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Study of the vulnerability of soil to water erosion by remote sensing and GIS: Case of El Kala National Park (Algeria)

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Abstract

The consequences of soil degradation through water erosion are no longer demonstrated; however, their spatial extension tends to affect areas deemed to be immune to this scourge. This is the case of the El Kala National Park in the far northeast of Algeria, where particular natural and anthropogenic conditions contribute to the vulnerability of this natural heritage. The present study, which is based on the use of GIS, remote sensing, the combination of data from different sources and field observation, has allowed for a contextualized mapping of all soil erosion factors by surface water. In addition, the application of the revised universal soil loss equation (RUSLE) adapted to conditions in northern Algeria has produced a map of the risk of soil erosion where erosion affects 18.08 % of the total surface of the watersheds of El Kala National Park ,where soil losses are estimated at an average of 13.83 t / ha / year. This modest cartographic result is a perfect base for park managers as a means of observation, analysis and monitoring for the protection and safeguarding of a Ramsar site.

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Introduction

Water erosion, natural phenomenon with disastrous consequences, imposes it as the scourge of the Algerian mountain said (Sari, 1977). An expression that remains relevant despite the long time spent, effectively this azonal phenomenon, continues to impact man and society, it significantly reduces soil fertility 45 % of the fertile lands of Algeria are affected, significantly reduce the storage capacity of dams, the average annual specific degradation varies between 2000 and 4000 t / km² (Demmak, 1982).It affects both the northern and southern mountains indifferently. Because of its effects and extent, this phenomenon is eligible for the first-degree national natural hazard stage, affecting more than 20 % of the country's total area, 238 million hectares (Mostephaoui *et al.*, 2013). Areas that tend to increase given the permanence of erosive agent exposure situations. Despite the numerous contributions on the subject (Heush *et al.*, 1970; Demmak, 1982; Arabi, 1991; Meddi, 1992; Brahmia, 1993; Roose *et al.*, 1993; Touaibia *et al.*, 2000; Laouina *et al.*, 2000; Mazour *et al.*, 2002) and the list is still long, it continues to attract interest. Also, this study comes to reveal the conditions which prevail in the appearance and the extent of this phenomenon, in a part of the mountain Northeast Algerian. It is not a question here of returning to the mechanisms of erosion, but rather to shed light on the local factors that threaten or undermine the specific and particular characteristics of this northern mountain Atlas National Park. The watersheds of El Kala National Park, which are the subject of this study, combine all the natural conditions that predispose them to accelerated degradation. The proliferation of anthropogenic impacts, overgrazing, deforestation, fires, mishandling of agricultural work, extraction of sand, accelerated urbanization, the passage of the east-west highway (17 km), a wound now inscribed in the landscape of zones of Ain Assel and Bougous, in this case the idea of a park is seriously compromised. In this specific context of vulnerability of the physical components on the one hand and the social and economic moment that the park is going through on the other hand, any backup operation becomes problematic as the problems are multi-sectoral and multiscale. Erosion modeling is a way to identify ongoing land degradation processes in El Kala National Park.

The terms of the Revised Universal Soil Loss Equation (Renard *et al.*, 1997) lend themselves to spatial interpolation, which makes it possible to map all the factors and to spatialize the most sensitive zones to erosion. The objective of this study is to map the risk of water erosion using the RUSLE model, remote sensing and GIS in the watersheds of El Kala National Park. However, the database developed in this study can be used for the implementation of a management planning policy to protect and preserve the watersheds and water resources of lakes and dams in this park.

Materials and methods

Study area

The El Kala National Park, one of the first parks created in Algeria, with an area of 80,510 ha, is located in the far northeast of Algeria, bounded by the following geographical coordinates: Latitude: between 36 ° 56'N and 36 ° 34 'N, Longitude: between 8 ° 12'E and 8 ° 41'E (Fig. 1).

Geographically is limited to the East by the Algerian-Tunisian border, to the North by the Mediterranean Sea, to the West by the end of the alluvial plain of Annaba and to the South by the mountains of the Medjerda. Seen by the satellite images, the park emits a mosaic of topographical and color forms.

The first topographic form that is obvious in the eyes is that occupied by water, it is the low-lying areas where the altitude is sometimes negative; it is the domain of the lakes: Tonga, Obeira and Mellah, geographically they form an intermediate space between the coastal hills overlooking the sea by modest altitudes not exceeding 200 m and the mountain environment which in reality is only the eastern end of the Tellian range.

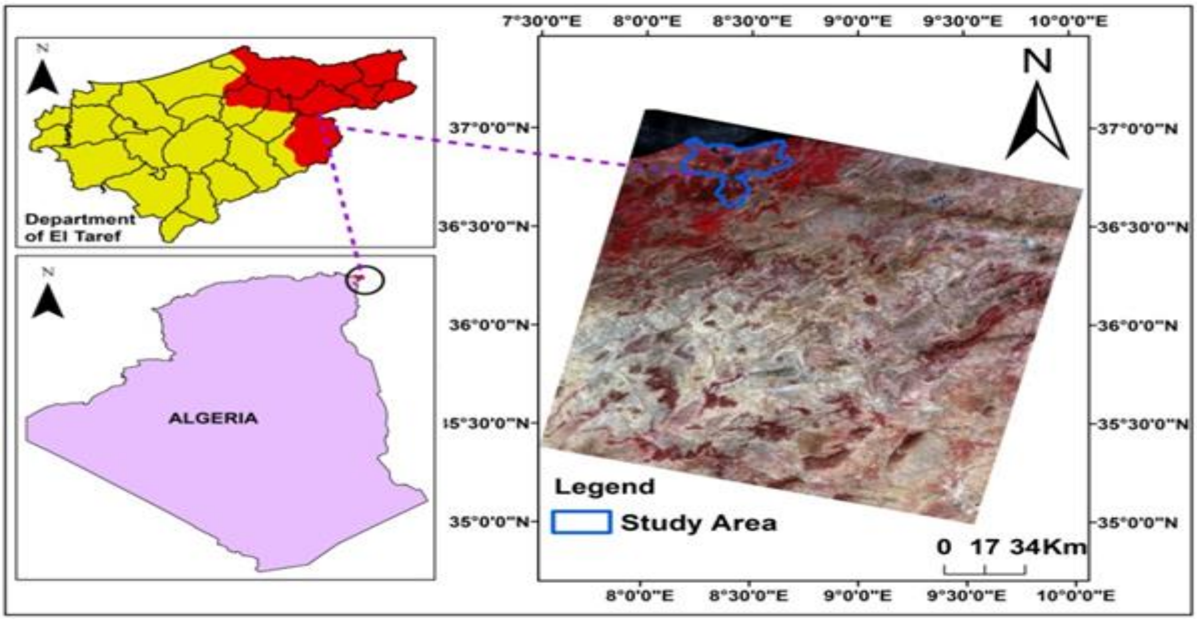

Fig. 1. Location of study area.

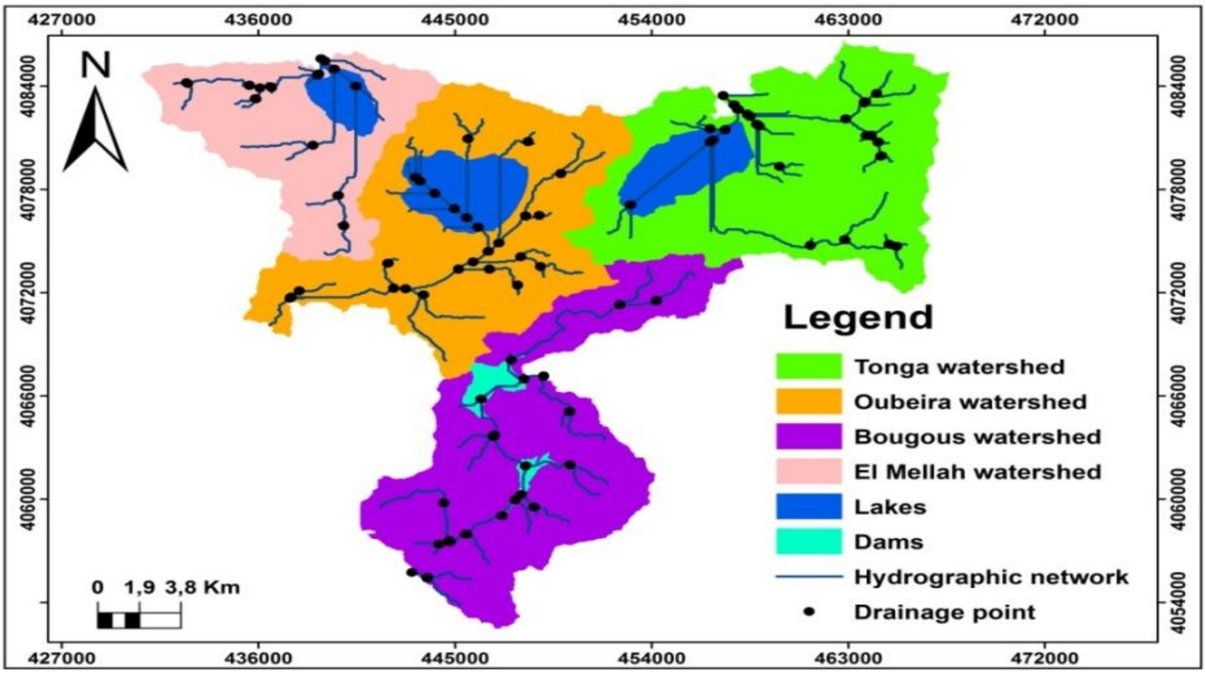

Fig. 2. Map of Main Watersheds of El Kala National Park.

It is in the form of mounds of modest altitudes 400 and 500 m. Nevertheless, this physical unit can reach 1073 m of altitude inside the chain. The climate is sub-humid Mediterranean with a rainy period from October to April and a dry period from May to September, with rainfall amounts ranging from 710 to 910 mm / year. The average annual temperature is around 18 °C or the hottest months are July and August, when the average temperature hovers around 25 °C. The coldest months are December and January with average temperatures of around 12 °C.

The vegetation cover in this wetland is very diverse and takes different forms, globally divided into forests, maquis, reforestation, rangelands and agricultural land.

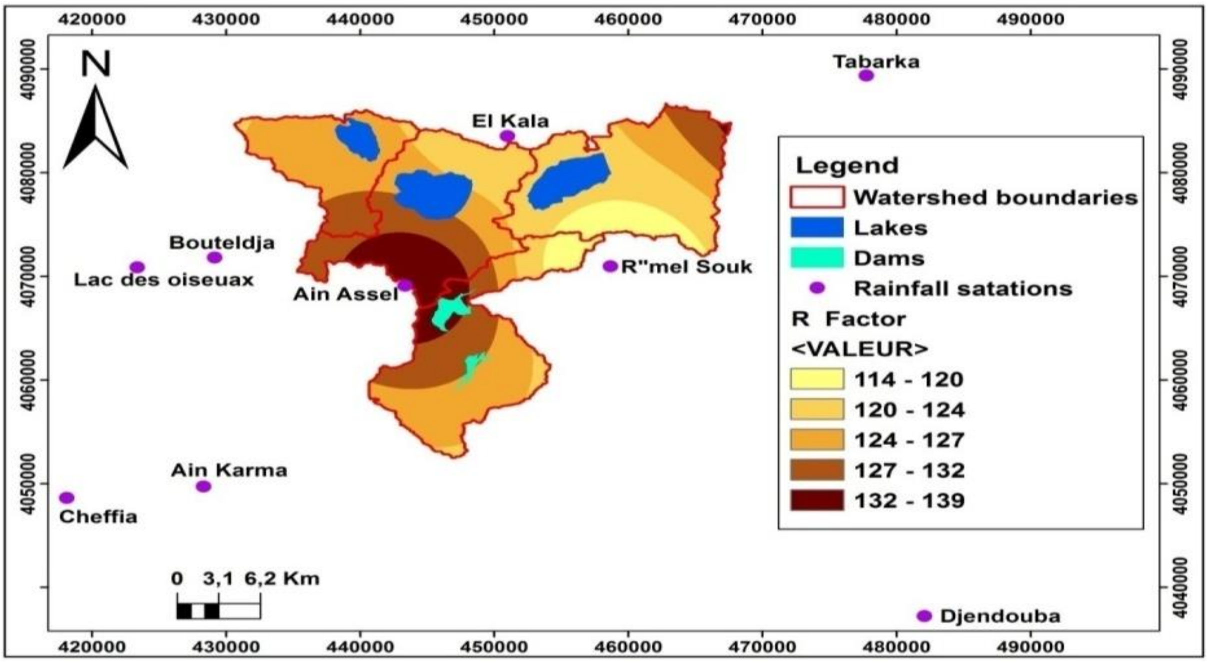

Fig. 3. Map of the factor R (Watersheds of El Kala National Park).

This particular feature of the park has experienced in recent years an alarming regression caused by several factors, the most important of which are anthropogenic (fires, clearing, overgrazing and urbanization).Hydrologically, the park was voluntarily segmented into watersheds (Oued Bougous, Tonga Lake, Oubeira Lake and El Mellah Lake) and this to meet the methodological requirements (estimation of erosion on the watershed) but also for the ease of identification of the starting areas of sediments (Fig.2), important data for erosion risk mapping and vulnerable areas close to water bodies.

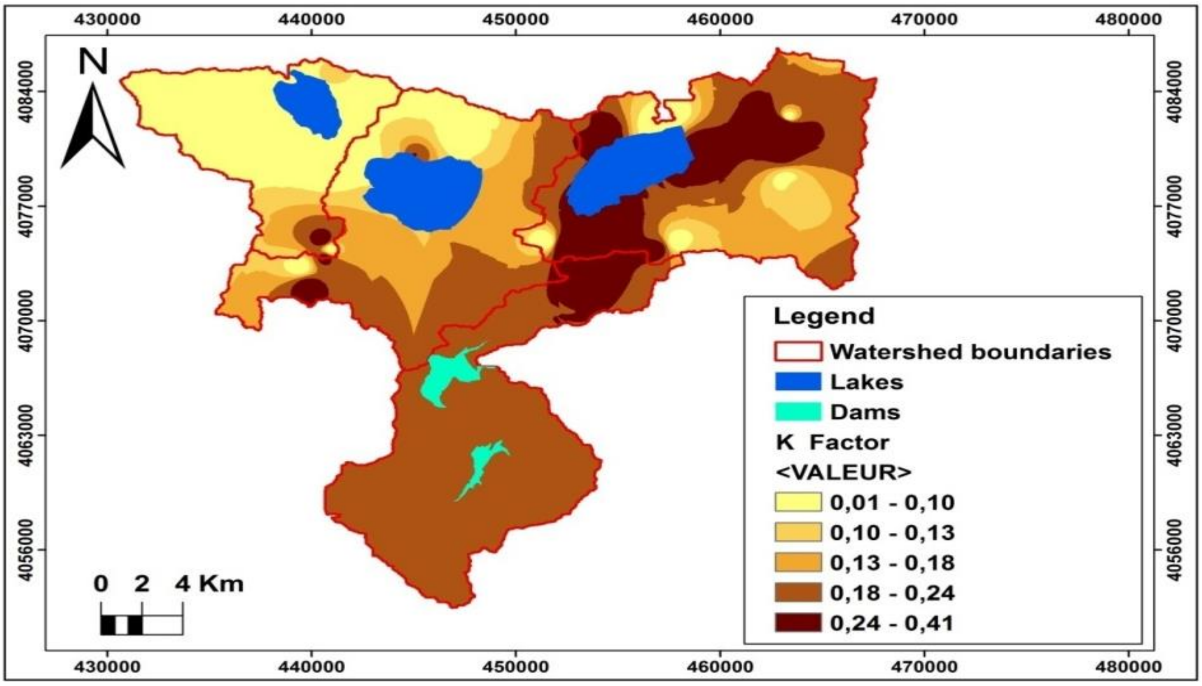

Fig. 4. Map of the factor K (Watersheds of El Kala National Park).

Description and calculation of RUSLE factors

This study is based on the use of the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997; Hyeon, 2006).However; its application is hindered by the availability and quality of the data. Overall, the geographic data that satisfies the application of the digitized equation are non-existent and those that exist are made at different or outdated scales, hence the use of online databases on a global scale. Also, we had recourse to: A 30 m resolution Aster GDEM image of 17/11/2011 and an image of the LandSat 8 OLI / TIRS program of 27/08/2016. Rainfall data provided by the National Water Resources Agency, Annaba Unit and field observations, March 2015, February 2016 and April 2017.The processing, analysis and development of the thematic maps were carried out on the software (ENVI 5.1, ArcGis 10.2.2 and Google Earth) punctuated by verifications in the field and localized using a (GPS).This equation is written as follows: A = R. K. LS. C. P (1) where**:**

A: (t / ha / yr), is the annual rate of soil loss.

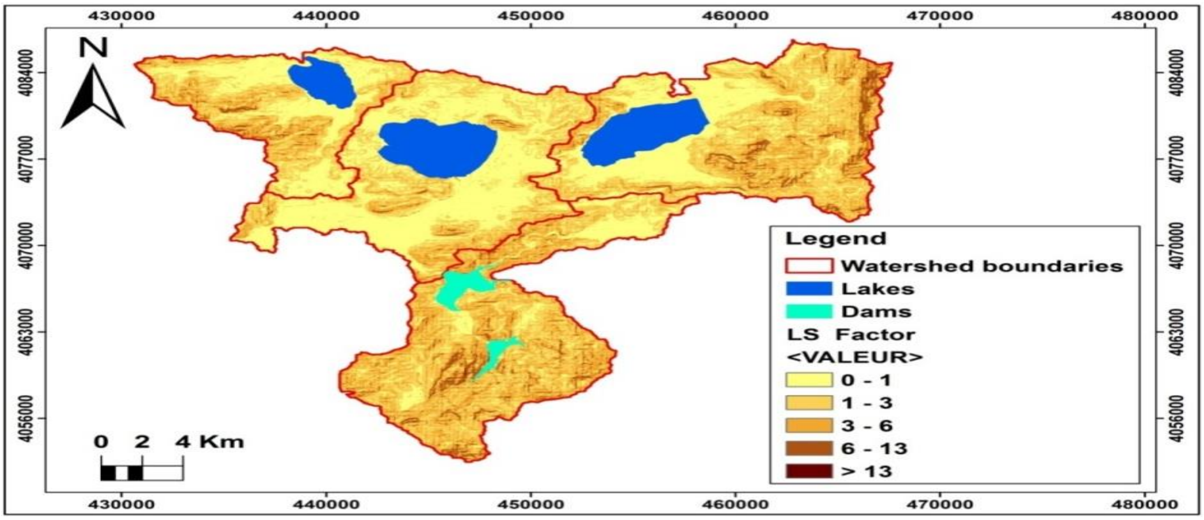

Fig. 5. Map of the factor LS factor (Watersheds of El Kala National Park).

R: The erosivity factor of the rains expressed in MegaJoul. Mm / ha is defined as the potential rainfall capacity to cause erosion and given as the product (EI30) of the total rain energy (E) and the maximum intensity for 30 min (I30) (Wischmeier and Smith, 1978).

Since the study area is not covered by a system of pluviograph which is essential for the calculation of R, and then to satisfy the requirement of the model we have opted for the index of erosivity of the rains according to Arnoldus (1980) in such a situation (Meddi, 2013;kouadri *et al.*, 2016) as a good approximation of the R-factor of the universal equation. Equation 2 developed by Meddi (2015), used to calculate the Modified Fournier Index MFI), was selected, it is written as follows:

$MFI = 0.43 * P^{0,94} * x^{-0.09}$ (2) where:

P: Annual rains in mm and X: Longitude in km.

The erosivity map established by the application of formula 2 required the mobilization of a large series of stations and accumulated 34 years of precipitation, and interpolation of the results by the IDW (Inverse Distance Weight) method.

K**:**The erodibility factor expresses the vulnerability of the soil to be eroded by rain .It depends on grain size, soil texture, organic carbon content, structural stability, porosity, permeability; all these parameters are embedded in an equation (Wischmeier and Smith, 1978):

K = 2.1 * M1.14 * 10-4 (12- a) + 3, 25 * (b-2) + 2.5 * (c-3) (3) where:

M: Is calculated by the formula M = (% fine sand + silt) x (100 -% clay) (4)
A: Is the percentage of organic matter.
B: Is the code of permeability.
C: Is the code of the structure.

The K factor was extracted from the soil profiles, gathered from all the research carried out on the territory of the El Kala National Park, ie 60 soil profiles. (Benslama, 2007; Siaghi, 2012; Fetni 2012; Djalouli, 2014)Based on the physical properties (Clay %, Limon%, Sand % and OM %) of the profiles encountered, the texture of the soils was determined using the texture triangle then calculated the average values of the factor K using the table of Stone and Hilborn (2000). For the spatialization of the K factor, the average values of the K factor calculated for each localized soil profile are interpolated by the IDW (Inverse Distance Weight) method over the entire study area.

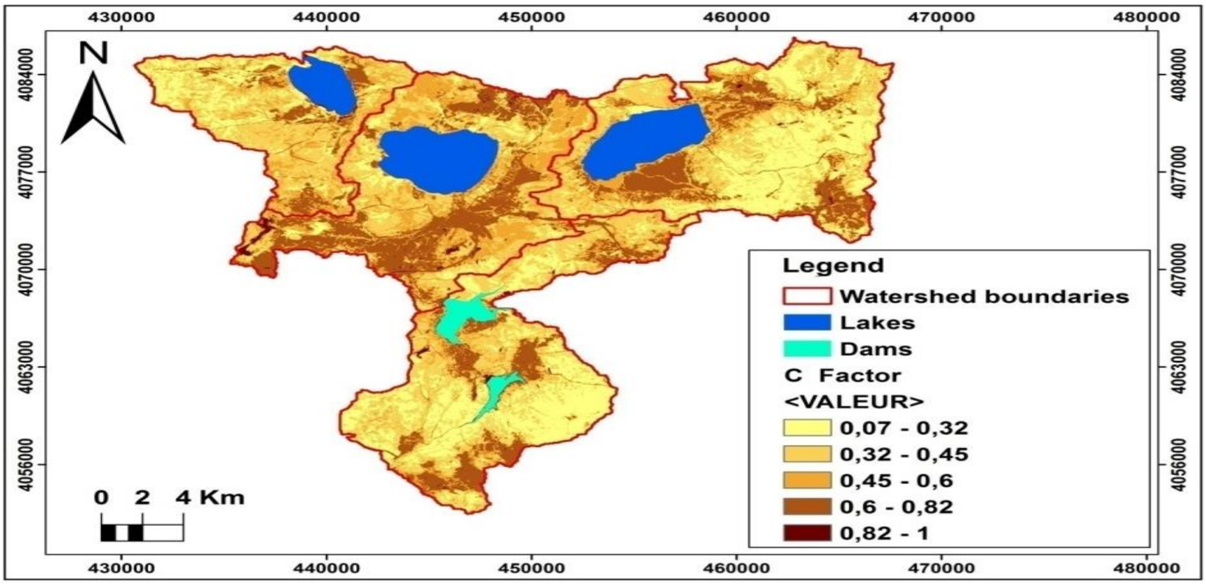

Fig. 6. Map of the factor C (Watersheds of El Kala National Park.

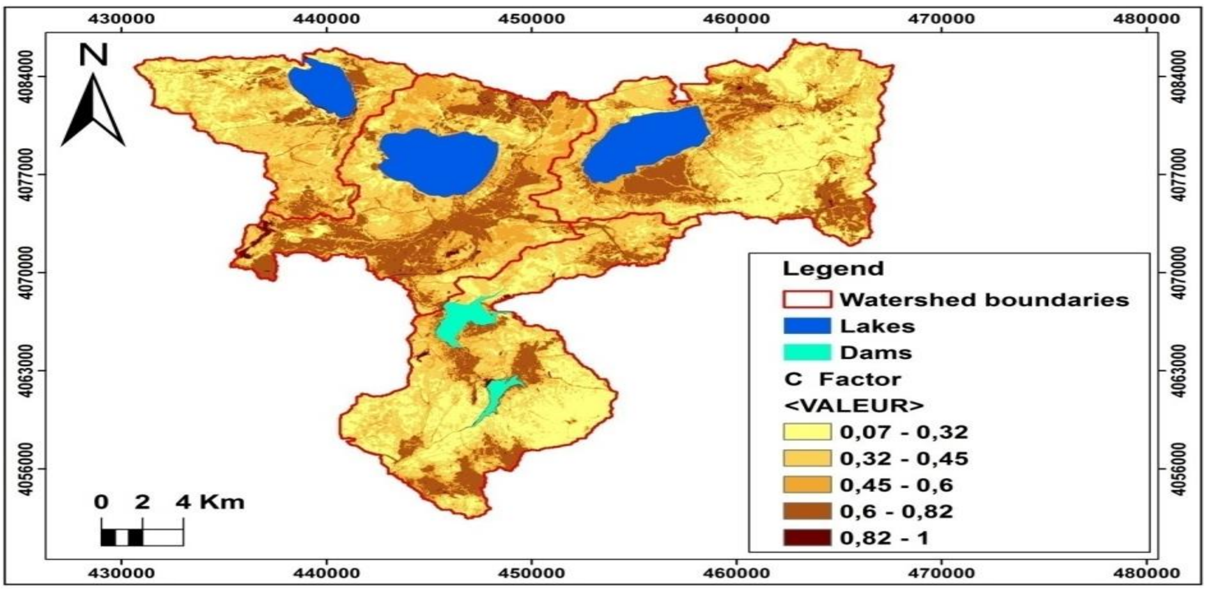

Fig. 7. Map of the factor P (Watersheds of El Kala National Park.

LS: Topographic factor LS represents the effect of slope length (L) and inclination of slope (S) on erosion. These two elements are important parameters; they condition the volume and the speed of the runoff water. The LS factor can be calculated from the Aster GDEM (Global Digital Elevation Map) image at a resolution of 30 m. The length of slope (L) in m can be expressed as a function of the drainage area according to the following formula (Desmet and Govers, 1996):

$$L_{(i,j)} = \frac{\left(A_{(i,j)} + D^2\right)^{m+1} - A_{(i,j)}^{m+1}}{X^m * D^{m+2} * (22,13)^m} \quad (5)$$

Where

$L_{(i,j)}$:Is the slope length in (m).

$A_{(i,j)}$:in (m) is the unit area at the input of a pixel (flow accumulation).

D: Is the pixel trimming (spatial resolution of the DTM).

m:is the exponent of the length of the slope. *X*:Is the correction factor of the formula equal to 1. The factor S can be estimated by two simple regressions applied as a function of the angle of inclination, with the slope in degree (McCool *et al.*, 1989).

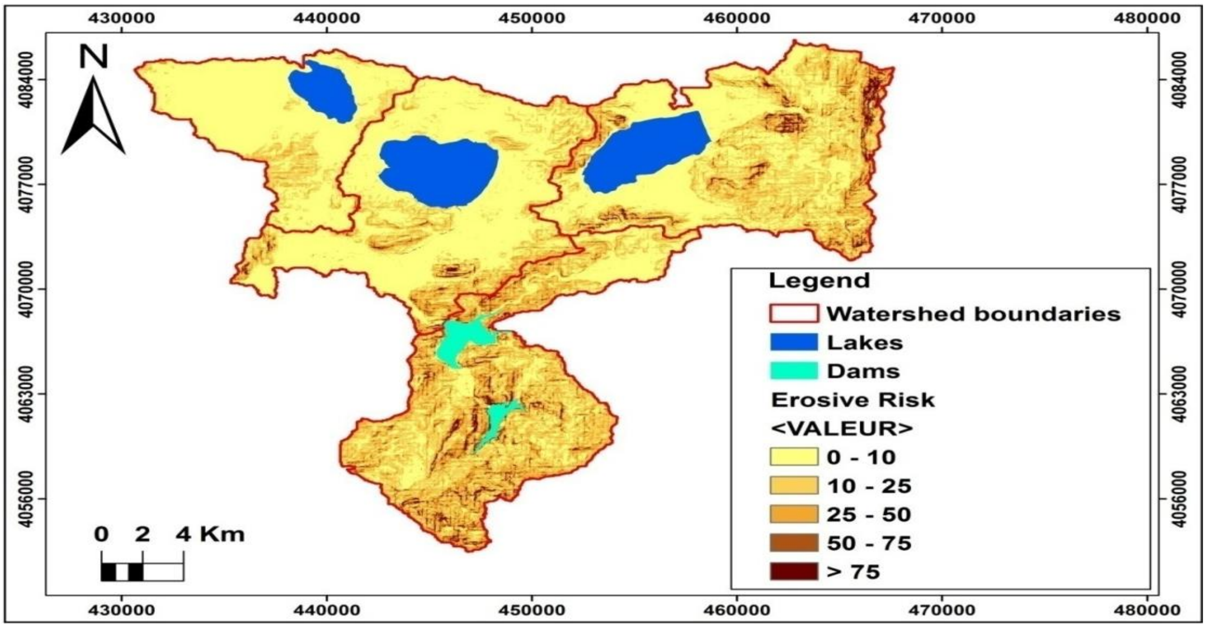

Fig. 8. Water erosion risk map (watersheds of El Kala National Park).

$$S_{(i,j)} = \begin{cases} 10,8 \sin \beta_{(i,j)} + 0,03 \rightarrow \tan \beta_{(i,j)} < 0,09 \\ 16,8 \sin \beta_{(i,j)} - 0,50 \rightarrow \tan \beta_{i,j} \geq 0,09 \end{cases} \quad (6)$$

In our case, the LS factor generation approach consists in delimiting watersheds using the Arc Gis "Arc Hydro" extension and then integrating the equations mentioned above under the ArcGis version 10.2 .Both factors L and S are estimated separately from the Digital Terrain Model (DTM). The LS factor is obtained from the multiplication of the two factors L and S according to the formula LS = "L" * "S" C: is defined as the ratio of bare soil loss under specific conditions to losses in soils corresponding to soils under an agricultural system (Wischmeier and Smith, 1978).

This dimensionless factor represents the effect of vegetation cover. Due to the lack of seasonal data on the state of the vegetation cover in the study area. The factor C has been substituted by NDVI normalized difference vegetation index (Jensen, 2000; Ioannis, 2009).

The relationship between the NDVI and C is determined by the equation: C= exp (-α *NDVI/ (β-NDVI)) (7) (Ioannis, 2009) where:

α, β:Parameters determining the shape of the NDVI-C curve whose values α = 2 and β = 1 give reasonable results (Van der Knijff *et al.*, 2000). For the case of the watersheds of the El Kala National Park NDVI the factor "c" is generated from the Landsat 8 OLI image (spatial resolution of 30 m).

P: Dimensionless factor, integrates anti-erosion cropping techniques, designed to favor infiltration and limit runoff, namely cropping in contour furrows, alternating strips or terraces, reforestation in banquettes, hoeing.

The values of the factor P are extracted according to the sloping cultivation methods cited by (Shin, 1999), determined from the two values of P between 0 and 1, where the value 0 represents a medium resistant to anthropogenic erosion and the value 1 indicates a lack of anti-erosive practices. The preprocessing and image processing were done under ENVI 5.1 software, while the analysis, the combination of all the data and the application of the model were done with the ArcGis 10.2.2 software. The working resolution is 30 m and the projection system applied to all our data is Transverse Mercator zone 32N.

Results and discussion

The results obtained, present the computation and the spatialization of the various factors of the RUSLE equation (Revisioned Universal Soil Loss Equation) on the one hand and the estimate of the losses of soils on the scale of the El Kala national park of other share. This result is the first attempt to assess the risk of water erosion in this region.

Table 1. Distribution classes of the factor R by watershed (El Kala National Park).

Watershed		R-factor classes (MJ.mm/ha.h.year)					Total
		114 - 120	120 - 124	124 - 127	127 - 132	132 - 139	
Tonga	161,91 km²	27,33	93,71	25,8	14,37	0,7	161,91
	%	16,88	57,88	15,93	8,88	0,43	100
Oubeira	153,8 Km²	0	38	39,06	42,74	34	153,8
	%	0	24,7	25,4	27,79	22,11	100
Bougous	147,44 Km²	11,2	13,74	66,78	40,97	14,75	147,44
	%	7,6	9,32	45,29	27,79	10	100
El Mellah	86,75 Km²	0	2,83	68,91	15,01	0	86,75
	%	0	3,26	79,44	17,3	0	100

The R factor

R-factor estimates give values between 114 and 139 Megajoul.mm/hectar. hour.year. The spatialization clears two zones, where the erosive power of the rains and particularly important from 127 to 139 Megajoul.mm/hectar.hour.an to the Northwest and Southeast and a third central zone (zones of the depressions, the lakes) marked by low to medium values of the class (114 to 127 MJ.mm/ha.h.year). Globally, more than 66.03 % of the surface of the study area is subjected to a rain aggression, greater than or equal to 124 MJ.mm/ha.h.year. However, the Oubeira watershed (Fig.3) is the one with the strongest R values (127-139 MJ.mm/ha.h.year), or 13.96 % of the surface of the study (Table 1). Comparatively, in interior work, the values of the factor R obtained in our case study, vary from 114 to 139 MJ.mm/ha.h. year), are close to those found by Meddi in 2015 (120-140 MJ.mm/ha.h.year).

The K factor

The values of the factor K (Fig.4) vary globally from 0.01 t.ha.h / ha.MJ.mm for the most resistant soils to 0.41 t.ha.h / ha.MJ.mm for soils the most erodible. The spatialization of the factor K brings out two large areas: the first very erodible (0.18 - 0.41 t.ha.h / ha.MJ.mm), or 55.66 % of the global surface follows a North-axis east, southwest and a second on either side of this axis with mean to low values that vary between (0.01 - 0.18 t.ha.h / ha.MJ.mm) represent 44.34 % of the total area. The Oued Bougous watershed stands out as the hydrological entity with the largest erodible soil surface area, i.e. 26.74 % of the overall surface of the study area (Table 2).

Table 2. Distribution classes of the factor K by watershed (El Kala National Park).

Watershed		K-factor classes (t.ha.h/ha.MJ.mm)					Total
		0,01 - 0,10	0,10 - 0,13	0,13 - 0,18	0,18 - 0,24	0,24 - 0,41	
Tonga	161,91 km²	8	17,1	31,3	55,03	50,48	161,91
	%	4,94	10,56	19,33	33,99	31,18	100
Oubeira	153,8 Km²	21,19	29,82	53,58	45,83	3,38	153,8
	%	13,78	19,38	34,84	29,8	2,2	100
Bougous	147,44 Km²	0	0,1	0,29	133,76	13,29	147,44
	%	0	0,07	0,2	90,72	9,01	100
El Mellah	86,75 Km²	69,9	7,8	4,76	3,3	0,99	86,75
	%	80,58	8,99	5,49	3,8	1,14	100

In the absence of previous work to compare the values obtained, the 60 soil profiles collected from all the research carried out on the territory of El Kala National Park are poorly represented throughout the study area; this is mainly due to the irregular spatial distribution of these profiles.

The LS factor

The modesty of the globally collinear relief logically, reflects the modesty of LS values. It is the lowest value of the world, which is most likely to be found in the plains around the lakes, dams and the hydrographic network. However, the averages to moderate values between 6 and 13 or greater than 13 are the mountain range in the Northeast, West and South (Fig.5).

Nevertheless, in terms of scope, the values of the class greater than or equal to 6 remain low at just 2.57 % of the total area (Table 3).

Table 3. Distribution classes of the factor LS by watershed (El Kala National Park).

Watershed		LS-factor classes					Total
		0 - 1	1 - 3	3 - 6	6 - 13	> 13	
Tonga	161,91 km²	82,55	48,66	24,72	5,91	0,07	161,91
	%	50,99	30,05	15,27	3,65	0,04	100
Oubeira	153,8 Km²	115,44	29,47	8,29	0,6	0	153,8
	%	71,11	22,2	6,24	0,45	0	100
Bougous	147,44 Km²	42,58	62,33	36,37	6,05	0,11	147,44
	%	26,52	43,67	25,51	4,24	0,06	100
El Mellah	86,75 Km²	51,16	23,46	10,74	1,39	0	86,75
	%	54,5	29,99	13,73	1,78	0	100

The highest values > 13, are located in the mountainous basins, Bougous and Tonga. The equation used to calculate the LS factor, shows satisfactory results compared to the actual topography of the watersheds of El Kala National Park, whose slope is on average less than 5 % and the maximum slope length estimated at 263 m.

The C factor

The vegetation cover combined with the cultivation technique is undoubtedly the factor par excellence for combating the effects of splash and runoff.

The literature demonstrates an effective reduction in erosion, according to the nature of the vegetation cover and cropping techniques (Masson, 1971; Wischmeier and Smith, 1978; Roose *et al.*, 1994; Roose, 1996; Farhan, 2013; Lubna *et al.*,2014). Also the factor C varies between 1 for a bare soil and less than 0.1 for a soil under vegetal cover. The Fig.6 shows five classes of the "C" factor in the El Kala Park. The lowest values of 0.07 to 0.45 correspond to dense forests and maquis, which is 52.84 % of the total surface of the study area. However, the values of 0.45 to 0.60 correspond to less dense reforestation, rangelands and arboriculture; they occupy 24.19 % of the total area. The values between 0.60 and 1, occupy 22.97 % of the park, they correspond to the annual crops, the fallow soils, the bare grounds and the urban fabric. These represent the most sensitivity to erosion.

Table 4. Distribution classes of the factor C by watershed (El Kala National Park).

Watershed		C-factor classes					Total
		0,07 - 0,32	0,32 - 0,45	0,45 - 0,60	0,60 - 0,82	0,82 - 1,00	
Tonga	161,91 km²	21,2	76,76	36,91	25,96	1,08	161,91
	%	13,09	47,41	22,8	16,03	0,67	100
Oubeira	153,8 Km²	2,03	44,24	50,25	34,39	22,89	153,8
	%	1,32	28,76	32,67	22,36	14,88	100
Bougous	147,44 Km²	13,56	83,24	24,38	18,27	7,99	147,44
	%	9,2	56,46	16,54	12,39	5,42	100
El Mellah	86,75 Km²	7,03	42,52	21,5	6,86	8,84	86,75
	%	8,1	49,01	24,78	7,91	10,19	100

However, most of the area sensitive to erosion is located in the Oubeira watershed, which is 10.42 % of the total surface of the study area. It is also the most urbanized of all watersheds (Table 4).

In the lack of internal work on our study area, the field verification allowed us to notice that the equation proposed by Knijff *et al.* (2000) is used to evaluate erosion risks in Europe. It gives acceptable values in our study area.

The P factor. P-factor refers to the effect of anti-erosion cultural practices. These practices affect erosion by altering the flow pattern or surface flow direction and reducing the amount and rate of runoff (Renard and Foster, 1983). For our case study (Fig.7) the values of the Factor P vary from 0.55 to 0.80 for the low and medium slopes (plains) represent 76.55 % of the total surface of the study area and from 0.80 to 1, correspond to the steep to very steep slopes (mountains), 23.45 % of the total area (Table 5) where we did not observe any anti-erosion practice, especially in the watersheds of Oued Bougous and Tonga Lake, which represent 10, 35 % and 7.41 % respectively of the total surface of the study area. Because we do not have internal work on the study area, concerning this factor to compare the result obtained, the values of the factor P are extracted after observations made in the field. This is the only factor that perfectly reflects the reality on the ground.

Table 5. Distribution classes of the factor P by watershed (El Kala National Park).

Watershed		P-factor classes					Total
		0,55	0,55 - 0,60	0,60 - 0,80	0,80 - 0,90	0,90 - 1	
Tonga	161,91 km²	63,24	24,62	33,29	25,58	15,18	161,91
	%	39,06	15,2	20,56	15,8	9,38	100
Oubeira	153,8 Km²	95,14	23,5	21,02	11,1	3,04	153,8
	%	17,69	15,46	28,26	25,69	12,9	100
Bougous	147,44 Km²	26,08	22,8	41,67	37,88	19,01	147,44
	%	17,69	15,46	28,26	25,69	12,9	100
El Mellah	86,75 Km²	39,81	13,81	16	11,91	5,22	86,75
	%	45,89	15,92	18,44	13,73	6,02	100

Estimation of soil losses

The superposition of the five layers representing the erosion factors in the watersheds of El Kala National Park presents the spatial distribution of potential erosion values. The figure 8 shows erosion rates ranging from 0 to > 75 t/ha / year, with an average of around 13.83 t/ha/year, close to the average soil tolerance limit at erosion1 to15 t/ha/year (Roose, 2010).

Overall the erosive risk is limited, spatially the values above the tolerance threshold are the area of low foothills 25 to 50 t/ha /year, 50 - 75 t /ha /year and > 75 t/ha/year, respectively represents than 13.48 %, 3.38 % and 1.22 % of the total area. However, the breakdown by hydrological unit (Fig.8 and Table 6) shows that the watersheds of Oued Bougous and Tonga have on average the highest erosive risk (23.67 t/ha/year and 15.04 t/ha/year).

Table 6. Distribution of soil loss classes by watershed (El Kala National Park).

Watershed		Classes of erosive risk (t / ha / year)					Total
		0-10	10-25	25-50	50-75	> 75	
Tonga	161,91 km²	91,26	39,62	22,04	6,21	2,78	161,91
	%	56,36	24,47	13,61	3,84	1,72	100
Oubeira	153,8 Km²	119,5	20,79	11,08	1,89	0,54	153,8
	%	74,16	15,66	8,35	1,42	0,41	100
Bougous	147,44 Km²	43,96	50,37	39,27	10,43	3,41	147,44
	%	29,82	34,16	26,63	7,07	2,32	100
El Mellah	86,75 Km²	75,59	9,36	1,73	0,07	0	86,75
	%	85,73	11,97	2,21	0,09	0	100

These values are explained by higher soil erodibility accompanied by steeper slopes, and insufficient vegetation cover. The result of (13.83 t/ha/year on average) obtained from the application of the universal erosion equation in the watersheds of the El Kala National Park is quite close to those encountered in the literature (Toumi *et al.*, 2013) 12, 43 t/ha/year, notwithstanding the climatic differences between the study areas. A comparison to in situ measurements would have been more meaningful.

Conclusion

This study is a first attempt to introduce a risk map of soil erosion for all watersheds of the El Kala national park. However, the application of the RUSLE model combined with GIS and remote sensing made it possible to map all the erosion factors and to estimate their erosion sensitivity and to establish a map of erosive risk that shows the area's most affected by erosion.In addition, the result of the calculations obtained by the revised universal equation places the average erosion rate at manageable levels of 13.83 t/ha/year. Nevertheless, it remains worrying for the quality Park and the reserve of the biosphere, the result denotes the fragility of the Park, which presents itself as a favorable environment for the development of the erosion in all its forms.

Indeed, 18.09 % of the total surface of the study area has values > 25 t/ha/year. To this end, the watersheds of Oued Bougous and Tonga Lake stand out as a priority in the foreground, on average (23.67 t/ha/year and 15.04 t/ha/year). Also, this study is an important database that can be used to protect and to preserve the watersheds of El Kala National Park, by establishing an urgent response plan for the area's most affected by this phenomenon.

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