soils: poorly developed soils, Mediterranean fersiallitic red soils K=0.1-0.2	Medium	2
		sandy marl and silty alluvium: K=0.2-0.3	Strong	3
		sodium vertisols, marls and clays: K=0.3-0.38	Very strong	4
		Alluvial plains 0-8°	Low	1
Slopes in degree factor(S)	2	Hills and foothills 8-15°	Medium	2
		Valleys, Mountains 15-23°	Strong	3
		Rugged and steep terrain 23-52°	Very strong	4
		very dense vegetation: (C=0.01-0.2) Maquis and reforestation	Low	1
Vegetation Cover factor (C)	3	sparse or medium density vegetation:Arboriculture (C=0.2-0.35)	Medium	2
		Extensive cultivation and/or fallow land cropland(C=0.4)	Strong	3
		bare land, range (C=0.8)	Very strong	4

### The Water Erosion Risk Map

To produce the map of the multifactorial risk of erosion in the catchment area, a first index (I) is first determined for each sector to assess the potential sensitivity of the land to erosion from the crossing of data on soils, land use and slope by the following formula:

$$I = \sum_{j=1}^4 \sum_{i=1}^3 P_i * S_j \tag{1}$$

Where Pi: represents the weight of parameter i (soil, slope, vegetation), Sj: is the contribution of class j for each of the parameters i.

Thus, for class 123, which represents stony lithosols outcropping on a slope varying from 8 to 15° on cultivated land, the index is 14(1×1+2×2+3×3). Four erosion vulnerability classes were drawn: low (indices 6 to 14), medium (indices 15 to 17), high (indices 18 to 20) and very high (indices 21 to 24). An index (I') is then calculated by cross-referencing the potential sensitivity with the erosivity factor R to assess the erosion risk:

$$I' = R_j \times I \tag{2}$$

where Rj is the contribution of the Erosivity factor for j between 1 and 4.

Thus, the cross-referencing of factors according to selected qualitative rules allowed us to develop a map describing four classes of multifactorial risk of soils to water erosion (**Fig. 3**). Areas at high and very high risk of erosion represent 39% of the area studied. They occupy a large majority of the upstream part of the basin, with extensions in the middle and northeast. These regions are exposed to intense erosivity and the soils have a high erodibility (K>0.3) with fairly steep slopes (>15°), dolomites, limestones and sandstones with argillaceous intercalations of the Jurassic. In the center and towards the far north of the basin, at the level of the lower parts of the plains and valleys, recent alluvial deposits outcrop consisting of clays, sands and gravels where one observes sparse vegetation and agriculture practiced on sloping ground which accentuates the appearance of a network of ravines and cuts in the banks towards the main watercourse. The strong erosive dynamics can also occur by mass movements and mudslides at altitude on little evolved brown soils which prevent the infiltration of water. The middle class affects 35% of the basin and is mainly observed in the center and downstream of the basin with a part in the southeast.

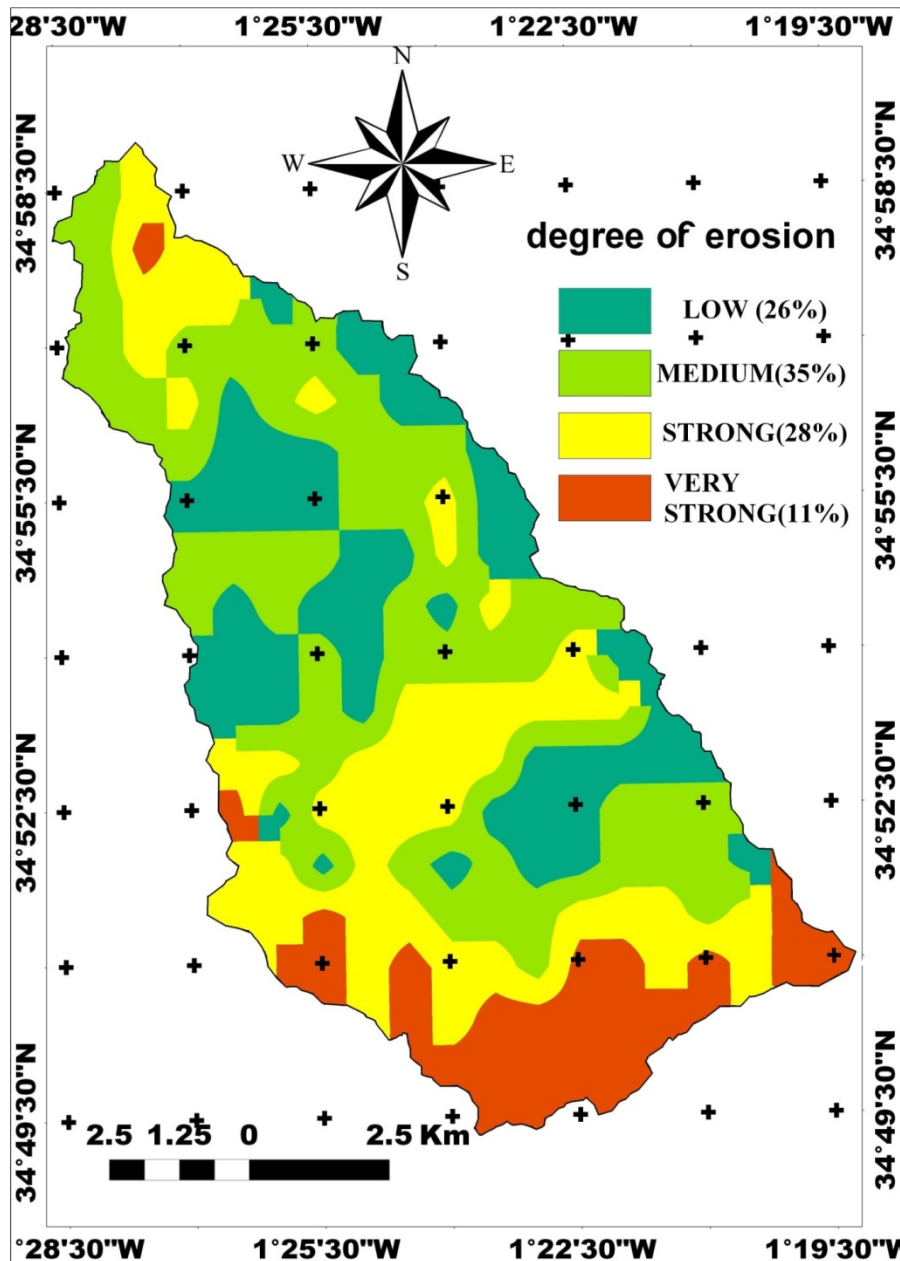


Fig.3 Multifactorial risk of water erosion in the Boumessaoud wadi basin.

These sectors are sensitive to the formation of the slaking crust and have no protective vegetation cover. Cultivated land, degraded maquis and sparse paths on moderate slopes (5-10°) are the seat of this type of erosive dynamic. The predominant forms of erosion are diffuse runoff which evolves into gullies on brown limestone soils and red fersiallitic soils where the erodibility exceeds 0.2. The presence of zones with a low degree of erosion (26%) can be observed in the south on dolomitic sandstone soils characterized by maquis and dense forest cover, and in the center on gently sloping soils (<5°) subject to less the erosivity of the rainsand where the erosion is attenuated by the

presence of cereal rotations and some arboriculture land.

**Validation**

Various methods have been used to validate the results of this type of approach, for example: measurement of sediment accumulation in a reservoir, measurement by radioactive tracers and magnetic susceptibility of sediments (Ait Fora, 1995 ) or even direct confrontation with the reality on the ground according to adapted visual criteria (Bou Kheir, 2001). In this perspective, we adopted this last technique, and physical criteria marked the changes of the landscapes according to different

potential sensitivities observed such as the rootlets of shrubs, the roots of bare trees, residual mounds of soil and height and width of the gullies. The degree of degradation caused to the types of soil shows a concordance between the map thus produced and the reality on the ground of about 80%. Finally, anti-erosion measures should be proposed in order to limit soil degradation. The solutions are based on appropriate management techniques and methods of cultural practices, such as stubble cultivation, hoeing, peeling, setting up and maintaining grass strips, hedges, embankments, fascines ( bundles of branches to limit runoff), the prohibition of agricultural practices on slopes of more than 15°, the protection of the forest, the reforestation of bare areas, the installation of retaining walls and the construction of terraces that conserve land for agriculture (Druais, 2009, Roose *et al.*, 2012).

## CONCLUSION

This study shows that the Boumessaoud wadi basin faces a high and medium risk of water erosion affecting more than 60% of the soil. This is the consequence of the combined effect of natural factors such as the presence of steep slopes, an alarming degradation of the plant cover, and very friable outcrops. The erosivity of rainfall further increases the risk on soils classified as highly sensitive to slaking (downstream) and on steep terrain devoid of dense vegetation (upstream). In order to arrive at much more reliable results, it would be necessary to update the available data and improve the logical combination procedures that have been implemented (prioritization of parameters, etc.). This study could contribute to better orienting the priority of intervention of decision-makers at the scale of the watershed according to the most potential erosion risks.

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