Chapter

Spatial Estimation of Soil Erosion Risk Using RUSLE/GIS Techniques and Practices Conservation Suggested for Reducing Soil Erosion in Wadi Mina Catchment (Northwest, Algeria)

Ahmed Benchettouh, Sihem Jebari and Lakhdar Kouri

Abstract

To meet the pressing water needs in Algeria, the state has put in place a strategy consisting of the creation of hydraulic infrastructure for the mobilization of surface water resources. In fact, 74 dams are currently in operation; these structures are silting up at a rapid pace, generating an estimated annual loss of 45 million m^3. Sidi Mhamed Benaouda dam located in the Oranian hill, with a water capacity of respectively 241 million m^3 plays a crucial economic role in this region. The protection of this dam against erosive processes is a pressing economic goal. To do this, the RUSLE/GIS approach was used to map the erosive hazard. The results obtained in the Mina catchment, following a subdivision of 1315 homogeneous land parcels, show a total annual loss of 60 million tons/year with an average loss of 11.2 t/ha/year. About 50% of the catchment area was predicted to have very low to low erosion risk, with soil loss between 0 and 7.4 t/ha/year. Erosion risk is moderate over 13.9% of the catchment, where calculated soil loss is between 7.4 and 12 t/ha/year. Erosion risk is high to dangerous over 36.1% of the catchment, where calculated soil loss is more than 12 t/ha/year. According to this study, it appeared clearly that we must intervene quickly by using reliable and effective conservation techniques.

Keywords: Oranian hill, catchment, Sidi Mhamed Benaouda, soil loss modeling

1. Introduction

Water erosion is a phenomenon that results from the degradation of the surface layers of the ground cover and the displacement of the constituent materials [1] under the effect of the kinetic energy of the raindrops and the transport of soil particles from their original location [2]. It is one of the main causes of soil degradation in the world [3] leading to a significant threat to both human societies and the environment [4]. It also affects the quality of surface water and/or groundwater [5], reducing the capacity of the dams [6] and decreasing the soil fertility for agricultural activities [7]. Accordingly, the land area damaged by soil erosion is estimated at 1100 million hectares of land worldwide [8] resulting in the transportation of 2.0 to 2.5 x 10^{10} Mg of soil to the oceans each year [9]. This makes it a serious problem on a global scale and particularly worrying in certain regions of the world [10].

In 1930, in the United States, 20% of arable land was severely damaged by erosion following a prolonged drought. This is the dark era of the "dust bowl" phenomenon [11]. This resulted in the establishment of a water and soil conservation service by the US government. At the same time, a network of research stations was set up, which, thirty years later, resulted in the formulation of the USLE Equation [12].

Globally, [13] showed that of 13.5 billion hectares of land affected by water erosion, only 22% of the land is cultivable. During the last decades, the losses of cultivable land increased from 7 to 10 million hectares per year and at this rate, two centuries would be enough to destroy all the cultivable/agricultural land.

According to the United Nations Report on the State of the World's Soil Resources, published in 2015, cereal production losses due to erosion have been estimated at 7.6 million tons per year [14]. As a result of this report, researchers around the world have found that if nothing is done to mitigate erosion, we could achieve a reduction of more than 253 million tons of cereals by 2050. This loss of yield would be equivalent to removing nearly 15 billion hectares of land from farming [15]. According to this author, these more dramatic figures raised the alarm in different countries of the world in order to take all the necessary measures. In fact, due to the torrential nature of the rains, the high vulnerability of the land and the unfavorable human activities impact (deforestation, fires, overgrazing, poor agricultural behavior, chaotic town planning, etc.) more degradation will affect the agricultural landscape. Consequently, due to the relevance of this problem, several studies have been carried out on agricultural plots of about 100 square meters [2, 16–19], on micro-watersheds of a few hectares [20–23], on large basins of thousands of square kilometers [6, 24–26] and over large areas (countries and/or regions of the world) [27–29].

The results of soil loss vary from 1 to 200 t/ha/year (up to 700 t/ha/year) under crops specific to forest regions where slopes ranging from 30 to 60% and 0.5 to 40 t/ha/year under millet, sorghum, peanuts and cotton on long tropical ferruginous glacis of the Sudano-Sahelian regions whose slopes vary between 4 and 25% [30]. In the United States, on cultivated land, soil losses were estimated between 5 and 12 t/ha/year [31]. In Europe, [32] estimates that 25 million hectares have been seriously affected by erosion.

In the Maghreb, the water and soil potentials are seriously threatened [22, 33–36] and the phenomenon of water erosion is very widespread. The majority of watersheds are characterized by severe degradation exceeding 20 tons/ha/year [6], which leads to an average annual siltation of dam reservoirs at a rate of 125 million m^3 [37]. According to [38], water erosion in Morocco causes soil losses ranging from 5 t/ha/year to more than 50 t/ha/year depending on the region, and an average annual siltation of the reservoirs of the dams of the order of 75 million m^3. That is to say an annual reduction of 0.5% of their storage capacity, which causes deterioration in the quality of the drinking water mobilized and a decrease in water resources that can irrigate 10000 ha/year. Northern and central Tunisia currently has more than 30 dams with a total storage capacity of 3.5 billion m^3 [23, 38, 39]. Monitoring the siltation of these hydraulic structures made it possible to assess a loss of their storage capacity estimated at 30 million m^3/year, i.e. an annual reduction of 1%. Soil erosion has affected nearly 3 million hectares of agricultural land in the country, or more than half of the useful agricultural area in affecting the production capacity of Tunisian agriculture [23, 40].

In Algeria, the annual volume of sediment deposited in the 74 dams is estimated at 65 million m^3 [41]. Although soil erosion is characterized as a natural phenomenon, human activities such as agriculture can accelerate it further in Algeria [42]. Thus, 14 million hectares of land in the country are threatened by water erosion [43]. Therefore, Algeria is a country that witnesses an enormous deficit of water (i.e. below the theoretical scarcity threshold set by the World Bank, which is around 1000 m^3 per inhabitant/year) [44]. According to [45], Algeria is qualified in the category of the poorest African countries in terms of water potential. In 1962, the theoretical availability of water/capita/year was 1500 m^3; it was only 720 m^3 in 1990, 680 m^3 in 1995, 630 m^3 in 1998, 430 m^3 in 2020. To meet Algeria's urgent water needs, the States has implemented a strategy consisting of creating 94 hydraulic dams for the mobilization of surface water resources distributed throughout the national territory. The sector expected to build around 139 dams by 2030 [46]. One of these dams is that of wadi Mina catchment with a filling capacity of 241 million m^3. The dam Sidi Mhamed Benaouda (also named dam Es-Saada) is threatened by the silting from its site [6]. It is located at the extreme north of watershed of the wadi Mina (Algeria); its catchment area is subjected to intense water erosion with a volume of sediments which reaches the tank annually. This volume is on average about 3.2 million m^3 [47]. During these last decades and in a preoccupation with a management fight by the Algerian State, the catchment area of the wadi Mina was retained within the framework of a pilot project of integrated installation and development [47, 48]. The dam Sidi Mhamed Benaouda was built in 1978 with the downstream of this zone. According to [49], the marly sector located in the northern part constitutes the major source of sediments deposited in this dam.

Thus, the problem of water erosion mobilizes the scientific community to find solutions likely to ensure soil conservation [50]. In a context marked by global climate change and sustained human pressure on natural resources, the threat of soil erosion requires special and continued attention [51].

2. Methodology and data used

2.1 Tolerance to erosion

The tolerance level for soil loss varies from region to region of the world. It is linked to the productivity of the land and its uses [6]. Indeed, in Asia, [20] found that the tolerance threshold for soil loss in the Kelara sub-watershed in India was less than 1.5 t/ha/year. According to [52], the results of the study of water erosion in the Tamil Nadu basin (India) indicate that the average soil losses in this region are of the order of 6 t/ha/year. In Europe, [27] deduced that when soil losses exceed a threshold of 5 t/ha/year on cultivated land, the latter becomes intolerable. In a study conducted in the south-eastern region of Spain by [53], a rate of soil loss was recorded below the tolerable annual rates for the northern Mediterranean region. Almost 90% of its basins have average annual rates of less than 2 t/ha. In northwestern Turkey, the results obtained in the Buyukcekmece region by [54], show that a soil loss rate is low for a value of less than 1 t/ha/year, while beyond 10 t/ha/year, the phenomenon of erosion becomes a serious problem. Also, in the Alaca basin in Turkey, [55] estimated a water erosion tolerance rate of up to 12 t/ha/year. [56] underlines that any loss of soil greater than 1 t/ha/year is considered irreversible over a period of 50 to 100 years. A soil loss of 12 to 15 t/ha/year, or about 1 mm of soil per year (surface stripping) is sufficient to exceed the rate of alteration of the rocks. [54, 57] estimated the global tolerance rate for soil loss to be 10.2 t/ha/year.

In Morocco in regions similar to our study area, [58, 59] reported that soils can sustain loss of up to 7.4 t/ha/year on average. In Tunisia and according to the work of [22] carried out in the wadi Jannet watershed, a tolerance threshold of 8 t/ha/year has been suggested, above which the level of erosion risk will be high.

According to the above published work regarding the quantification of soil loss by the RUSLE model, it is clear that the tolerance threshold presents some difference. This is linked to the type of soil and its pedogenesis. In fact, in a region with shallow soil in a climate of accentuated summer aridity, the production of soil (pedogenesis) will be slow and consequently the tolerance threshold will be less. This is the case, for example, in arid and semi-arid Mediterranean regions [60].

2.2 Classification of soils and relationship with soil erosion

Given the objective pursued aimed at identifying the regions participating in the siltation of the Sidi Mhamed Benaouda dam, we have therefore adopted the American classification which is based on a tolerance threshold of 7.4 t/ha/year on average while supporting sustainably a high level of agricultural production and that if the losses exceed 20 t/ha/year, they can become dangerous [58]. We note that this classification has been adopted in Morocco, in the wadi Boussouab watershed, region similar to our study region in terms of climate, vegetation cover and soil substrate.

According to this classification, soil losses will be divided into five categories:

- Very low, when they do not exceed 5 t/ha/year.
- Low, when they are between 5 and 7.4 t/ha/year.
- Moderate when they are between 7.4 and 12 t/ha/year.
- Strong when they have values between 12 and 20 t/ha/year.
- Very strong and dangerous when losses exceed 20 t/ha/year.

2.3 Study area

Before proposing such a development, it is necessary to give a bibliographical overview of the research work relating to water erosion carried out in this region of interest. The watershed of wadi Mina is located at the northwest of Algeria in the Tellian hill area between 34° 42″ 36″ to 35° 35″ 2″ N latitude and between 0° 23″ 51″ to 1° 8″ 56″ E longitude (**Figure 1**). It lengthens on 90 km on Frenda and Mina mounts at north and on 50 km from the west to east between Bani-Chougrane mounts and the Ouarsenis massive. This watershed covers an area of 4800 km^2 [6].

2.4 Data used

The methodology adopted for this study rests on the exploitation of the multi-source data (satellite, pedological, climate condition and of the observations to carry out on the ground (in situ)). All these data are integrated and analyzed by the GIS for the cartography of the zones exposed to soil erosion in our study area.
1- Four images Shuttle Radar Topography Mission of resolution 30 m, coordinates: N35E000, N35E001, N34E000 and N34E001, were obtained from the SRTM (2011).
2- Two spectral scenes multi Landsat_8 OLI/TIRS (Operational Land To color) (Thermal Infrared Sensor) of Path_197/Row_035 (LC81970352014077LGN00) and

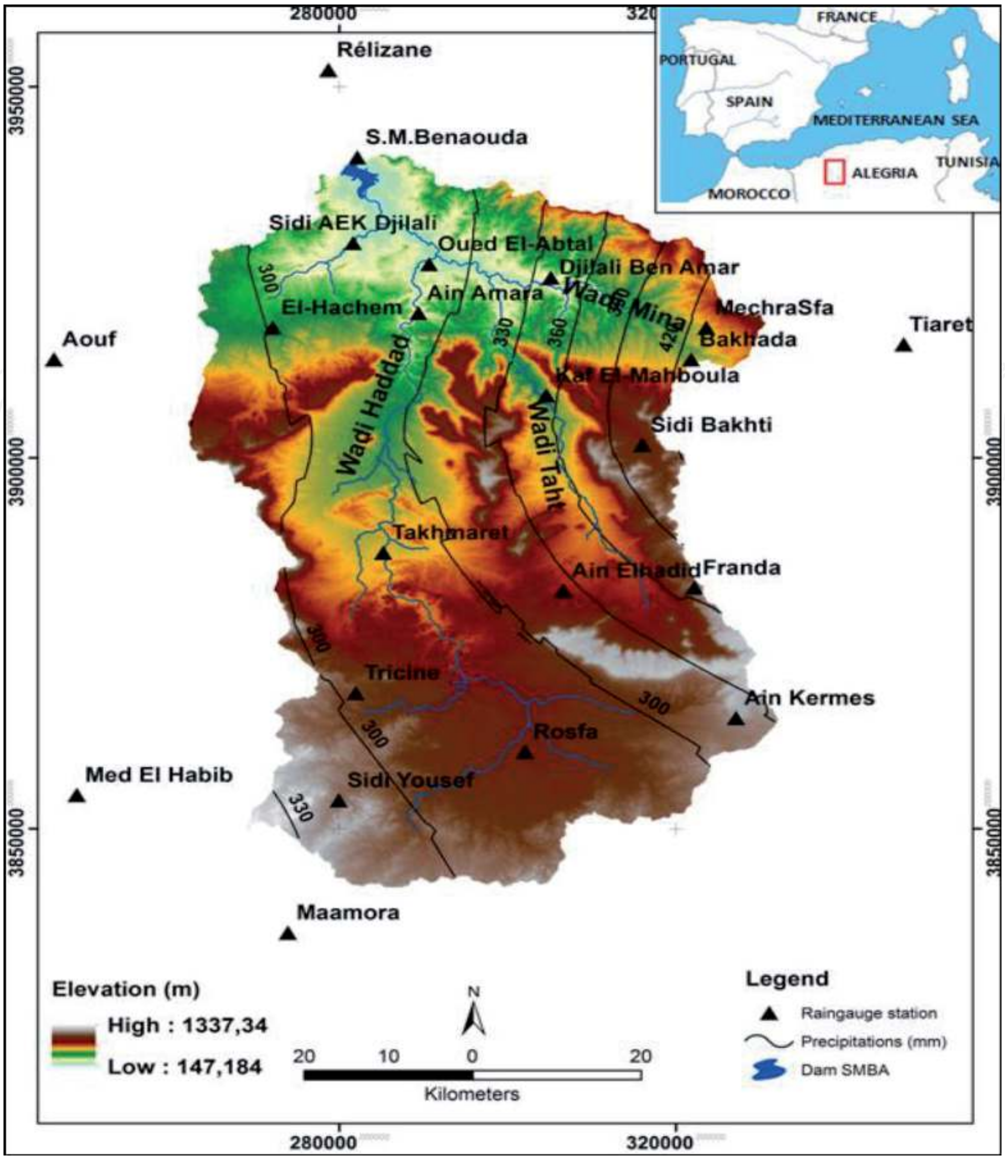

Figure 1.
Study area location map (source: [6]).

that of Path_197/Row_036 (LC81970362014077LGN00) were acquired on March 18th, 2014. These satellite images are uploaded from USGS (2014), with the Geotif format. 3- Observations on the ground, obtained after a descent on the ground in March and April 2014. 4- A detailed pedological map, catchment area of wadi Mina, drawn up by the BNEDER (2004). 5- Rainfall records (daily precipitations) provided by the National office of Meteorology on twenty two stations. They are spread over a period of 36 years (1978–2014) and cover our zone of interest.

2.5 RUSLE-Model

RUSLE- model proposes the same formula as the USLE [12] but several improvements were carried out for the determination of the various erosive factors. This included an approach different from the erodibility of the soil K-factor, a new equation for topographic LS-factor, and a new value for the crop management C-factor and the practices of conservation P-factor. The application of RUSLE model requires the calculation of the various factors intervening on the erosive processes and their spatialization in the form of the thematical maps. The integration of these data in the GIS makes it possible to superimpose them and evaluate the rate of water erosion by applying the formula of: $A = R*K*LS*C*P$.

Where: A: is the soil loss per unit of area (t/ha/yr). The R-factor is rainfall and runoff erosivity factor (MJ mm/ha h yr). K (t h/MJ mm) is soil erodibility factor, LS (unit-less) is a topographic factor, C (unit-less) is a crop management factor and P (unit-less) is a conservation practice factor.

3. Results and discussion

The combination of different thematic maps of erosive factors with their data bases was a subdivision of these into 1315 homogeneous plots with a total annual amount of land loss of 60 million tones. These losses vary between 0 t/ha/year and 521 t/ha/year, with an annual average of 11.2 t/ha and a standard deviation of 18.6/t/ha/yr. Spatially (**Figure 2**), the resulting map shows that the rate of soil loss varies from one sector to another in the study area. In fact, the low to very low soil loss classes are mainly located in the middle of the study area.

Although, this sector is characterized by steep topography and relatively high soil vulnerability. Our results are in agreement with those of the work of [61]. These authors found that in Algeria, not only runoff, but also soil erosion, does not systematically increase with the topography, in particular the slope. In addition, we note that the erosion risk in this sector is generally very low, recording an average of around 3.5 t/ha/year (**Table 2**). This clearly explains why the plant cover factor, in particular the forest one, plays a protective role. Indeed, [62] show that factor

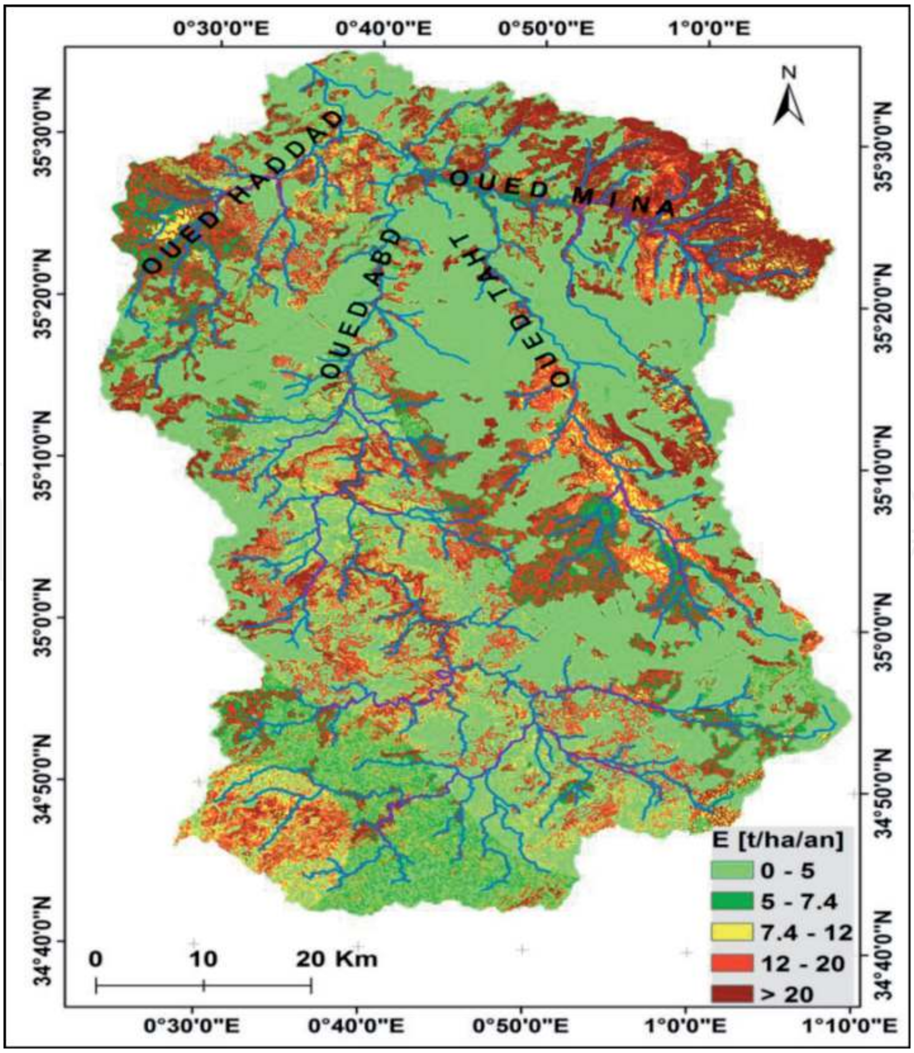

Figure 2.
Map of soil losses in the Wadi Mina basin.

C decreases the risk of erosion to 0.01 under perennial crops with cover plants or meadows and to 0.001 under forests associated with mulched crops compared to a bare plot.

The high and dangerous soil loss classes are noted exclusively in the northern and northeastern part of the study area. These regions are subject to an interweaving of natural and anthropogenic factors every year. The nature of the soils and the superficial lithological formation resulting from mainly marly terrain shows great fragility to water erosion. This is all the more important since the land has been almost completely bare and cultivated. [63, 64] show that these areas, which form an important part of the wadi Mina basin (1000 km^2), are strongly affected by water erosion.

According to the soil loss map obtained and according to the classification described above, the distribution of soil loss classes in the wadi Mina watershed is shown in **Table 1**.

The results of soil losses show that approximately 50% of the study area is classified in category where the erosion risk is low to very low (< 7.4 t/ha/year). 13.9% of the study area are classified in category where soil losses are moderate (7.4 to 12 t/ha/year). Actually, 36.1% of the study area is considered to be located in high risk and dangerous regions where losses exceed a threshold of 20 t/ha/year. The average rate of soil loss estimated at 11.2 t/ha/year is in the moderate erosion risk category.

Figure 3 highlights the following points (i) Sectors where soil loss exceeds the average of 11.2 t/ha/year, represent only 31.7% of the watershed. Their contribution to the overall soil loss is estimated at 92.5%. (ii) The sectors where the soil loss is lower than the average, occupy 68.3% of the surface of the basin. Their contribution represents only 7.5% of the global loss of soil**.**

The wadi Mina watershed has been the subject of several studies. These were carried out following the development of the Sidi Mhamed Benaouda dam and concerns raised by the scale of the erosive phenomenon and its consequences on the siltation

Risk of erosion	Soil loss class (t / ha / year)	Area (Km^2)	Area (%)	Category
Very low	0–5	1709.8	35.6	C
Low	5–7.4	688.9	14.4	
Moderate	7.4–12	665.9	13.9	B
Strong	12–20	903.7	18.8	A
Very strong and dangerous	> 20	831.7	17.3	

Table 1.
Soil loss classes in the Wadi Mina catchment.

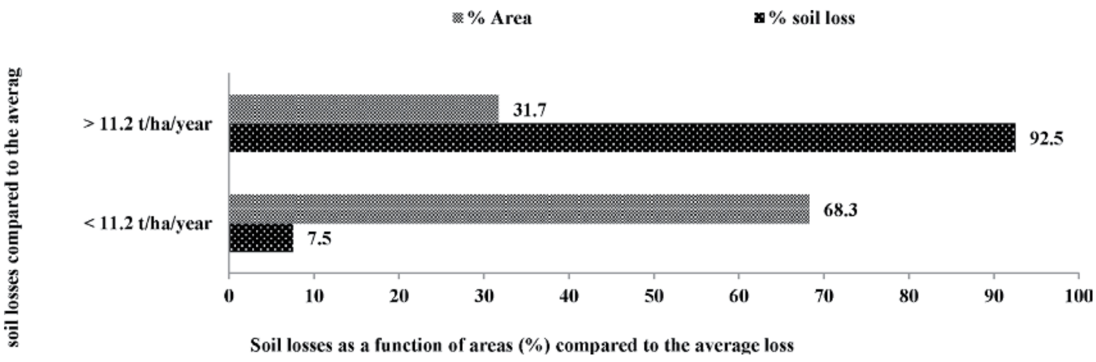

Figure 3.
Distribution of soil loss compared to the average in the Mina basin.

of the dam and the degradation of soil fertility from the 1990s. [65] established, from the classified parameters, the map of the sensitivity of marly lands to gullying in the western part of the watershed. This shows a predominance of land sensitive to linear erosion processes on the order of 57% of the territory. In fact, 25% of the land is strongly and very strongly sensitive to the incision and is mainly located on the right bank of wadi Mina, as well as in the downstream sector of the left bank of wadi Haddad. However, 18% of the basin surface is highly sensitive to solifluxion.

According to [62] and his collaborators observed that the different marly textures evolve by landslide and skin slide and those other environmental variables determine linear erosion namely: the slope, the vegetation cover and the morphology of the walls. The specific erosion of the wadi Mina basin estimated by the National Dams and Transfer Agency was on average around 3.26 t/ha/year, while the estimated soil losses in micro-watersheds with an area of 1000 km^2 located in the marly part can exceed a rate of 16 t/ha/year.

In 2001, [66] evaluated soil losses between 0.5 t/ha/year and 36 t/ha/year over the entire territory of the watershed. Most of this loss was recorded in the marl area with a rate exceeding 20 t/ha/year. However, [67] found that not only the marly areas participate in the production of sediments but the southern part of the basin of the wadi Mina can also participate with a significant contribution of sediments deposited in the lake of the Sidi Mhamed Benaouda dam.

In parallel, in 2004, the Algerian State under the supervision of Ministry of Agriculture and Rural Development launched a cooperation project with GTZ in order to develop a master plan for land use in the wadi Mina watershed. This is part of the conservation of soil and water strategy/planning. In 2006, under the supervision of the Ministry of Water Resources in collaboration with the Canadian consultancy firm (TECSULT), the Algerian State launched a study to identify and specify the measures to be undertaken to adequately fight against the siltation of reservoirs located in the Tellian hill including the wadi Mina basin which is one of these regions. The proposed developments have only been affected in areas classified as priorities A and B located in the marly region. According to this study, experts have shown that, if the improvements are made correctly in time, the lifespan of the Sidi Mhamed Benaouda dam will be increased twice as much as without it.

Before carrying out the development works according to the land use of our study area, it is first necessary to determine the average loss of each class as well as the degree of erosion risk. **Table 2** shows the sensitivity of the different types of land use to the risk of erosion. In fact, heavily vegetated areas, represented by vegetable crops and forests, are associated with low to very low soil losses, with 5.5 t/ha/year and 3.5 t/ha/year respectively. However, the higher and more dangerous ones correspond to bare soils with an average soil loss of around 29.8 t/ha/year. Soils used for agriculture, often protected during heavy spring showers, represent the type of vegetation cover most sensitive to erosion processes with an average soil loss of 16.1 t/ha/year. These last results are in agreement with those found by [68]. These authors have shown that cultivated fields can contribute significantly to sediment production. The formations based on scrub/scrubland, pasture and steppe produce moderate soil loss values with respective averages of 12 t/ha/year, 10.5 t/ha/year and 8.4 t/ha/year. This would be due to deforestation, overgrazing and bush fires which tend to substitute primitive formations for secondary cover of a different nature, such as savanna grassland.

The results of the evaluation of soil losses allowed us to deduce that an area of nearly 2400 km^2 of the slopes of the study area (**Table 2**) will require intervention measures to counter soil erosion. However, in order to optimize the allocation of resources intended for the short-term reduction of the siltation of the Sidi Mhamed Benaouda dam, we propose that only priority areas receive special attention in terms

Land use class	Area		R (Mj.mm/ha.h.year)	K (t.h/Mj.mm)	LS	C*	E avrg. (t/ha/year)	Risk of erosion at the threshold of 7.4 t/ha/year
	Km^2	%						
Forest	821.0	17.1	864	0.144	2.7	0.01	3.5	Very low
Agglomerations	64.7	1.3	902.8	0.023	1.6	0	0	00
Agriculture	160.2	33.4	743	0.039	0.9	0.65	16.1	High
Firewall	75.4	1.6	872	0.013	1.9	1	1.9	High
Market gardening	718.4	15.0	844	0.203	1.8	0.018	5.5	Low
Scrub and Scrubland	532.6	11.1	889	0.034	1.8	0.25	12	Moderate
Pasture	61.3	1.3	489	0.19	1.03	0.1	10.5	Moderate
Bare soil	150.0	3.1	565	0.032	1.7	1	29.8	dangerous
Steppe	767.0	16.0	611	0.064	1.1	0.25	8.4	Moderate
Dam	8.4	0.2	0	0	0	0	0	00
Total/Moyenne	4800	100	523	0,0501	1,5	/	11,2	Modéré

C: Factor C data are obtained from National Research Institute for Rural Engineering, Water and Forestry (INRGREF), Tunisia (2014).*

Table 2.
Soil losses according to land use classes in the Wadi Mina basin.

of anti-erosion measures, including those classified in the two categories A and B where the risk of erosion is moderate to dangerous (> 7.4 t/ha/year) (**Table 1**).

Bare soils and firebreaks covering 150 km^2 and 75.4 km^2, respectively, are the main lithological occupations, and will require the most interventions in the watershed. These interventions are mainly intended to counter the gullying. These areas produce a significant amount of sediment estimated annually at an average of 29.8 t/ha and 19.9 t/ha respectively (**Table 2**). The protection strategy for these lands consists of installing torrential correction sills, constructing drains and outlets on slopes in order to avoid landslides with marly substrate, implanting dry stone lines and prohibiting their exploitation by livestock during the spring period when the soils must be covered.

The areas with agricultural activity adjacent to the Sidi Mhamed Benaouda dam and which come in second priority are responsible for a significant proportion of the siltation of this reservoir where soil losses exceed a threshold of 16.1 t/ha/year on an area of 1601.2 km^2, or 33.4% of the study area. The anti-erosion interventions recommended in these areas are the installation of arboriculture on terraces built along the contour lines, the establishment of living hedges, stone lines, drains and outlets along the road accesses as well as torrential correction thresholds in order to reduce the speed of runoff. In addition, it is important to ensure that farmers adhere to the principles of protection of arable slopes by mastering good mechanization which consists of working along the contour lines.

The scrubland and pastures with degraded soils and steppes are the third types of land use in terms of priority. Their erosion risk is between 7.4 t/ha/year and 12 t/ha/year requiring anti-erosion interventions. These interventions suggested over an area of approximately 600 km^2 include the establishment of torrential correction thresholds in the gullies, the planting of opuntia, revegetation and the installation of bulges, drains and outlets.

4. Conclusions

In view of our results, using the RUSLE approach in a GIS environment has many advantages, especially those related to the large number of findings. Indeed, it makes it possible to rationally manage a considerable quantity of quantitative and qualitative data relating to the various erosive factors. This allow, to disentangle their interdependence by successive crossing of thematic maps and to establish a synthetic map of the degree of erosion as well as the vulnerability of the different soils. Although the validity of soil losses is debatable, this method helps:

- Planners to suggest specific devices and techniques to prevent erosion processes

- Simulate landscape degradation while considering different management scenarios

Acknowledgements

The authors are very grateful to the Laboratory of Biodiversity, Conservation of Water and Soil (LBCWS) University of Abdel Hamid Ibn Badis, Mostaganem, to the University of Amar Telidji Laghouat (Algeria) and to the National Institute for Research in Rural Engineering, waters and forests (Tunisia). This scientific collaboration is dedicated to the exchange of experience and scientific know-how in the field of water resources management at the watershed scale. S. Jebari acknowledge helpful funding from the European Union Horizon 2020 programme, under Faster project, grant agreement N°[810812].

Author details

Ahmed Benchettouh[1]*, Sihem Jebari[2] and Lakhdar Kouri[3]

1 Laboratory Biodiversity and Conservation of Water and the Soils, University Abdelhamid Ibn Badis, Amar Telidji University, Mostaganem, Laghouat, Algeria

2 National Research Institute for Rural Engineering, Water, and Forestry, Ariana, Tunis, Tunisia

3 Laboratory Biodiversity and Conservation of Water and the Soils, University Abdelhamid Ibn Badis, Kharouba, Mostaganem, Algeria

*Address all correspondence to: ahben17@yahoo.fr
and a.benchettouh@lagh-univ.dz

References

[1] Antoni, V., Le Bissonnais, Y., Thorette, J., Zaidi, N., Laroche, B., Barthès, S., ... & Arrouays, D. (2006). Modélisation de l'aléa érosif des sols en contexte méditerranéen à l'aide d'un Référentiel Régional Pédologique au 1/250.000 et confrontation aux enjeux locaux. Etude et Gestion des Sosls, *13*(3), 201-222.

[2] Kinnell, P.I.A. (2016). A review of the design and operation of runoff and soil loss plots. Catena 145 (2016) 257-265. 10.1016/j.catena.2016.06.013.

[3] Beatriz, S., Ranieri, L., Lier, Q. J., Sparovek, G., & Flanagan, D. C. (2002). Erosion database interface (EDI): A computer program for georeferenced application of erosion prediction models. Computer & Geoscience, 28(5), 661-668.

[4] Singh, R. P., Huerta-Espino, J., Sharma, R., Joshi, A. K., & Trethowan, R. (2007). Highyielding spring bread wheat germplasm for global irrigated and rainfed production systems. Euphytica, 157(3), 351-363.

[5] Ostovari, Y., Ghorbani-Dashtaki, S., Bahrami, H. A., Naderi, M., & Dematte, J. A. M. (2017). Soil loss estimation using RUSLE model, GIS and remote sensing techniques: A case study from the Dembecha Watershed, Northwestern Ethiopia. Geoderma regional, *11*, 28-36. 10.1016/j.geodrs.2017.06.003

[6] Benchettouh, A., Kouri, L., Jebari, S. (2017). Spatial estimation of soil erosion risk using RUSLE/GIS techniques and practices conservation suggested for reducing soil erosion in wadi Mina watershed (northwest, Algeria). Arab J Geosci,10:79. 10.1007/s12517-017-2875-6.

[7] Ahmed, K. R., & Akter, S. (2017). Analysis of landcover change in southwest Bengal delta due to floods by NDVI, NDWI and K-means cluster with Landsat multi-spectral surface reflectance satellite data. Remote Sensing Applications: Society and Environment, *8*, 168-181. 10.1016/j.rsase.2017.08.010

[8] Ganasri, B.P., Ramesh, H. (2015). Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin. Geoscience Frontiers, 1-9. 10.1016/j.gsf.2015.10.007.

[9] Markus, W. (2004). ECA annual report. *Eastern and Central Africa R Nairobi, Kenya.* http://www.worldagroforestry.org/eca/downloads/ECAAnnualReport.pdf.

[10] Mondal, S., Singh, R. P., Mason, E. R., Huerta-Espino, J., Autrique, E., & Joshi, A. K. (2016). Grain yield, adaptation and progress in breeding for early-maturing and heat-tolerant wheat lines in South Asia. Field Crops Research, *192*, 78-85. 10.1016/j.fcr.2016.04.017.

[11] Römkens, M. J. M. (2010). Erosion and sedimentation research in agricultural watersheds in the USA: from past to present and beyond. Sediment dynamics for a changing future, *337*, 17-26.

[12] Wischmeier, W. H. & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning* (No. 537). Department of Agriculture, Science and Education Administration.

[13] Kanwar, J. S. (1982). Managing soil resources to meet the challenges to mankind: presidential address.

[14] F.A.O. (2017). Les sols sont en danger, mais la dégradation n'est pas irréversible. Site web: http://www.fao.

org/news/story/fr/item/357221/icode. Consulté le, 27/01/2017.

[15] Benchettouh, A. (2019). L'érosion hydrique dans les régions marneuses du tell oranais cas des bassins versants de la Mina (Relizane) et Kramis (Mostaganem) (*Dissertation doctorale*). Université Abdelhamid Ibn Badis Mostaganem (Algérie)

[16] Bertol, I., Schick, J., Bandeira, D. H., Paz-Ferreiro, J., & Vázquez, E. V. (2017). Multifractal and joint multifractal analysis of water and soil losses from erosion plots: A case study under subtropical conditions in Santa Catarina highlands, Brazil. Geoderma, *287*, 116-125. 10.1016/j.geoderma.2016.08.008.

[17] Fernández, C., Vega, José, A. (2016). Evaluation of RUSLE and PESERA models for predicting soil erosion losses in the first year after wildfire in NW Spain. Geoderma 273, 64-72. 10.1016/j.geoderma.2016.03.016.

[18] Sadeghi, S.H.R., Sharifi, M. E., Khaledi D. A. (2016). Effects of subsequent rainfall events on runoff and soil erosion components from small plots treated by vinasse. Catena 138, 1-12. 10.1016/j.catena.2015.11.007.

[19] Anache, J.A.A., Wendland, E.C, Oliveira, P.T.S., Flanaganb, D.C., Nearing M.A. (2017). Runoff and soil erosion plot-scale studies under natural rainfall: A meta-analysis of the Brazilian experience. Catena 152, 29-39. 10.1016/j.catena.2017.01.003.

[20] Prasannakumar, V., Vijith, H., Abinod, S., & Geetha, N. J. G. F. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geoscience Frontiers, *3*(2), 209-215. 10.1016/j.gsf.2011.11.003.

[21] Ozsoy, G., Aksoy, E., Dirim, M. S., & Tumsavas, Z. (2012). Determination of soil erosion risk in the Mustafakemalpasa River Basin, Turkey, using the revised universal soil loss equation, geographic information system, and remote sensing. Environmental management, *50*(4), 679-694.

[22] Jebari, S., Berndtsson, R., Olsson, J., & Bahri, A. (2012). Soil erosion estimation based on rainfall disaggregation. Journal of hydrology, *436*, 102-110.

[23] Ben Slimane, A. (2013). *Rôle de l'érosion ravinaire dans l'envasement des retenues collinaires dans la Dorsale tunisienne et le Cap Bon* (Doctoral dissertation, Montpellier, SupAgro).

[24] Ganasri, B. P. & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. Geoscience Frontiers, *7*(6), 953-961. 10.1016/j.gsf.2015.10.007

[25] Haregeweyn, N. Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D.T., Fenta, A.A., Nyssen, J. Adgo, E. (2017). Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. Science of the Total Environment 574, 95-108. 10.1016/j.scitotenv.2016.09.019.

[26] Zhang, S., Fana, W., Li, Y., Yi, Y. (2017).The influence of changes in land use and landscape patterns on soil erosion in a watershed. Science of the Total Environment 574: 34-45. 10.1016/j.scitotenv.2016.09.024.

[27] Panagos, P., Borrelli, P., Meusburger, K., Van der Zanden, E. H., Poesen, J., Alewell, C. (2015). Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environnemental science et policy 51: 23-34. 10.1016/j.envsci.2015.03.012.

[28] Zhang, W., Zhou, J., Feng, G., Weindorf, D. C., Hu, G., Sheng, J. (2015). Characteristics of water erosion and conservation practice in arid regions of central Asia: Xinjiang province, China as an example. International soil and water conservation reseach.2095-6339, 30061-7. 10.1016/j.iswcr.2015.06.002.

[29] Wang, J., Huang, J., Zhao, X., Wu, P., Horwath, W.R., Li, H., Jing, Z., Chen, X. (2016). Simulated study on effects of ground managements on soil water and available nutrients in jujube orchards. Land Degradation & Development 27, 35-42. 10.1002/ldr.2334.

[30] BOLI, B. Z., Roose, E., Ziem, B. B. A., Sanon, K., & Waechter, F. (1993). Effets des techniques culturales sur le ruissellement, l'érosion et la production de coton et maïs sur un sol ferrugineux tropical sableux. Cahier ORSTOM, Série Pédagogique, *28*(2), 309-325.

[31] Pimentel, D., Harvey, C., Resosudarmo, K., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. Science 267, 1117-1123.

[32] De Ploey, J. (1989). A Soil Erosion Map for Western Europe. Catena Verlag.

[33] Roose, E., Arabi, M., Brahmia, K., Chebani, R., Mazour, M., Morsli, B. (1993). Recherche sur la réduction des risques d'érosion par la GCES en moyenne montagne méditerranéenne algérienne. *Cahier ORSTOM*, Sérier Pédologique, 28 (2), 289-307.

[34] Touaibia, B. (2000). Erosion-Transport Solide-Envasement de barrage.Cas du bassin versant de l'Oued Mina - Wilaya de Relizane. Thèse de doctorat d'Etat, Institut Nationale Agronomique, Alger, 200 p.

[35] Mazour, M. et Roose, E. (2002). Influence de la couverture végétale sur le ruissellement et l'érosion des sols sur parcelles d'érosion dans les bassins versants du nord-ouest de l'Algérie Bull Réseau Erosion; 21 ·320-30.

[36] Morsli, B., Habi, M., Mazour, M., Hamoudi, A., Halitim, A. (2012). Erosion et ruissellement en montagnes méditerranéennes d'Algérie du Nord: analyse des facteurs conditionnels sous pluies naturelles et artificielles. *Rev. Mar. Sci. Agron. Vét.*1:33-40

[37] Remini, W., Remini, B. (2003). La sedimentation dans les barrages de l'Afrique du nord. Larhyss Journal, ISSN 1112-3680, n° 02, Juin 2003, pp. 45-54.

[38] Souadi, Y. (2011). L'érosion hydrique au maghreb étude d'un cas: le bassin" versant de l'oued barbara (tunisie septentrionale). Mémoire présenté comme exigence partielle de la maitrise en géographie. Université du Québec à Montréal. 143 P.

[39] Hajji, O., Abidi, S, Hermassi, T., Habaieb, H., Raouf, M.M. (2015). Cartographie de la vulnérabilité multifactorielle à l'envasement des lacs collinaires de la Tunisie centrale. International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol. 10 No. 4, pp. 1251-1266.

[40] Jebari, S. (2009).Water Erosion Modeling using Fractal Rainfall Disaggregation – A Study in Semiarid Tunisia. PhD Thesis, Rep. 1047, Dept. of Water Resour. Engng., Lund Univ, pp. 1-140.

[41] Remini, B. Une nouvelle approche de gestion de l'envasement des barrages. Larhyss Journal, (31) (2017) 51-81

[42] Mahé, G., AlKarkouri, J., Benabdelfadel, H., Bensafia, D., Brou, T., Chaker, M., Chikhaoui, M., Coupleux, S., Crouzevialle, R., Dieulin, C., Emran, A., Ezzaouini, M.,

Goussot, E., Hallouz, F., Khomsi, K ., Laouina, A., Machouri, N., Maleval, V., Meddi, M., Nging, M., Planchon, O., Remini, B., Saadi, H., Sfa, M., Sinan, M., Snoussi, M., Taibi, S., Toumi, S., Tra Bi, A. (2013). Etude de l'évolution de l'occupation du sol sur deux grands bassins d'Algérie et du Maroc, et relation avec la sédimentation dans les barrages. In: Considering hydrological change in reservoir planning and management (Schumann, A. *et al*., Eds.) IAHS Publ. 362, 115-123.

[43] Meddi, M., Toumi, S., Assani, A.A. (2016). Spatial and temporal variability of the rainfall erosivity factor in Northern Algeria. Arabian Journal of Geosciences, 9(4) 282. 10.1007/s12517-015-2303-8

[44] Bouzid, T. (2010). Les barrages et la politique hydraulique en Algérie: état, diagnostic et perspectives d'un aménagement durable (Dissertation doctorale). Université de Mentouri–Constantine.

[45] Mohammed, T., Al-Amin, A.Q. (2018). Climate change and water resources in Algeria: vulnerability, impact and adaptation strategy. Economic and Environmental Studies, 18(1) (2018) 411-429. 10.25167/ees.2018.45.23

[46] Ministry of Water Resources and Environment (MWRE) (2020). Algeria - Laghouat | The project of completing the Sklava Dam with a capacity of 55 million cubic meters. Retrieved from https://www.youtube.com/watch?v=h_xYEv8P1bI

[47] Achite, M., Touaibia, B., & Ouillon, S. (2006). Erosion hydrique en Algérie du Nord: Ampleur, conséquences et Perspectives. In *14th International Soil Conservation Organization Conference. Water Management and Soil Conservation in Semi-Arid Environments. Marrakech, Morocco*.

[48] GTZ (1996). L'aménagement des zones Marneuses dans les bassins-Versants des Montagnes de l'Atlas Tellien Semi-Aride, Deutsche Gesellschaft fur Technische Zusammenabeit (GTZ).

[49] Kouri, L., & Gomer, D. (2010). Analyse des processus de ravinement et détermination de la sensibilité des terrains marneux dans le Tell oranais (Algérie). Science et changements planétaires/Sécheresse, *21*(4), 257-265.

[50] Aké, G. É., Kouadio, B. H., Adja, M. G., Ettien, J. B., Effebi, K. R., & Biémi, J. (2012). Cartographie de la vulnérabilité multifactorielle à l'érosion hydrique des sols de la région de Bonoua (Sud-Est de la Côte d'Ivoire). *Physio-Géo. Géographie physique et environnement*, (Volume 6), 1-42.

[51] Aiello, A., Adamo, M., Canora, F. (2015). Remote sensing and GIS to assess soil erosion with RUSLE3D and USPED at river basin scale in southern Italy. Catena 131, 174-185. 10.1016/j.catena.2015.04.003.

[52] Balasubramani, K., Veena, M., Kumaraswamy, K., & Saravanabavan, V. (2015). Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (rusle) model through GIS. Modeling Earth Systems and Environment, *1*(3), 10. 10.1007/s40808-015-0015-4.

[53] Sougnez, N., van Wesemael, B., & Vanacker, V. (2011). Low erosion rates measured for steep, sparsely vegetated catchments in southeast Spain. Catena, *84*(1-2), 1-11.

[54] Demirci, A., & Karaburun, A. (2012). Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcekmece Lake watershed, northwest Turkey. Environmental Earth Sciences, *66*(3), 903-913.

[55] Imamoglu, A., Dengiz, O. (2016). Determination of soil erosion risk using RUSLE model and soil organic carbon loss in Alaca catchment (Central Black Sea region, Turkey). Rend. Fis. Acc. Lincei.: 10.1007/s12210-016-0556-0.

[56] Kouli, M., Soupios, P., & Vallianatos, F. (2009). Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environmental Geology, *57*(3), 483-497.

[57] Yang, D., Kanae, S., Oki, T., Koike, T., & Musiake, K. (2003). Global potential soil erosion with reference to land use and climate changes. Hydrological processes, *17*(14), 2913-2928.

[58] Sadiki, A. (2004). Estimation des taux d'érosion et de l'état de dégradation des sols dans le bassin versant de l'oued Boussouab, Maroc nord oriental : application du modèle empirique (USLE), de la technique du radio-isotope ^{137}Cs et de la susceptibilité magnétique. Thèse Doctorat d'Etat. Université Mohamed Premier, Oujda, 320 p.

[59] Yjjou, M., Bouabid, R., El Hmaidi, A., Essahlaoui, A., & El Abassi, M. (2014). Modélisation de l'érosion hydrique via les SIG et l'équation universelle des pertes en sol au niveau du bassin versant de l'Oum Er-Rbia. The International Journal Of Engineering And Science (IJES), *3*(8), 83-91.

[60] Kheir, R. B., Girard, M. C., Khawle, M., & Abdallah, C. (2001). Érosion hydrique des sols dans les milieux méditerranéens. Études et gestion des sols, *8*(4), 231-245.

[61] Kouri, L. (1993). *L'erosion hydrique des sols dans le bassin versant de l'oued mina (algerie). Etude des processus et types fonctionnels de ravins dans la zone des marnes tertiaires* (Doctoral dissertation, Strasbourg 1).

[62] Roose, É., Sabir, M., Arabi, M., Morsli, B., & Mazour, M. (2012). Soixante années de recherches en coopération sur l'érosion hydrique et la lutte antiérosive au Maghreb. *Physio-Géo. Géographie physique et environnement*, (Volume 6), 43-69.

[63] Toumi, S. (2013). *Application des techniques nucléaires et de la télédétection à l'étude de l'érosion hydrique dans le bassin versant de l'oued Mina* (Doctoral dissertation, Thèse de Doctorat, Ecole Nationale de l'Hydraulique, Algérie, p 9 et 36).

[64] Achite, M., & Meddi, M. (2004). Estimation du transport solide dans le bassin-versant de l'oued Haddad (Nord-Ouest algérien). Science et changements planétaires/Sécheresse, *15*(4), 367-373.

[65] Achite, M., & Ouillon, S. (2007). Suspended sediment transport in a semiarid watershed, Wadi Abd, Algeria (1973-1995). Journal of hydrology, *343*(3-4), 187-202.

[66] Touaibia, B., Gomer, D., Aïdaoui, A. et Achite, M. (2001). Quantification et variabilité temporelles de l'écoulement solide en zone semi-aride, de l'Algérie du Nord. Journal des sciences hydrologiques 46 (1), Pp. 41-53.

[67] Touaibia, B., Bouaïchi, I., & Dernouni, F. (2006). approche de calcul de l'exposant climatique en cas d'insuffisance de donnees: cas de la region de Tipaza. Production scientifique-Communications, 1.

[68] Alejandro, M., & Omasa, K. (2007). Estimation of vegetation parameter for modeling soil erosion using linear Spectral Mixture Analysis of Landsat ETM data. ISPRS Journal of Photogrammetry and Remote Sensing, *62*(4), 309-324.