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Application of remote sensing and GIS to the mapping of water erosion in the oued seybouse watershed (North-East of Algeria)

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Abstract

In Algeria, the spatial extension of water erosion is a real threat for areas known to be immune, such as the case of the Oued Seybouse watershed, where they combine all the natural and anthropogenic conditions that predispose them to accelerated degradation. The present study is based on the use of remote sensing and GIS to map soil erosion by surface water in the Oued Seybouse watershed in northeastern Algeria, using the Revised Universal Soil Loss Equation (RUSLE). The combinations of data from different sources and field observations have provided a contextualized mapping of all soil erosion factors by surface water. The integration of the RUSLE model in the GIS gave a first estimate of the risk of water erosion, ie 32.50% of the total area of the Oued Seybouse watershed is affected, where the soil losses are estimated in average at 13.63t/ha/year. This modest cartographic result is an improved base for the managers of this watershed, which has not yet been observed, analyzed and monitored for protecting and safeguarding one of the largest watersheds in Algeria.

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Introduction

Water erosion is a very widespread natural phenomenon in North Africa, particularly in the Maghreb countries (Bouguerra, 2018). It has become a relevant issue globally. In recent years, this phenomenon has experienced a spectacular extension and is causing increasingly worrying effects (Koussa *et al*., 2018). It is the main cause of soil degradation as well as the deterioration of the geochemical quality of water (Khallef, 2019). This azonal phenomenon, continues to impact man and society, it considerably reduces soil fertility 45% of the fertile land in Algeria is affected there, considerably reduces the storage capacity of dams, the average annual specific degradation varies between 2000 and 4000t/km^2 (Demmak, 1982). Due to its effects and its extent, this phenomenon is eligible for the first degree of national natural risk; it affects more than 20% of the country's total surface, 238 million hectares (Mostephaoui *et al*., 2013). Areas that tend to increase given the permanence of situations of exposure to erosive agents. Despite the numerous contributions on the subject (Heush *et al*., 1970; Demmak, 1982; Arabi, 1991; Meddi, 1992; Roose *et al*., 1993; Brahamia, 1994; Touaibia *et al*., 2000; Laouina *et al*., 2000; Mazour *et al*., 2002) and the list is still long, it continues to arouse interest (Khallef *et al*., 2018). The Oued Seybouse watershed covered by this study meets all the natural conditions which predispose them to accelerated degradation. Add to this the proliferation of anthropogenic impacts (overgrazing, deforestation, fires, poor management of agricultural work, sand extraction and accelerated urbanization). In this context, the urgency and the gravity of the situation require methodological choices capable of embracing the complexity of the case study. Erosion modeling is one way to identify the ongoing soil degradation processes in the Oued Seybouse watershed. To do this, the revised universal soil loss equation (RUSLE) lends itself to spatial interpolation, which makes it possible to obtain a map of all the factors and to spatialize the area's most sensitive to erosion. The objective of this study is to map the risk of water erosion using the revised version of the Universal Soil Loss Equation (RUSLE), remote sensing and GIS in the Oued Seybouse watershed. However, the database developed in this study can be used for the implementation of a management planning policy aimed at protecting and preserving the water resources of this watershed.

Materials and methods

Presentation of the study area

The Oued Seybouse watershed is located in the northeast of Algeria, bounded by the following geographic coordinates: Latitude between 36°15´N and 37°N, Longitude 7°15´E and 7°55'E (Fig. 1). It covers an area of 6028km^2, geographically limited to the north by the Mediterranean Sea, to the south by the mountains of Mahouna, Ain Larbi and Sedrata, to the west by the Edough massif, the mountains of Houara and Debagh and to the east by the eastern extension of the Annaba-Bouteldja aquifer system and the mountains of Nador N'bail. The perimeter of study is registered in the territory of seven Wilayas, it is the South and South-East part of the Wilaya of Annaba, the majority of the Wilaya of Guelma, the West part of the Wilaya of El Taref, the southern and southwestern part of Wilaya de Souk Ahras, the northern and northeastern part of the Wilaya of Oum El Bouaghi, the western part of the Wilaya of Constantine and the southern part of the Wilaya of Skikda. The Oued Seybouse watershed is considered to be the most important basin in Algeria by the length of its course, its surface area and the number of its tributaries. It is currency in three parts: the high plains (high Seybouse), the southern tell (average Seybouse) and the northern tell (low Seybouse). The topography of the study perimeter is characterized by a significant altitudinal variation, ranging from 1 m to 1579m. From a lithological point of view, the Oued Seybouse watershed encompasses a multitude of lithological formations composed mainly by; Numidian sandstones, clays, marls, limestones, marly-limestones, shales, conglomerates and surface formations. These facies going from the quaternary to the Triassic, present variations in resistance of facies going from the hardest rocks represented by limestone and sandstone rocks, to the tenderest clayey rocks. The climate of the study area is Mediterranean, characterized by a cold rainy winter and a dry and hot summer. Average annual rainfall ranges from 500mm to 800mm. The rainiest months are January, February and March, totaling 237.63mm, with a maximum rainfall which reaches the value of 81.92mm recorded during the month of February for the period 2009-2017. The average temperature is 18°C; the minimum average temperature is 4.68°C in February, while the maximum average is 36.81°C for the month of July. Land use is mainly represented by natural vegetation in the form of forests and maquis, rangelands, agricultural land, bare soil and urban.

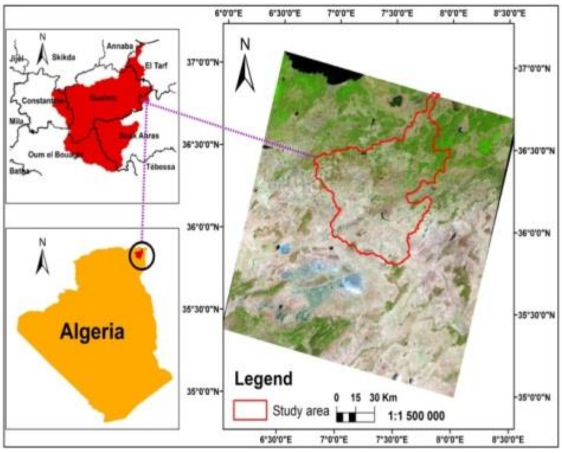

Fig. 1. Location of study area.

Description of the model (rusle)

Wischmeier's equation in its revised version (RUSLE) applies to the estimation of soil losses caused by surface erosion (Khallef, 2019). It is a multiplicative function of the five factors that control water erosion: rain erosion, soil erodibility, slope and length of slope, land use and anti-erosion practices (Koussa *et al.*, 2018). This equation, which adapts well to remote sensing and GIS, has been used by several researchers in Algeria to assess water erosion (Meghraoui *et al.*, 2017; Khallef *et al.*, 2018; Bouguerra, 2018; Toubal *et al.*, 2018; Benchettouh, 2019; Sahli *et al.*, 2019). Despite criticisms of the misuse of this equation in its revised version, it has appeared in practice that the RUSLE factor modeling approach remains an acceptable strategy for estimating and evaluating soil water erosion (Mostephaoui *et al.*, 2013).

This equation is written as follows:

$A = R.K.LS.C.P (1)$ Such as:

A: is the annual soil loss rate (t/ha/year).

R: the erosiveness factor of rainfall expressed in Mega Joul. mm/ha is defined as the potential rain capacity to cause erosion and given as the product (EI30) of the total rain energy (E) and the maximum intensity for 30 min (I30) (Wischmeïer and Smith, 1978).

K: The erodibility factor expresses the vulnerability of the soil to be eroded by rain. It depends on the grain size, soil texture, organic carbon content, structural stability, porosity, permeability..... etc (Khallef *et al.*, 2018).

LS: The topographic factor LS represents the effect of the slope length (L) and the inclination of the slope (S) on erosion. These two elements are important parameters; they condition the volume and speed of runoff (Payet *et al.*, 2011).

C: is a dimensionless factor representing the effect of plant cover, it is defined as the ratio between the losses of bare soil under specific conditions and the losses of soil corresponding to soils under the farming system (Wischmeier and Smith, 1978; Brahamia, 1994).

P: dimensionless factor, integrates anti-erosion farming techniques; supposed to promote infiltration and limit runoff, namely crops in furrows along contour lines, in alternating strips or on terraces, reforestation in benches, hoeing (Khali Issa *et al.*, 2016; Koussa *et al.*, 2018; Khallef *et al.*, 2018).

This study is based on the use of the revised universal soil loss equation (RUSLE) (Renard *et al.*, 1997; Hyeon Sik Kim, 2006).However, its application comes up against the availability and quality of data. In the case of the Oued Seybouse watershed, the data used are collected from a global online database.Also, we had recourse to:

- An Aster GDEM image with a resolution of 30 m from 17/11/2011
- An image of the LandSat 8 OLI / TIRS Program of 08/11/2019 which can be downloaded free of charge from the website www. Earth explorer.

- A GeoTIF raster image of rainfall data downloaded from the Center for Hydrometeorology and Remote Sensing (CHRS RainSphere).
- A vector soil map (SHP) of the world downloaded from the FOA database.

The preprocessing and image processing were carried out using ENVI 5.1 software, while the analysis, the combination of all the data and the application of the model were carried out with 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. Fig. 2 presents a general diagram of the methodology process used.

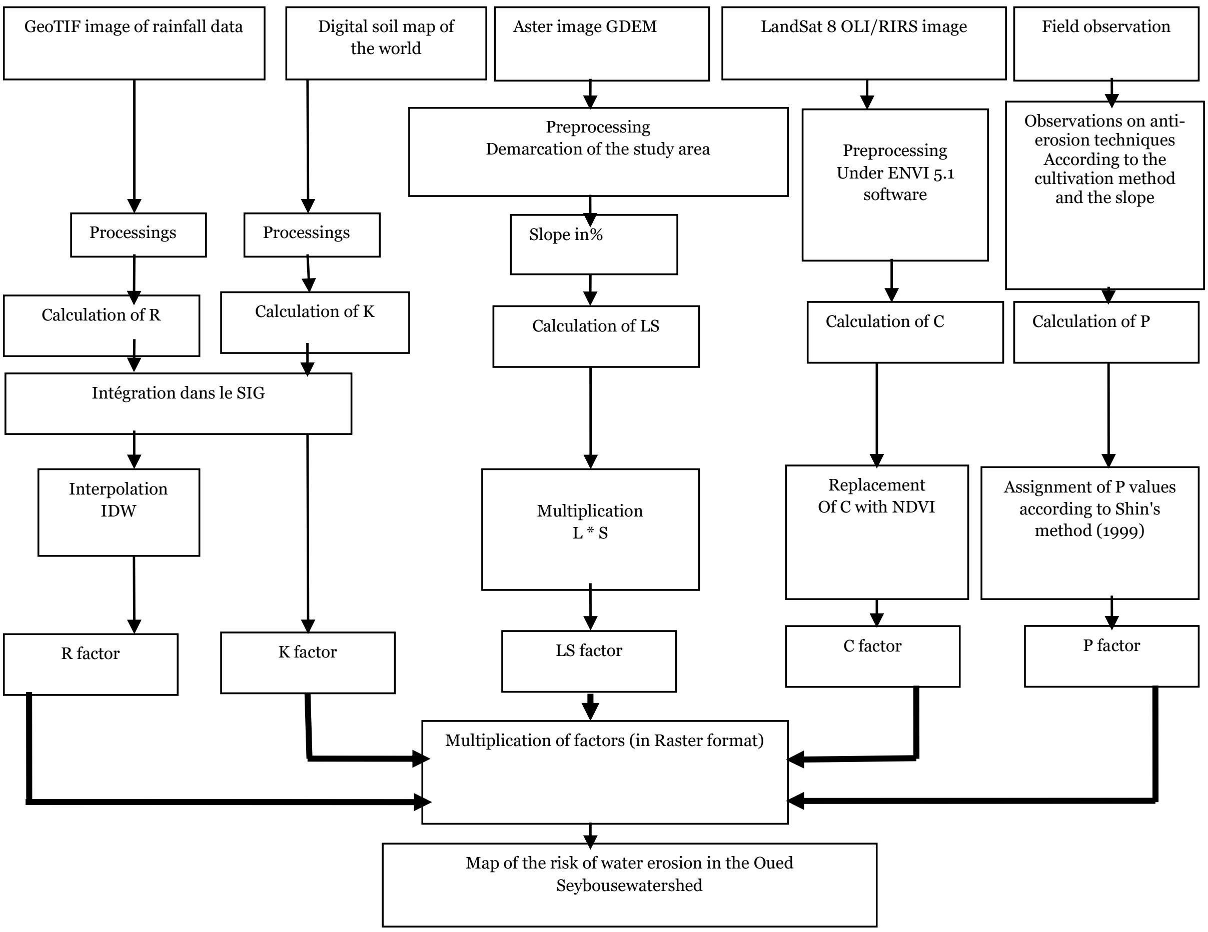

Fig. 2. Flowchart of the methodology followed in this study.

Calculation and mapping of rusle model factors

The R factor

The aggressiveness of the rains was calculated according to equation N° 2 developed by Renard and Freimund (1993) and tested on the Beni Haroun watershed in eastern Algeria (Koussa *et al.*, 2018). Its formula is written as follows:

$$R = 0,04830.P^{1,610} (2)$$

Such that P<850mm where

R: is the annual erosivity of precipitation (MJ.mm.ha-1.h-1.an-1).

P: annual precipitation in (mm).

The calculation of the R factor is based on a series of processing performed on the GeoTIF image of the pluviometric data (downloaded from the CHRS RainSphere site) covering a total of 36 years of precipitation, then the calculated values are interpolated by the inverse distance weighting (IDW).

The calculation of the R factor gives values between 968 and 1140 Megajoul.mm/Hectar.heure.an (Fig. 3)

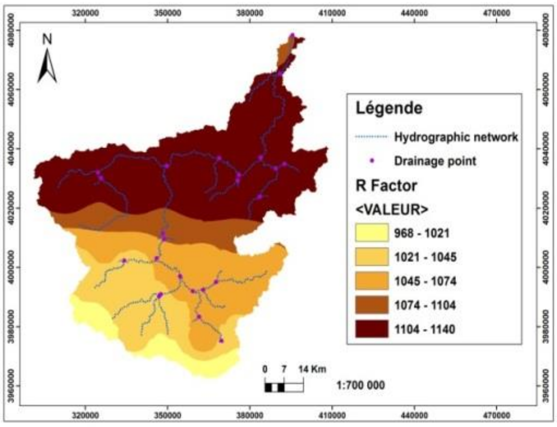

Fig. 3. Map of the erosiveness factor of rainfall (Oued Seybouse watershed).

The spatial distribution shows that the R factor values follow an increasing gradient from South to North and from West to East. The high values cover the northern part while the low values are located in the southern part.

The K factor

The soil erodibility was extracted from the digital soil map of the world (DSMW) using the equation developed by Williams (1995), its formula is as follows:

$$K_{RUSLE} = f_{csand} \cdot f_{cl-si} \cdot f_{orgaC} \cdot f_{hisand} \quad (3)$$

f_{csand} :is a factor that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand (Wawer *et al.*, 2005).

$$f_{csand} = \left\{ 0,2 + 0,3.\exp\left[-0,256.m_s.(1 - \frac{m_{silt}}{100}) \right] \right\} (4)$$

Where:

m_s: the sand fraction content (0.05-2.00mm diameter in %).

m_{silt}: the silt fraction content (0.002-0.05mm diameter in%).

f_{cl-si}: gives low soil erodibility factors for soils with high clay-to-silt ratios (Koussa *et al.*, 2018).

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}} \right)^{0,3} \quad (5)$$

Where:

m_c: the clay fraction content (< 0.002mm diameter in%).

f_{orgC} :reduces K values in soils with high organic carbon content (Anache *et al.*, 2015).

$$f_{orgaC} = \left(1 - \frac{0,25.orgC}{orgC + \exp(3,72 - 2,95.orgC)} \right) (6)$$

f_{hisand}:lowers K values for soils with extremely high sand content(Koussa *et al.*, 2018):

$$f_{hisand} = \left(1 - \frac{0,7(1 - \frac{m_s}{100})}{\frac{m_s}{100} + \exp\left[-5,5 + 22,9.(1 - \frac{m_s}{100}) \right]} \right) (7)$$

Numerical processing of the world soil map using ArcGis software made it possible to calculate the factor K 'using the equation of Williams (1995). The results of the calculation are summarized in Table 1.

Table 1. Factor K values (Oued Seybouse watershed).

Soil unit symbol	Sand% topsoil	Silt % topsoil	Clay% topsoil	OC % topsoil	F_{c-sand}	F_{cl-si}	F_{org}	$F_{hi-sand}$	k_{RUSLE}	K
VC	22,4	24,5	53	0,69	0,20395	0,70788	0,99709	1,00000	0,14	0,01896
BK	81,6	6,8	11,7	0,44	0,20000	0,74063	0,99904	0,71848	0,11	0,01400
XK	48,7	29,9	21,6	0,64	0,20005	0,84949	0,99762	0,99930	0,17	0,02231

The study area generally has a low erodibility (0,014 - 0,016) covering 63% of the total surface of the study area, followed by a high erodibility (0.019 - 0.022) with 34.29% and the average (0,016 - 0,019) with 2, 70% of the total surface of the watershed (Fig. 4). The high erodibility values are located in the southern part of the watershed which is characterized by a dry arid climate while the soils which have an average erodibility are found in the central part with a humid to sub humid climate where the soils are well protected by a dense vegetation cover. The values which have low erodibility (varies from 0,014 to 0,016) occupy the littoral part of the watershed with sub humid climate.

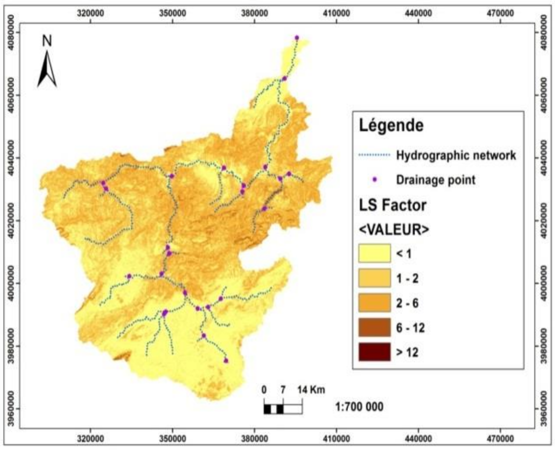

Fig. 4. Map of the topography factor (Oued Seybouse watershed).

The LS factor

With the development of digital terrain models and geographic information systems, the LS factor can be calculated from the Aster GDEM image (resolution of 30 m). To calculate the topographic factor at the Oued Seybouse watershed level, several developed models were tested. Among these tested models, the equation developed by David (1987) and tested on the Oued El Hamel watershed (Mostephaoui *et al.*, 2013) gave values representing the reality on the ground. This equation is expressed by the following formula:

$LS = 0,10+0,12*S^{3/4}$ (8) where S: is the slope in (%).

The LS topographic factor is classified according to values varying between < 1 to > 12 (Fig. 5). The minimum values (<1, 1-2) are generally located in the south and north of the watershed, generally coinciding with flat areas and slight slopes. The average values between 2 and 6 are distributed throughout the rest of the study area. The maximum values (6 to> 12) are dispersed in the parts, central, north-west, south and south-east generally coinciding with areas of hills, mountains and high slopes.

The C factor

The factor C was replaced by the standardized vegetation index derived from NDVI (Jensen, 2000; Ioannis, 2009).The relationship between NDVI and C is determined by the following equation:

$C = \exp(-\alpha.NDVI/(\beta - NDVI)$ (9)(Ioannis, 2009)

where

α, β: Parameters determining the shape of the NDVI-C curve whose values $\alpha = 2$ and $\beta = 1$ give reasonable results (Van Der Knijff J.M *et al.*, 2000).In the case of the Oued Seybouse watershed, the NDVI factor "c" is generated from the Landsat 8 OLI / TIRS image of 08/11/2019 (spatial resolution of 30 m).

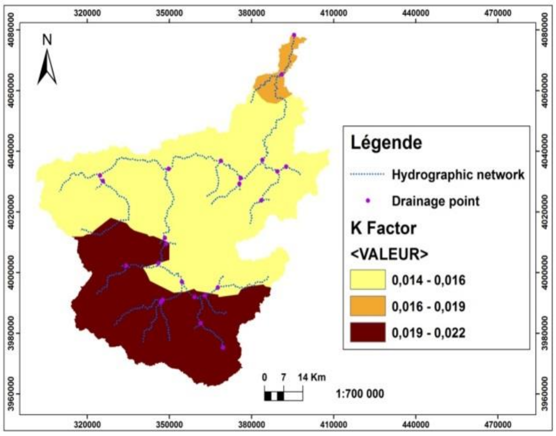

Fig. 5. Map of the soil erodibility factor (Oued Seybouse watershed)

From Fig. 6 we can distinguish five types of major occupations that occupy the entire territory of the Oued Seybouse watershed. Low to lower values of 0, 06 to 0, 52 remain in the forest and scrub areas. However, the values of 0, 52 0 to 0, 64 are located in the areas covered by rangelands and arboriculture. The values between 0, 60 and 1 correspond to bare soil, urban and cropland. Bare soils are the most susceptible to water erosion.

The P factor

The P factor is calculated according to the slope cultivation methods (Table 2) cited by Shin (1999), determined from the two P values; between 0 and 1, where the value 0 represents an environment resistant to anthropogenic erosion and the value 1 indicates an absence of anti-erosion practices.

Anti-erosion practice is the ratio of the loss of soil with specific practical support on agricultural land to the corresponding loss with plowing of parallel slope (Wischmeïerand Smith, 1978).

For our case study, the values of factor P are varied from 0, 55 to 1 (Fig. 7). The lowest and average values correspond to a low and to medium slope, located mainly in the plains and valleys. For the sharp slopes, the values of the factor P vary from 0, 80 to 1, are generally found in the foothills of the mountainous and high hills. Observation on the ground allows us to attest an almost total absence of anti-erosive practices in these areas.

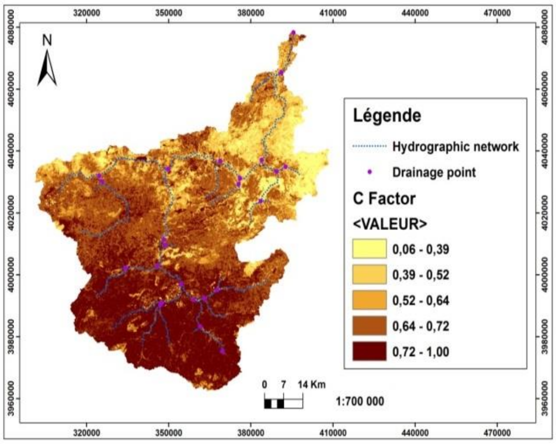

Fig. 6. Map of the land cover factor (Oued Seybouse watershed).

Table 2. The values of the factor P according to the method of Shin (1999).

Pentes (%)	P factor value
0,0 - 7,0	0,55
7,0 - 11,3	0,55 - 0,60
11,3 - 17,6	0,60 - 0,80
17,6 - 26,8	0,80 - 0,90
> 26,8	0,90 - 1,00

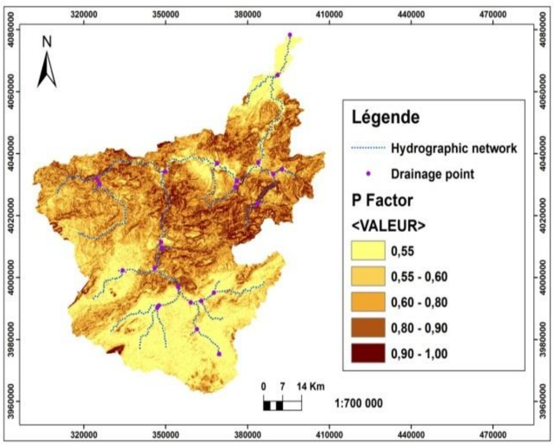

Fig. 7. Map of the factor of anti-erosion practices (Oued Seybouse watershed).

Results and discussions

The superposition of the five layers representing the factors of erosion in matrix format (Raster), allowed the elaboration at the level of the Oued Seybouse watershed area of the erosion risk map, expressing the spatial distribution of erosion values potential in t/ha/year. The result obtained represents by Fig. 8, shows erosion rates varying from 0 to> 60t/ha/year distributed over the entire study area, with an average of around 13,63t/ha/year.. It should be noted that the value 1 to 7t/ha/year (Sadiki *et al.*, 2009) and 1 to 15t/ha/year (Roose, 2010) is considered to be an average limit of soil tolerance to erosion. This value divides the Oued Seybouse watershed into three zones: class 0 to 15t/ha/year, the area affected represents 67, 50% (4,069km^2), it concerns the plains and valleys. The worrying values, between 15 to 30t/ha/year reflect significant soil losses and occupy 23, 19% (1398km^2) of the study area, most of which are located at the level of the lower foothills. The maximum values of soil losses belonging to the class 30 - 60t/ha/year and > 60t/ha/year, represent 9, 31% (561Km^2) of the total of the study area, are located in the central, south, south-east and north-west. A comparison of the result obtained with other studies carried out recently in other watersheds in northern Algeria shows the relative reliability of the applied model.

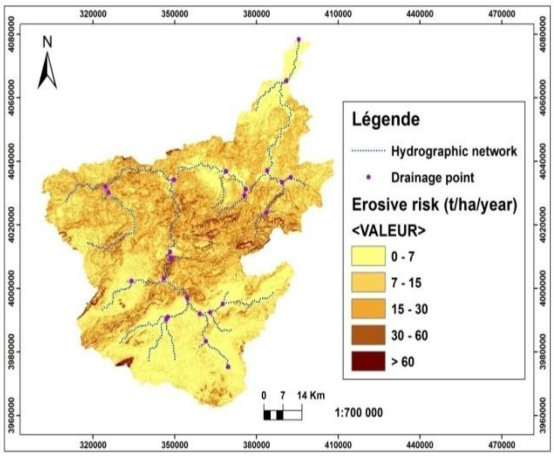

Fig. 8. Map of soil loss in (t/ha/year) (Oued Seybouse watershed).

Indeed Khallef *et al.* (2018), shows that the average soil losses in El Kala National Park (extreme Northeast of Algeria) reach 13,48t/ha/year, Koussa *et al.* (2018), estimates that the average soil losses at the Beni Haroun watershed, Mila, Algeria (northeast of Algeria) reach 12t/ha/year, Bouguerra (2018), finds that the average loss of soil by water erosion in the Oued Bouhamdane watershed (northeast of Algeria, this watershed is included in the Oued Seybouse watershed) reaches 11,18t/ha/year, Toumi *et al.* (2013), proves that in the Oued Mina watershed (northwest of Algeria) the average soil losses reach 12,43t/ha/year. In the absence of quantitative data from the in situ experimentation with water erosion in our study area, the result obtained (13, 63t/ha/year on average) is close to that found by other researchers in the watersheds of northern Algeria.

Conclusion

The application of the revised universal soil loss equation using remote sensing and geographic information system (GIS) has made it possible to estimate that soil losses at the scale of the watershed Oued Seybouse varies from 0 to > 60t/ha/year with an average annual loss of 13,63t/ha/year. This average value shows that this watershed is a favorable environment for the development of soil erosion processes, in fact 32,50% of the total surface of the study area has values> 15t/ha/year. This result is explained by the predominance of lithological formations with high erodibility (flysch, marls, alluvium and sand), degraded plant cover more particularly in the southern and southwestern part with very steep slopes> 24% and the aggressiveness of the quite heavy rains. Field observations have shown that erosion is present and visible in the places visited, particularly in the municipalities of Bouhachana, Sallaoua Anouna, Ain Larbi, Bouhamdane, Bordj Sabath, Ain Regada and Tamlouka. In addition, this study is an important database that can be used to protect and preserve the Oued Seybouse watershed, by establishing an urgent intervention plan for the area's most affected by this phenomenon.

References

Arabi M. 1991. Influence de quatre systèmes de production sur le ruissellement et l'érosion en milieu montagnard méditerranéen (Médéa, Algérie). Thèse de doctorat, Université de Grenoble. France: 272 p.

Benchettouh A. 2019. L'erosion hydrique dans les régions marneuses du Tell Oranais : cas des bassins versants de la Mina (Relizane) et Kramis (Mostaganem).Thèse de doctorat, Université de Abdelhamid Ben Badis Mostaganem. Algérie : 167 P.

Bouguerra H. 2018. Quantification et modélisation des transports solides, cartographie des zones à risques d'érosion hydrique par utilisation d'un SIG: application aux bassins de Bouhamdane et Ressoul (Nord-est Algérien).Thèse de doctorat 3 ème Cycle, Université Aboubakr Belkaïd Tlemcen. Algérie : 126 P.

Brahamia K. 1993. Essai sur la dynamique actuelle dans Ia moyenne montagne méditerranéenne : bassin versant de l'oued Mina (zone de Taassalet), Algérie. Thèse Géographie, Université de Grenoble, 241 p.

David WP. 1987. Soil and water conservation planning. Policies, Issues and recommendations. DENR Quezon City. Journal of Philippine Development **(26), Volume 15,** 47-84.

Demmak A. 1982. Contribution à l'étude de l'érosion et des transports solides en Algérie. These de Doctorat. Ing. Paris 6. France : 323 P.

Heusch B, Kalman R, Duhamel P, Robert P. 1970. Érosion, transport solide, sédimentation. Annal de recherche forestière Maroc. N° spécial. Etude sur l'érosion **10**, 390 p.

Ioannis Z. 2009. Multi-temporal soil erosion risk assessment in N. Chalkidiki using a modified usle raster model. EARSeL e Proceedings 2009 Vol. 8 No. **1** pp. 40-52 ref. 17.

Jensen JR. 2000. Remote sensing of the environment: An earth resource perspective, published as 1st ed. Upper Saddel River, New Jersey: Prentice. Hall, Inc.: Upper Saddle River, NJ. 2007. Xvi and 592 pp., diagrams, maps, photos, images, index. ISBN 0-13-188950-8. 656 P.

Khali issa L, Ben Hamman Lech-Hab K, Raissouni A, El Arrim A. 2016. Cartographie Quantitative du Risque d'Erosion des Sols par Approche SIG/USLE au Niveau du Bassin Versant Kalaya (Maroc Nord Occidental), J. Mater. Environ. Sci. **7 (8),** (2016) 2778-2795.

Khallef B. 2019. Contribution à l'étude des facteurs de vulnérabilité par des images satellitaires : Cas du Parc national d'El Kala Wilaya d'El Taref-Algérie. Thèse de doctorat, Université de Badji Mokhtar Annaba. Algérie : 163 P.

Khallef B, Brahamia k, Oularbi A. 2018. Study of the vulnerability of soil to water erosion by remote sensing and GIS: Case of El Kala National Park (Algeria), Journal of Biodiversity and Environmental Sciences*,* Vol. 13. N°. **6**, P. 52-65, 2018.

Koussa M, Bouziane M. 2018. Apport de SIG a la cartographie des zones à risque d'erosion hydrique dans le bassin versant de Beni Haroun, Mila, Algérie, Geo-Eco-Trop., 2018, 42, **1,** 43-56.

Laouina A, Nafaa R, Coelho C, Chaker M, Carvalho T, Boulet A, Ferreira A, Lubna S, Qaryouti D, Rakad A, Ta A. 2014. GIS modeling of water erosion in Jordan using "RUSLE. Bulletin for Environmental Researches **17(1)**, 57-75.

Mazour M, 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. Bulletin - Réseau Erosion **(21),** p 320-330.

Meddi M. 1992. Hydro-pluviométrie et transport solide dans le bassin versant de l'Oued Mina (Algérie). Thèse de doctorat, Université Louis Pasteur, Strasbourg. France: 285P.

Meghraoui M, Habi M, Morsli B, Regagba M, Seladji A. 2017. Mapping of soil erodibility and assessment of soil losses using the RUSLE model in the Sebaa Chioukh Mountains (northwest of Algeria), Journal of Water and Land Development, 2017, No. **34** (VII–IX): 205–213.

Mostephaoui T, Saïfi M, Sakaa B, Hanafi M. 2013. Cartographie des risques d'erosion hydrique par l'application de l'equation universelle de pertes en sol a l'aide d'un système d'information géographique dans le bassin versant d'el hamel (Boussaâda) Algérie. Journal Algérien des Régions Arides N°**11** spécial, pages 1-17.

Payet E, Dumas P, Pennober G. 2011.Modélisation de l'érosion hydrique des sols sur un bassin versant du sud-ouest de Madagascar, le Fiherenana », VertigO, Volume 11 Numéro **3**, décembre 2011.

Roose E. 2010. La degradation des terres et l'erosion du sol.URL :http://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers1209/010054913.pdf.

Roose E, Arabi M, Brahamia K, Chebbani R, Mazour M, Morsli B. 1993. Recherche sur la réduction des risques d'érosion par la GCES en moyenne montagne méditerranéenne algérienne. Cah. ORSTOM, Ser. Pédol **28(2)**, 289-307.

Sadiki A, Bouhlassa S, Auajjar J. 2004. Utilisation d'un SIG pour l'évaluation et la cartographie des risques d'érosion par l'Equation universelle des pertes en sol dans le Rif oriental (Maroc): cas du bassin versant de l'oued Boussouab. Bulletin de l'Institut Scientifique, Rabat, section Sciences de la Terre, n°**26**, 69-79.

Sahli Y, Mokhtari E, Merzouk B, Laignel B, Vial C, Madani K. 2019. Mapping surface water erosion potential in the Soummam watershed in Northeast Algeria with RUSLE model,Journal of Mountain Science*,* July 2019, **Volume 16, Issue** 7, pp 1606-1615.

Shin GJ. 1999. The analysis of soil erosion analysis in watershed using GIS, Ph.D. Dissertation, Department of Civil Engineering, Gang-won National University.

Touaibia B, Gomer D, Aidaoui A. 2000.Estimation de l'index d'érosion de Wischmeier dans les micros bassins expérimentaux de l'Oued Mina en Algérie du Nord. Bulletin. Réseau Erosion, n°**20**, Ed., IRD, Montpellier.

Toubal A, Achite M, Ouillon S, Dehni. 2018. Soil erodibility mapping using the RUSLE model to prioritize erosion control in the Wadi Sahouat basin, North-West of Algeria. Environ Monit Assess. 2018 Mar 12; 190 **(4),** 210.

Toumi S, Meddi M, Mahe G, Brou Y. 2013. Cartographie de l'erosion dans le bassin versant de l'Oued Mina en Algérie par télédétection et SIG. Hydrological Sciences Journal – Journal des Sciences Hydrologiques **58(7),** 2013.

Van der Knijff JM, Jones RJA, Montanarella L. 1999. Soil erosion risk assessment in Italy. European commission directorate general JRC joint research centre Space Applications InstituteEuropean Soil Bureau 51 P.

Wawer R, Nowocieñ E, Podolski B. 2005. Real and Calculated K_{USLE} Erodibility Factor for Selected Polish Soils. Polish Journal of Environmental Studies **Vol. 14, No 5**, 655-658.

Williams JR. 1995. Chapter 25: The EPIC model. In V.P. Singh (ed.) Computer models of watershed hydrology. Water Resources Publications*:* 909-1000.

Wischmeïer WH, Smith DD. 1978. Predicting Rainfall Erosion losses, Agriculture Handbook no. 57, US Department of Agriculture. Washington DC. USA. 58p.