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Soil erodibility mapping and its correlation with soil properties of Oued El Makhazine watershed, Morocco

A. Belasri[1*], A. Lakhouili[1], O. Iben Halima[2]

1. Faculty of Sciences and Techniques (FST), Hassan 1 University, Settat 577 Morocco
2. National Institute of Agricultural Research, Settat 589 Morocco

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A Belasri
belasri.asma@gmail.com
+212672594996

Abstract

Soil erosion is a result of many factors, such as rainfall intensity, steepness of slope, length of slope, vegetation cover, and management practices. Besides all this, the inherent properties of a soil influence the ability of water to detach and transport soil particles. This intrinsic property is classified as soil erodibility. Soil erodibility factor (K) from the Universal Soil Loss Equation (USLE) was used in this study to estimate the value of soil erodibility of Oued El Makhazine watershed. In fact, K factor is affected by soil primary particles , organic matter content, soil permeability and soil structure. In this study, the samples of surface soil were collected from Oued El Makhazine watershed and then analyzed in the laboratory. Using the K factor formula, soil erodibility was calculated for each soil sample. Geographical Information System (GIS) tools were used to represent the spatial representation of the soil erodibility in the study area.

1. Introduction

Soil erosion is the process of detachment and transport of soil materials by the erosive and transport agents (wind, water...) [1]. Soil loss by erosion is expanded worldwide and influence negatively the agricultural and forestry ecosystems [2,3,4].
An estimation at global level showed that arable land present more than 10 million hectare of soil loss per year [5] and this is severe threat especially in countries depending on agricultural activities like Morocco.
Prediction of soil loss intensity is an indispensable step to realize soil conservation measures and getting reliable predictions of their effectiveness in a study area.
Although the methods to estimate soil loss intensity are numerous [6], the Universal Soil Loss Equation (USLE) [7] and its revised version (RUSLE) [8] are still frequently used to predict soil loss at the plot scale. According to many authors, the popularity of USLE/RUSLE depend on many reasons i) a combination of acceptable efficiency with relative simplicity, ii) the ability to use quite basic data, and iii) the exclusivity to rely on a global (worldwide distributed) dataset [9, 10, 11]. Among many mathematical models, USLE [7] is widely used to predict soil erosion [6], this empirical equation is based on rainfall erosivity factor, soil erodibility factor, slope length factor, slope steepness factor, cover management factor, and support practice factor [12].
Soil erodibility factor is a good way to assess and determine soil loss worldwide [13], a strong correlation between K factor and soil loss was proven [14]. Many soil properties, including physical, chemical, biological, and mineralogical properties affect soil erodibility [15], it is linked to the combined actions of rainfall, runoff and infiltration on soil. K factor represents the effect of soil properties and soil profile characteristics on soil loss [5], recently, it has been considered as an indicator of erosion due to his sensitivity to detachment and transport particles [16].
The objectives of this study is to calculate K factor in Oued El Makhazine watershed or predict soil loss that extremely affects the agricultural production as well as the dam reservoir, using the geographic information systems to analyze the spatial variability of erodibility on the study area.

2. Material and Methods

2.1. Study area

Located in the north of morocco, Oued El Makhazine watershed (Figure 1) covers an area of 2414 km^2, and stretches from north latitudes 34°45'15.3" up to 35°15'44.6" and from west longitude 5°14'32.4" to 5°51'9.1", its altitude is between 10 m and 1677 m.

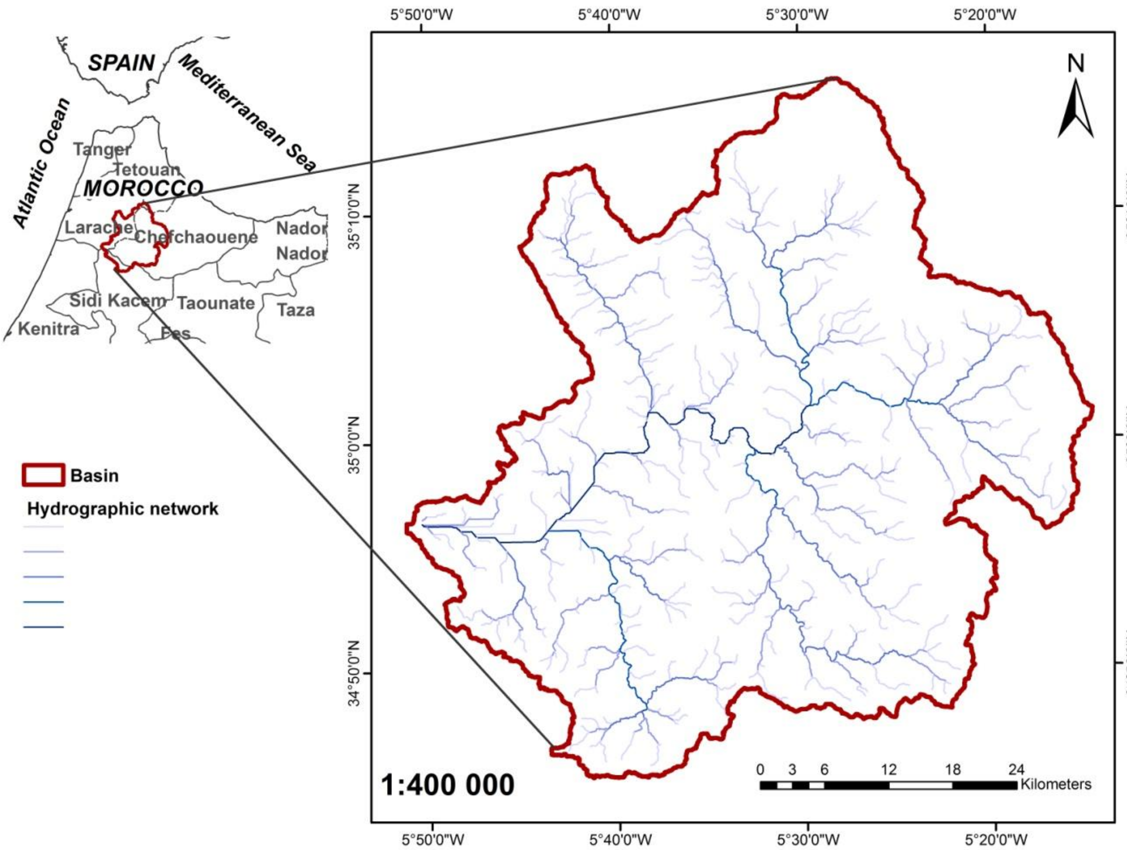

Figure 1: Study area location map

Oued El Makhazine watershed is composed to the west of plains with a very pronounced topography, while to the east the relief becomes more hilly and mountainous. The altitude increases gradually eastward with the first reliefs of the Rif mountain range, this configuration of the relief associated with the presence of the Atlantic Ocean to the west is the main cause of significant rainfall measured in the watershed, the study area receives an annual average rainfall of 1100 mm [17]. The predominance of impermeable soils in the watershed promotes runoff, which is increased by the slope effect as one progress eastward.

The vegetation cover of the watershed is defined by the presence of matorral, typical Mediterranean landscapes, with a predominance of forests. Most of the forest cover is at the upper watershed, while cultivate plains dominate downstream the basin.

2.2 *Soil erodibility factor (K)*

The meaning of "soil erodibility" is distinctly different from "soil erosion". In the soil loss equation, the rate of soil erosion may be influenced more by rainstorm characteristics, land slope, cover, and management than by inherent properties of soil. However, some soils erode more easily than others despite the similarity of factors that affect soil. This difference, produced by properties of the soil itself, is called soil erodibility [7]. Erodibility is controlled by four major soil properties: soil texture (particle size distribution), soil structure, organic matter content, and permeability.

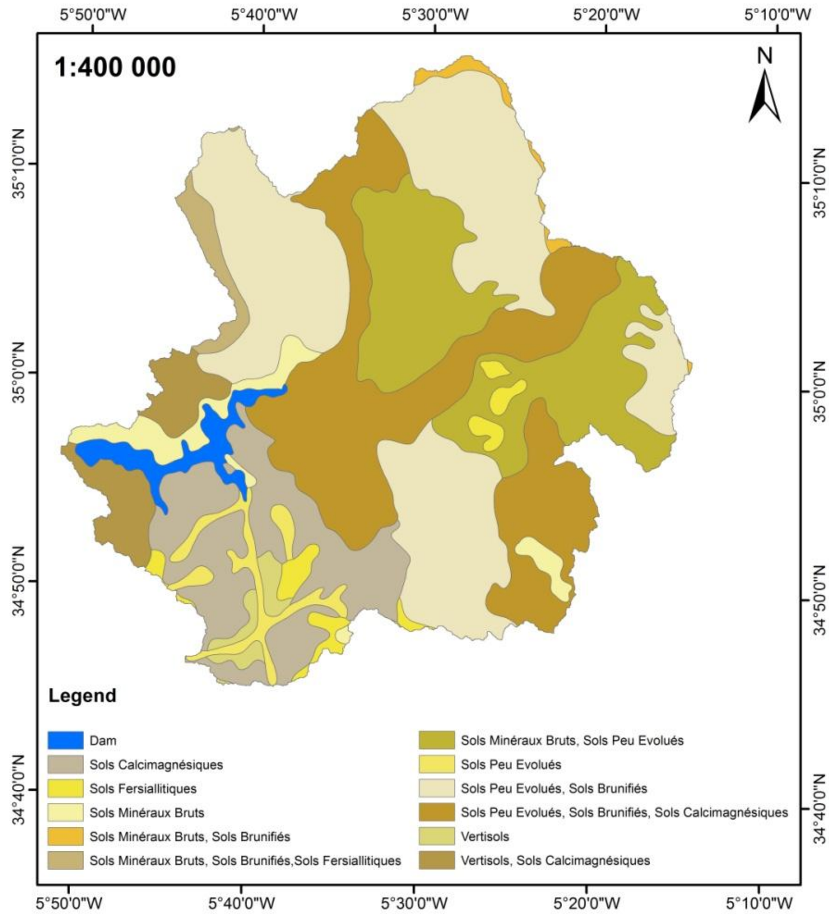

Figure 2: Oued El Makhazine watershed soil

In this study, soil map (Figure 2), based on French CPCS system [18] was used to locate and collect soil samples from Oued El Makhazine watershed.

The physicochemical analyses were determined in soil laboratory of National Institute of Agricultural Research of Settat, for each sample the particle size analysis was performed in five classes (sand, very fine sand, silt, very fine silt, and clay) using the Robinson’s pipette method [19]. Organic carbon was quantify by the Walkley–Black wet dichromate oxidation [20] and converted to organic matter by multiplying it by 1.724.

Soil permeability code was determined from the National Soils Handbook [21] and soil structure code was obtained using Soil Textural Pyramid [22].

To calculate soil erodibility, the formula of Wischmeier and Smith [7] was used.

$$K = \frac{2.173 \times \left(2.1 \times M^{1.14} \times (10^{-4}) \times (12 - a) + 3.25 \times (b - 2) + 2.5 \times (c - 3)\right)}{100}$$

K = soil erodibility (t·ha·h·ha^{-1}·Mj^{-1}· mm^{-1}), M = particles percentage (% of very fine sand + % of silt * (100-% clay), a = organic matter content (% C * 1.724), b = soil structure, c = soil permeability.

3. Results and discussion

Soil erodibility factor depends on four parameters: soil texture, soil structure, permeability and organic matter content. The soil characteristics analyzed in this research presented in Table 1.

Table 1: Soil physical and chemical characteristics determined for the study area

Soil Type	Clay (%)	Sand (%)	Silt (%)	Texture Class	OM	K	Area (km^2)	Area (%)
Sols calcimagnésiques	49.62	16.28	34.10	Clay	2.62	0.69	291.14	12.06
Sols Fersialitiques	48.52	27.47	24.01	Clay	4.57	0.81	51.08	2.12
Sols Minéraux Bruts	40.26	37.80	21.94	Clay	2.35	0.85	72.51	3.00
Sols Minéraux Bruts, Sols Brunifiés	42.09	35.97	21.94	Clay	2.20	0.85	16.21	0.67
Sols Minéraux Bruts, Sols Brunifiés, Sol Fersialitiques	21.18	69.69	9.13	Sandy Clay Loam	1.37	0.67	36.09	1.49
Sols Minéraux Bruts, Sols peu Evolués	49.16	22.31	28.53	Clay	1.47	0.68	415.61	17.22
Sols peu Evolués	63.41	12.11	24.48	Clay	3.24	0.37	57.21	2.37
Sols peu Evolués, Sols Brunifiés	44.05	34.01	21.94	Clay	2.05	0.85	735.47	30.47
Sols peu Evolués, Sols Calcimagnésiques	34.42	43.22	22.36	Clay Loam	2.00	0.79	553.91	22.95
Vertisols	53.67	24.64	21.69	Clay	3.06	0.54	29.50	1.22
Vertisols, Sols calcimagnésiques	68.85	12.48	18.67	Clay	2.29	0.24	99.15	4.11

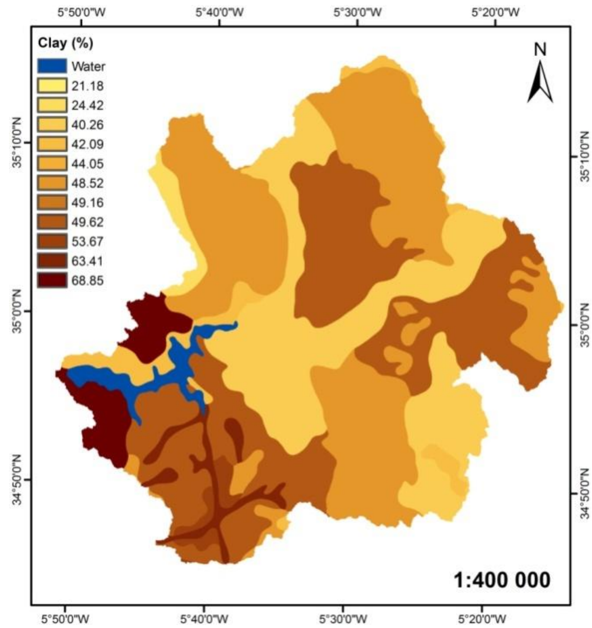

Figure 3: Spatial distribution of the clay fraction in the study area

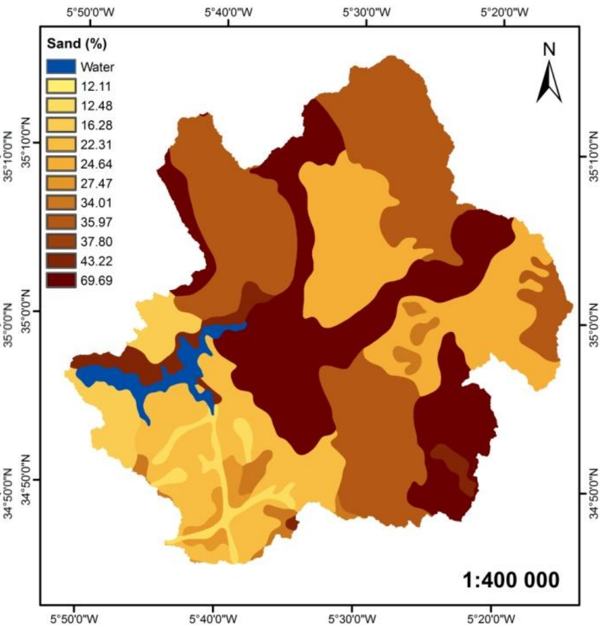

Figure 4: Spatial distribution of the sand fraction in the study area

Soil texture is determined by the mass percentage of sand, silt, and clay particles in a soil sample. The size of the soil particle determines whether it is sand, silt, or clay. Sand particles have a diameter of 0.05 mm to 2 mm, the diameter of a silt particle ranges from 0.002 mm to 0.05 mm, and the diameter of clay particles is smaller than 0.002 mm.

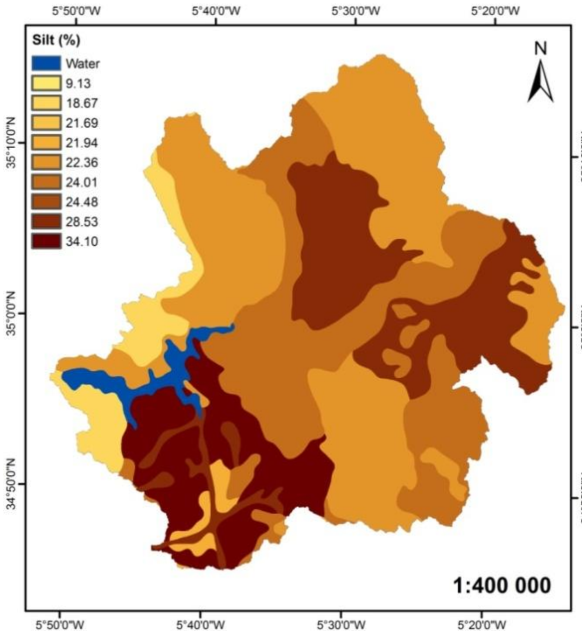

Figure 5: Spatial distribution of the silt fraction in the study area

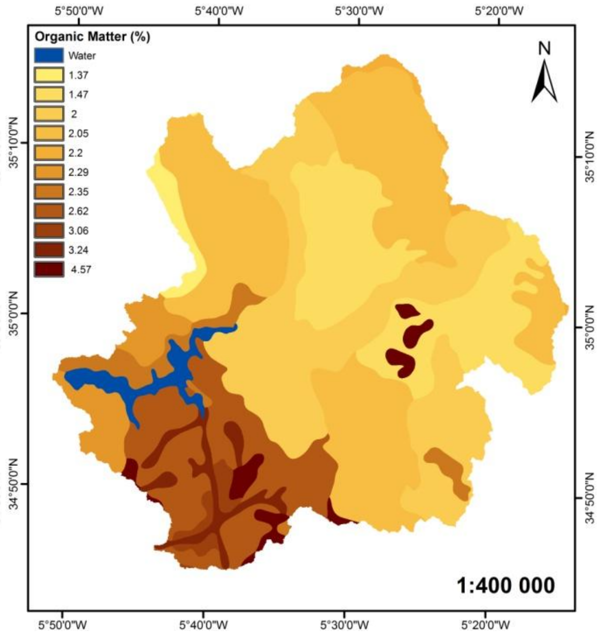

Figure 6: Spatial distribution of the organic matter content fraction in the study area

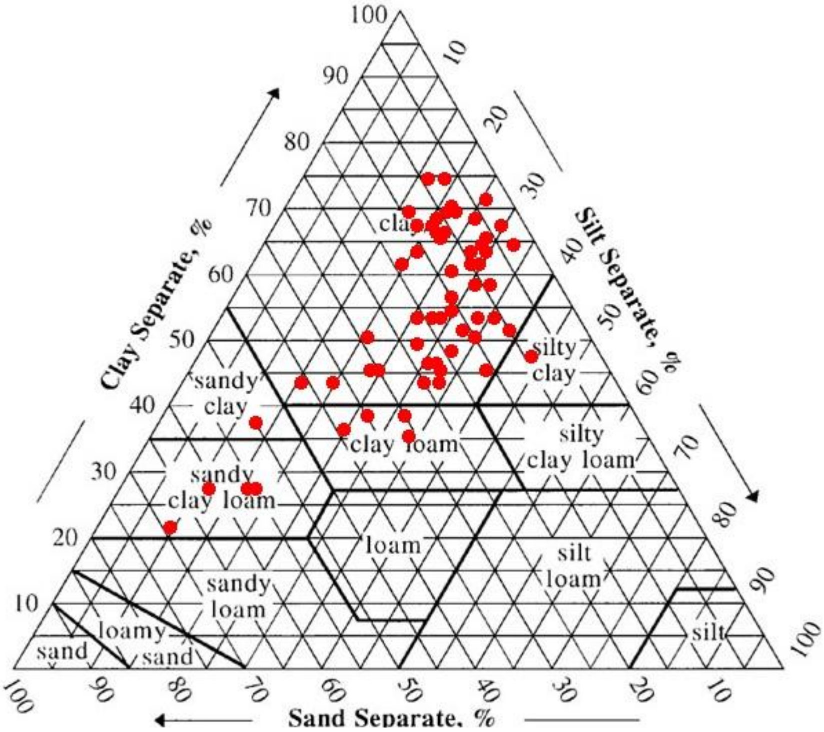

Figure 7: Distribution of clay, sand and silt in the soil samples

Texture is an important soil characteristic; it involves the potential of the soil to hold water, the rate of water movement through the soil, soil fertility and its workability.

According to the USDA triangle, soil types can be classified into 12, the result shows that 83.3% of samples had caly texture, 6.7% had Clay loam texture, 6.7% are Sandy clay loam, 1.7% are sandy clay, and 1.6% are silty clay (Figure 7). The study area had a high clay percentage that varied from 21.18% up to 68.85% (Figure 3). Whereas, the sand content ranged from 12.11% up to 69.69% (Figure 4) and silt content from 9.13% up to 34.10%, respectively (Figure 5).

Erodibility is low for clay-rich soils with a low shrink-swell capacity, because clay particles mass together and form large aggregates that resist detachment and transport processes [23].
It was found out that average soil loss is negatively correlated with clay content but positively correlated with very fine sand and silt plus very fine sand contents [24].
Physical and chemical properties of soil are often influenced by organic matter content, by building up aggregation, soil organic matter affects soil erodibility [25], infiltration [26], water detention [27], and shear strength of soil [28].
Using the Walkley-Black method to determine soil organic matter content, the results of this analysis showed that its content varied from the minimum of 1.37% up to maximum of 4.57% (Figure 6), with 72.13% (Table 1) of the area ranging from 1.37% up to 2.05% of organic matter content which is considered to be a moderate level that can prevent soil from detachment by the rainfall kinetic energy and provide a very low threshold of soil erodibility.
Since 1930's, the majority of studies, have defined soil erodibility according to inherent soil properties, they focus on the role of soil texture, chemical properties such as soil organic matter, and soil profile descriptors such as structure and permeability [29].
Permeability of a soil is described by a measure of the ease with which a particular fluid flows through its interconnecting voids.
Soil permeability is correlated with the grain size distribution of a soil and differs for each soil type.
To determine the permeability code of each soil type of the study area, the texture must be first calculated from the soil texture pyramid. The soil texture class has been used in Table 2 to determine the permeability code of the soil.

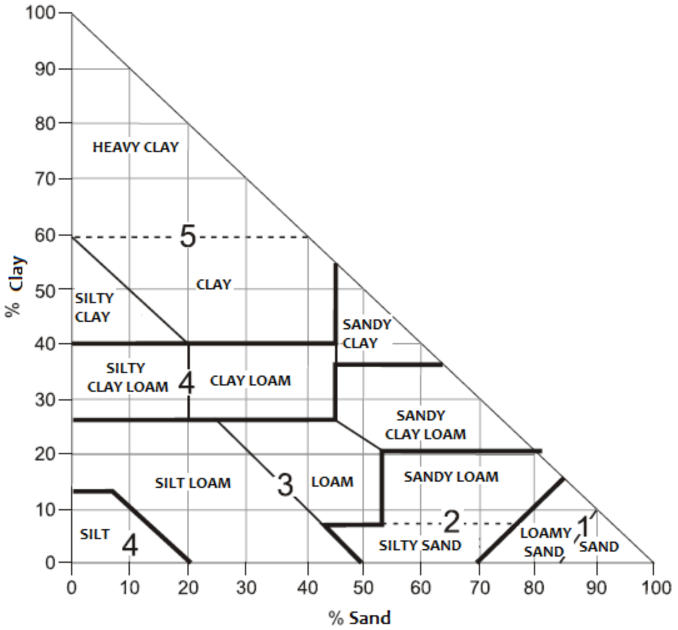

Figure 8: Soil structure based on textural classification

(Ontario Centre for Soil Resource Evaluation, 1993)

Table 2: Soil permeability code based on soil texture class
National Soil Handbook (USDA, 1983)

Soil texture	Permeability code
Heavy clay, Clay	6
Silty clay loam, Sandy clay	5
Sandy clay loam, Clay loam	4
Loam, Silt loam	3
Loamy sand, Sandy loam	2
Sand	1

The soil permeability code based on soil texture consists of 6 classes (Table 2), (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow. According to this classification, 81.81% of Oued El Makhazine watershed have soils with very slow permeability. It was observed in numerous publications [30, 31, 32] that the presence of clay decreases the level of soil permeability.
Soil erosion is a three step process. It begins with particle detachment, followed by particle transport and ends by deposition of transported sediment in a new location. These steps are largely affected by soil properties (soil texture, soil structure, organic matter content, and permeability).

ArcGis environment was used to calculate the soil erodibility factor and create the spatial distribution map for the entire study area. The result map shows that Oued El Makhazine watershed has relatively moderate to severe soil erodibility, ranges from 0.24 to 0.85 (Figure 9), for entire study area and about 71.27% of soils have soil erodibility factor ranges from 0.69 to 0.85 $t \cdot ha \cdot h \cdot ha^{-1} \cdot Mj^{-1} \cdot mm^{-1}$, which are considered as severe level.
Areas with severe erodibility in the basin have a high amounts of silt and very fine sand. as a result, these soils tend to have moderate to low permeability and low resistance to particle detachment.
Oued El Makhazine watershed is rich on clay particles, these particles are less susceptible to erosion than other types because of their ability to form stable aggregates. These soils are still moderately erodible, however, because they contain expansive clays that can cause surface crusting [23].

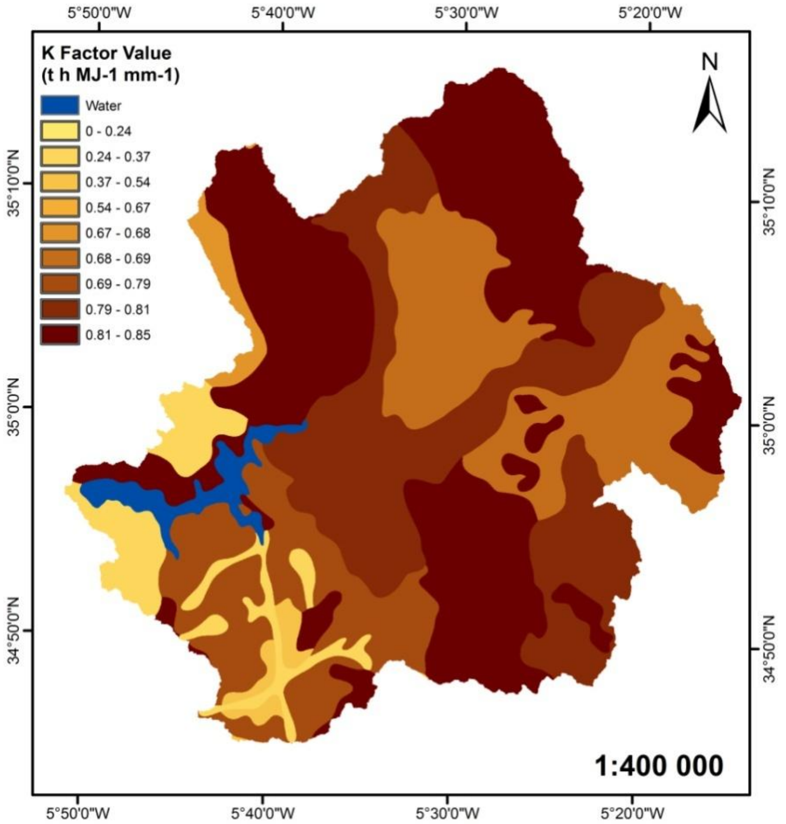

Figure 9: K factor of Oued El Makhazine watershed

According to the importance of K factor in USLE and other related soil erosion models, the map result has a significant implication in modeling and prediction of erosion and help to define the location and the type of soil conservation practices to use.

Conclusions

Soil erodibility factor (K) in USLE is strongly correlated with soil loss and considered as a key factor to predict soil erosion. USLE nomograph is the most widely used method to calculate K factor which was used in this study to generate soil erodibility map of Oued El Makhazine watershed.
The soil erodibility in this watershed was classified from moderate up to severe level.
Soil texture, soil structure, organic matter content and permeability presents the soil properties that influence the soil erodibility. However, the ability of clay particles to form stable aggregates that oppose particle detachment reduces the potential soil erodibility of our study area.

Erodibility values are derived solely from soil properties and do not consider factors such as slope, rainfall, surface cover, or management practices. Soil properties used for this interpretation include surface soil texture, permeability and organic matter. As a result, this interpretation reflects only the inherent properties of a soil body and represents the best case scenario in terms of soil erodibility.

The soil erodibility map constructed in this study provides an estimate of K factor values that will be used in the next study to evaluate soil erosion of the study area using USLE of Wischmeier and Smith [7].

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