

Predicting Soil Erosion and Sediment Yield in Oued El Abid Watershed, Morocco

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This study was conducted in the Oued El Abid watershed upstream of the Bin El Ouidane dam, in Tadla-Azilal province to quantify the dam siltation rates. To assess the annual soil erosion and the sediment yield the universal soil loss equation (USLE) was used. A geographic information system (GIS) was used to generate and integrate maps of the USLE factors. A spatial distribution of soil erosion in the Oued El Abid watershed was obtained. The soil erosion was determined for each rural commune in order to identify the soil erosion hotspot and estimate the amount of soil that has been transported downstream (Bin El Ouidane Dam). Soil erosion ranged from very limited values for flat and well covered areas to over 2100 t /ha/y in mountainous areas with sparse vegetation. The total annual soil loss within the watershed is estimated at 19.6 million tons per year. An equation of the sediment delivery ratio (SDR) based on river gradient was calculated. It was found that the value of SDR at the outlet of the watershed Oued El Abid was 0.65 with a sediment yield of 12.74 million tons per year which affect the durability of the dam.

Keywords: Erosion, GIS, SDR, Soil, USLE.

Introduction

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Soil erosion is a complex dynamic process by which productive soil particles are detached, transported and accumulated in a distant place. This results in the exposure of subsurface soil and sedimentation in reservoirs (Alexakis et al., 2013). In Morocco, the dam siltation retained annually reduces the storage capacity of 75 million m³, which represents 0.005% of the annual water mobilization with a total shortfall of 1 billion dollars per year. Out of the total area of 710 850 Km² of Morocco, it is estimated that about 150 000 km² is affected by serious water and wind erosion (Namr and Mrabet, 2004).

The entire downstream area of the High Atlas mountain chain is affected by a serious problem of soil erosion. All rivers flowing through this region transport a heavy load of sediment which is then trapped in several reservoirs. In this respect, this study aims at highlighting the relationships between the biophysical and hydrological conditions that control the erosion processes in Oued El Abid watershed upstream of the Bin El Ouidane dam which knew a shortage in its capacity of 274.5 million m³ between 1954 and 2008 with an average shortfall of 5 million m³ per year (ABHOER, 2015).

However, it is complicated to model soil erosion of the entanglement of factors that push the erosion process (Zhu et al., 2013). Many soil erosion models have been developed, ranging from simple empirical equations, such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and its revised version, RUSLE (Renard et al., 1997), to more sophisticated models, such as the Water Erosion Prediction Project (WEPP) (Flanagan et al., 2007) and EUROSEM (Morgan et al., 1998). The latter may be preferable than the empirical models, anyhow those models regularly need plenty of data and are more efficient to use in many circumstances, particularly to model soil erosion in medium- and large-scale watersheds (Wang et al., 2009). On the contrary, the USLE has been extensively applied all over the world at many scales mainly due to the simplicity of the model formulation and the possibility to estimate the input parameters with limited input data (Wang et al., 2009).

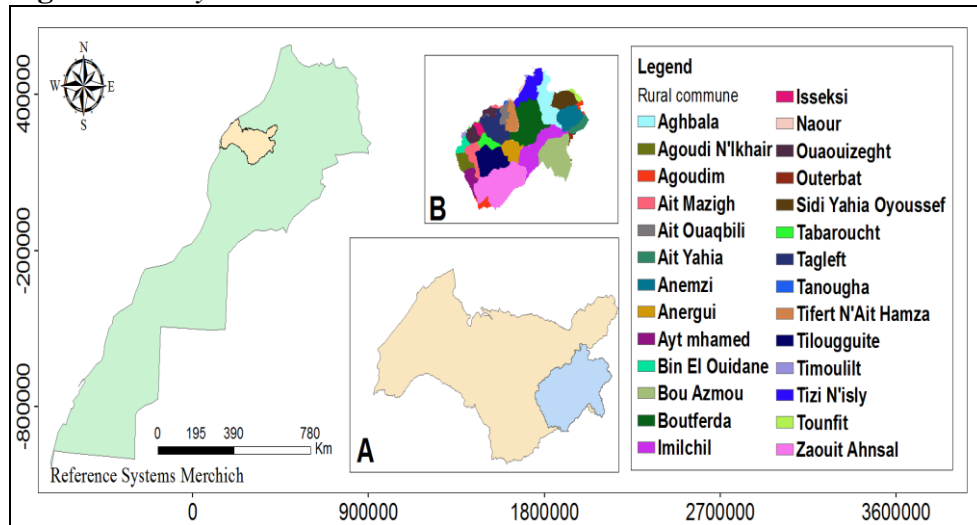
The USLE provides an estimation of the sediment mobilized by surface runoff, but is not able to model whether the sediment will be exported out of the catchment or re-deposited as colluvium or alluvium within the catchment (Hui et al., 2010). In fact, the sediment delivery ratio (SDR) was introduced to estimate the sediment yield in Bin El Ouidane reservoir based on the slope of drainage line extracted from the Data Elevation Model using Arc Hydro tools which is a geospatial and temporal data model for water resources designed to operate within ArcGIS (Zhang et al. 2010).

General Framework of the Study Area

The watershed of Oued El Abid with an area of 7686 km² is the upper part of the great Oum Er Rabia drainage basin of 50 000 km² (see Figure 1A). The Oued El Abid watershed is located upstream of the Bin El Ouidane dam in the region of Tadla Azilal between the High Atlas and the plain of Tadla. The main water course is the Oued El Abid, one of the most important water resources of Morocco which is used for irrigation and hydropower. The watershed stretches

over three different provinces and is divided into 27 administrative rural communities (see Figure 1B).

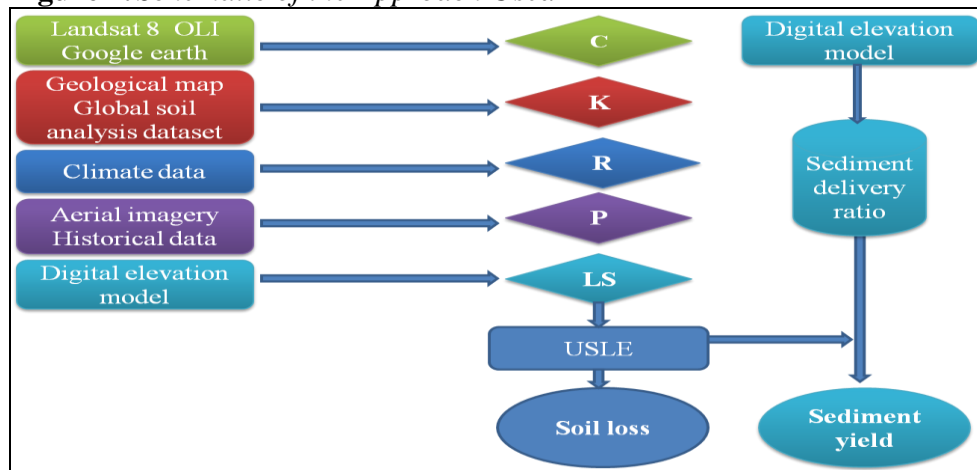
Figure 1. Study Area Localization



Methodological Approach

The general methodology (see Figure 2) involves the use of the USLE in a GIS environment. The individual raster layers were calculated for each USLE factor and processed in a GIS. The product of those factors has given the annual loss of soil in the entire watershed.

Figure 2. Schematic of the Approach Used



The sediment yield was calculated using the sediment delivery ratio (SDR) based on river gradient extracted from ASTER satellite imagery using arc hydro tools (Burns and Nolin, 2014).

Application of the Universal Soil Loss Equation (USLE)

The proposed method is based on the universal soil loss equation (Wischmeier and Smith, 1978). This equation provides the average annual erosion for a long period of time based on the slope of a field, data of rainfall, cropping system and management practice. Five key factors are used to calculate soil loss at a given location. Each factor is a numerical estimate of a particular component which affects the severity of soil erosion at that location.

$$A = R * K * LS * C * P$$

A: expresses the potential average annual soil loss in (Tonne / ha / y).

R: corresponds to the Rainfall erosivity factor.

K: is the soil erodibility factor.

LS: is the length factor and slope gradient.

C: corresponds to the land use factor.

P: is the conservation practice factor.

Topographic Factor LS

The LS factor was calculated using the following equation (see Equation 1) (Stone and Hilborn, 2012):

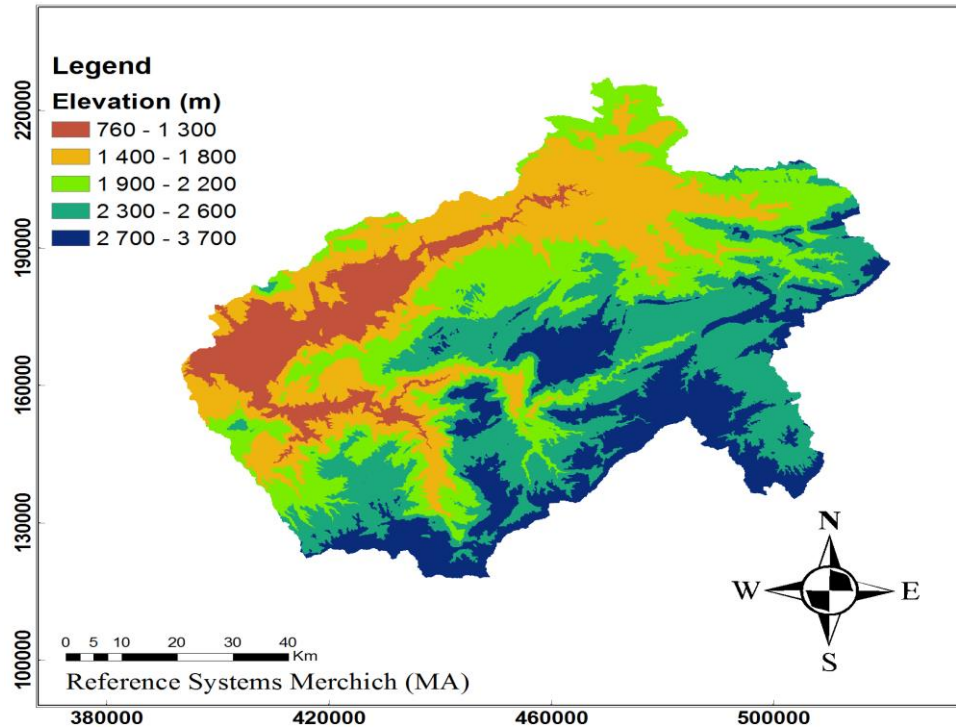
$$LS = [0.065 + 0.0456(Slope) + 0.0065(Slope)^2] \left(\frac{Slope\ length}{22.1} \right)^{0.5} \quad (1)$$

Where: Slope = slope steepness in %.

Slope length = (flow accumulation * cell resolution) in m (Van Remortel et al., 2004 ; Suhua et al., 2013).

The slope was extracted from SRTM with 30 m resolution (see Figure 3) using arc hydro extension.

Figure 3. Data Elevation Model



Rainfall Erosivity Factor R

In terms of climate, the watershed has a rainy winter and a dry summer. (Hui et al., 2010) The precipitation regime is irregular and the rainy period concentrated between the months of October and May.

To estimate this factor we have used the equation *Eq.2* which was used by FAO in Morocco to develop an iso-erodent (Hui et al., 2010) .

The equation expressed as follow (see Equation 2):

$$R = 0.264 \times F^{1.5} \quad (2)$$

F is the Fournier index modified expressed as follow (see Equation 3):

$$F = \sum_{i=1}^{12} \frac{r_i}{P} \quad (3)$$

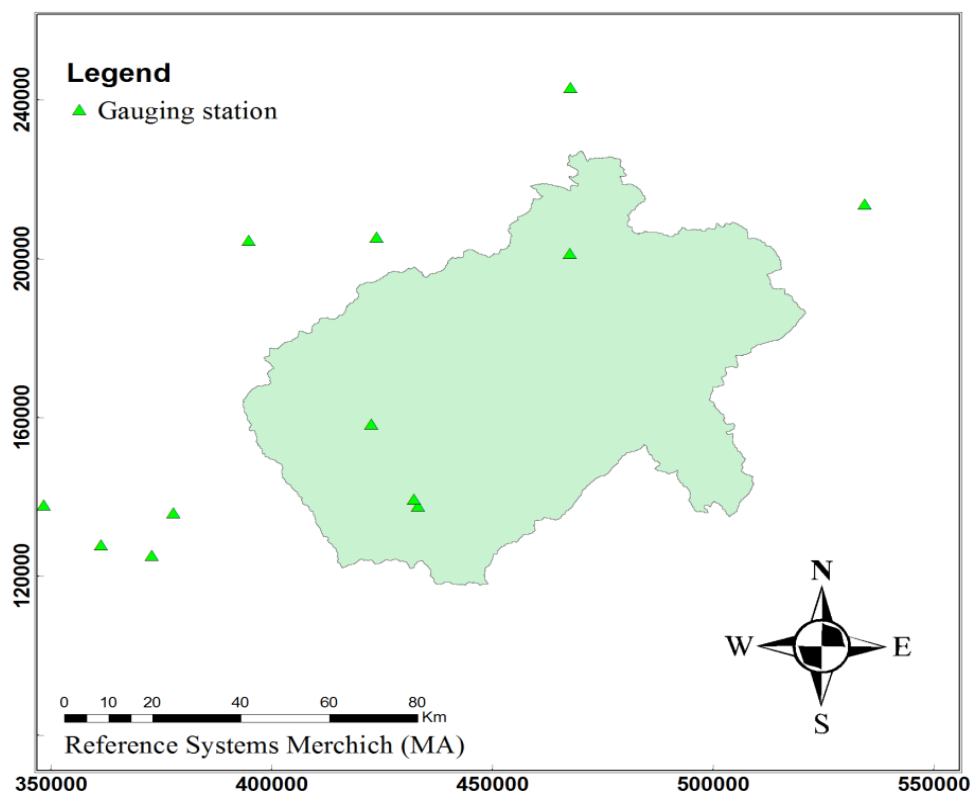
where r_i is the precipitation in the month i and P is the annual precipitation.

Table 1. Station Localization and Measurement Period

Station name	Station Number	X(m)	Y(m)	Measurement period
Z. Ahansal	8946	433282	137886	1984-2014
Toufint	5536	432300	139600	1969-2014
Tillouguit	8298	422670	158500	1979-2014
Taghzirt	7488	423900	205600	1967-2014
Sgatt	6624	377800	136100	1953-2014
O. Driss	6104	338950	192600	1969-2014

Tizi N Isly	8500	467680	201500	1975-2014
M. Eddahk	6472	394980	204800	1968-2014
C.N.Amllah	2558	467800	243300	1975-2014
ASSAKA	1304	348450	138100	1964-2014
A.Segmin	844	361400	128000	1971-2014
A. ouchen	812	534553	213845	1975-2014
Ademaghn	53	372900	125400	1983-2014

The Gauging stations selected have an acceptable spatial coverage (see Figure 4) and long periods of observation (see Table 1) and allow a prominent climate analysis of Oued El Abid watershed. The annual rainfall ranges from 200 mm in the North to 500 mm in the East.

Figure 4. *Spatial Coverage of Gauging Stations*

Soil Erodibility Factor K

Erodibility (K) is a function of the organic material and the texture of the soil, the permeability and the profile structure. K is defined as a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff (Panagos et al., 2014). It varies from 0.70 for the most fragile soils to 0.01 on the most stable soils (El Garouani et al., 2008).

Our results are obtained by using soil analysis of 54 soil samples (see table 2) and aggregate the data of the soil analysis provided by FAO in their harmonized database of the World Soil (Dewitte et al., 2013) and Sheet information of OMAFRA based on USLE (Stone and Hilborn, 2012).

Vegetation Cover Factor C

The land cover map is obtained from the recent (2013/2014) Landsat 8 OLI satellite image with 30m resolution using the supervised classification. The use of the Google earth image has brought more details especially for forests classes. The kappa coefficient calculated from the confusion matrix is used to determine the accuracy of the supervised classification.

Table 2. Soil Analysis Data

N	X(m)	Y(m)	Z(m)	Sand (%)	silt (%)	Organic Matter (%)	Clay (%)	Density (t/m ³)
P1	345637	184470	263	49	17	8	34	2.40
P2	344284	189718	266	45	18	10	37	2.50
P3	346298	173082	285	48	15	10	37	2.55
P4	368941	159905	560	47	21	13	32	2.30
P5	390459	170007	670	44	23	14	33	2.45
P6	399180	167559	845	45	21	12	34	2.25
P7	414547	171025	842	50	22	10	28	2.48
P8	411017	171767	915	53	20	9	27	2.24
P9	413438	177963	1433	49	23	9	28	2.40
P10	426061	179763	909	44	24	11	32	2.70
P11	419074	182648	1416	49	21	8	30	2.60
P12	428600	181453	1098	49	21	10	30	2.50
P13	440598	189712	1114	43	25	12	31	2.60
P14	448196	191857	1404	43	25	13	32	2.45
P15	460365	194792	1555	44	26	9	30	2.50
P26	473463	193341	1530	46	23	12	30	2.40
P27	477042	203032	1562	45	24	8	31	2.45
P28	474299	200025	1384	45	23	7	32	2.66
P29	473671	207147	1535	45	22	11	33	2.40
P30	463220	207420	1454	45	23	10	32	2.45
P31	410229	164435	1211	47	22	11	32	2.22
P32	423739	159237	1137	52	20	10	28	2.40
P33	428461	155976	1151	45	25	18	30	2.60
P34	434055	147979	1367	44	24	14	32	2.24
P35	435443	153220	1734	43	24	13	33	2.50
P36	438287	164126	1294	49	19	12	33	2.45
P37	448972	163708	1486	46	22	11	32	2.24
P38	418806	185929	1707	45	23	8	32	2.24
P39	434579	187102	1409	44	26	12	30	2.50
P40	440235	196160	1600	46	26	10	28	2.20
P41	444117	208698	1052	47	24	11	29	2.45
P42	452653	207356	1322	48	23	11	29	2.40
P43	467816	199214	1420	45	24	12	31	2.40
P44	476825	183970	1752	45	23	10	32	2.40
P45	469864	182667	2118	46	24	8	31	2.50
P46	462673	179683	2079	44	23	18	33	2.56
P47	454659	176501	2154	42	24	9	34	2.63
P48	448580	174642	2362	51	19	10	30	2.50
P49	438156	185927	1434	44	24	12	31	2.45
P50	396756	167243	1222	45	21	13	34	2.40
P51	389967	157998	1367	49	17	11	33	2.57
P52	394236	150337	1765	45	22	12	34	2.70
P53	410169	131201	2223	54	18	10	28	2.50
P54	430213	137871	2025	45	24	15	30	2.45

Soil Conservation Factor P

The erosion control practice factor is defined as the ratio of soil loss with a given surface condition to soil loss with up-and-down-hill plowing. It varies

between 1 in a soil without erosion control practice and 0.1 when on a slight slope, we practice tied ridging (Erdogan et al., 2007).

Sdr Module

The sediment delivery ratio is concerned by the many physical characteristics of a watershed. It changes with the drainage area, slope, relief-length ratio, runoff-rainfall factors, land use/land cover and sediment particle size, etc. The empirical equations based on one or more factors are still useful tools to estimate the SDR (Zhou and Wu, 2009).

We used the slope of the main stream channel to predict the sediment delivery ratio (Muhammad Mukhlisin and Sukoco, 2011). The model is written as follow (see Equation 4):

$$SDR = 0.627 \times SLP^{0.403} \quad (4)$$

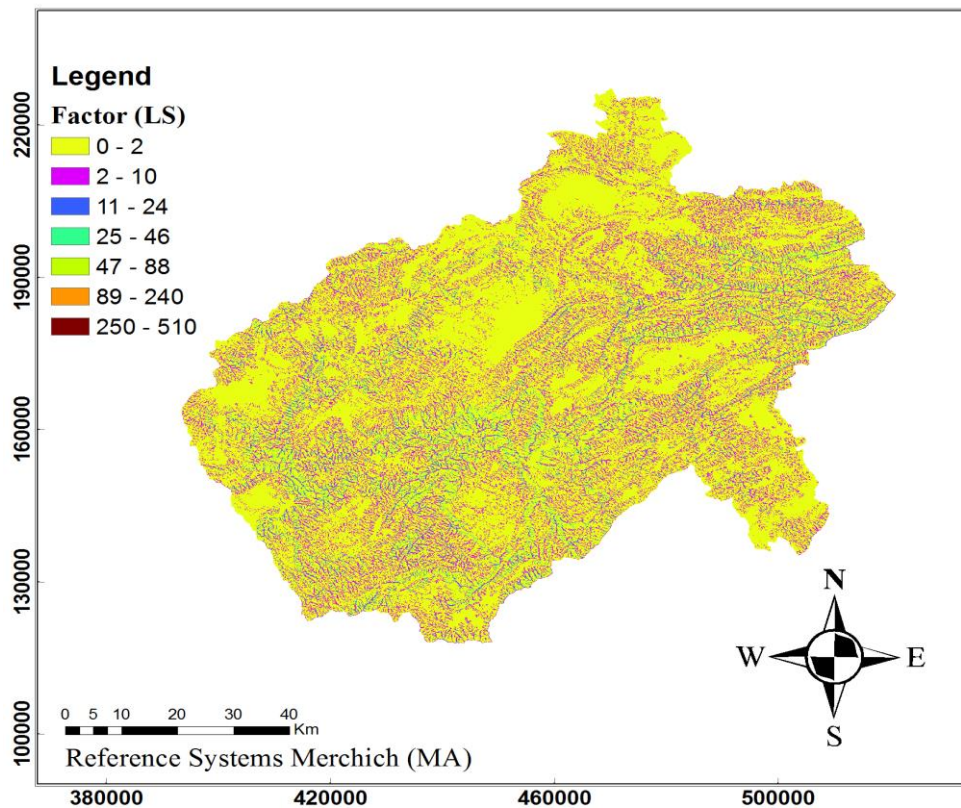
Where the *SLP* is the slope of drainage line in degree. In the first step, the drainage line was generated from the DEM using Arc Hydro Tools. Afterward the SDR for each cell in the flow path was computed in Arcgis using map algebra extension using the Eq.4 (Hui et al., 2010).

Each cell in the drainage line path can be viewed as the outlet of its upstream catchment. Therefore, at each cell the product of the SDR value and the annual soil loss amount upstream from that cell give us the net soil annual loss at that cell (Hui et al., 2010) .

Results

Topographic Factor LS

The integration of Eq.1 in map algebra extension gave us the LS factor map where the value ranges from 0 to 510 (see Figure 5)

Figure 5. Spatial Distribution of LS Factor

The distribution of the topographic factor shows that over 99.9 % of the Oued El Abid watershed corresponds to a LS value below 46 (see Table 3).

Table 3. LS Factor Distribution

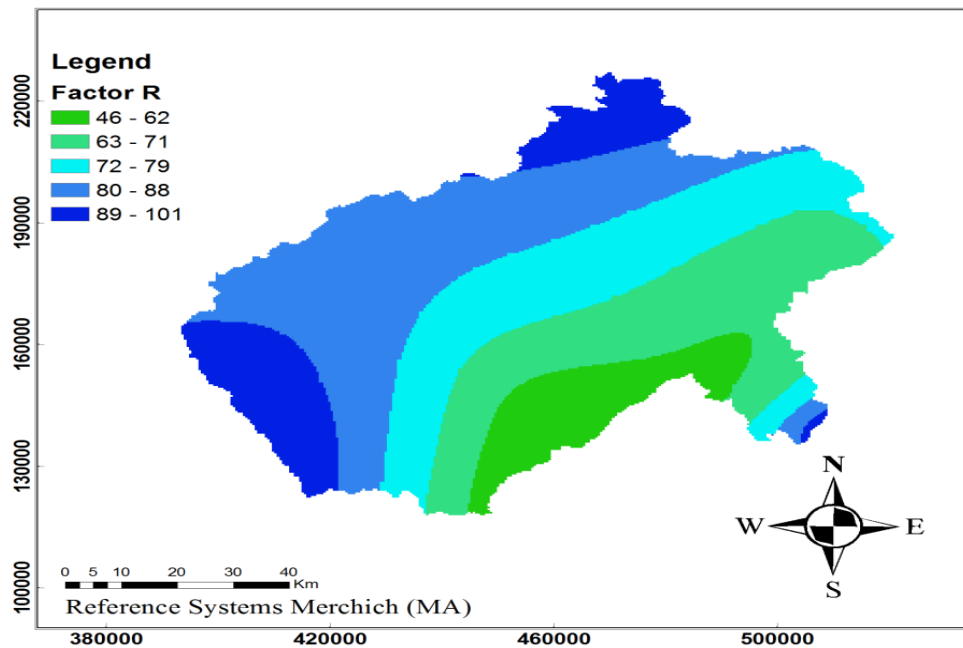
LS Factor	Area (ha)	Percent %
0-2	661319.25	86.05
2-10	72338.05	9.41
10-24	29551.56	3.84
24-46	4377.95	0.57
46-88	809.02	0.10
88-240	126.92	0.01
240-510	3.17	0.0004

Also large variations of LS values can be attributed to the complex mountainous terrain of the watershed, which is very typical in the areas affected by erosion.

Rainfall Erosivity Factor R

The results show that the factor value rises up from the East to West following the rain intensity (see Figure 6).

Figure 6. Spatial Distribution of R Factor

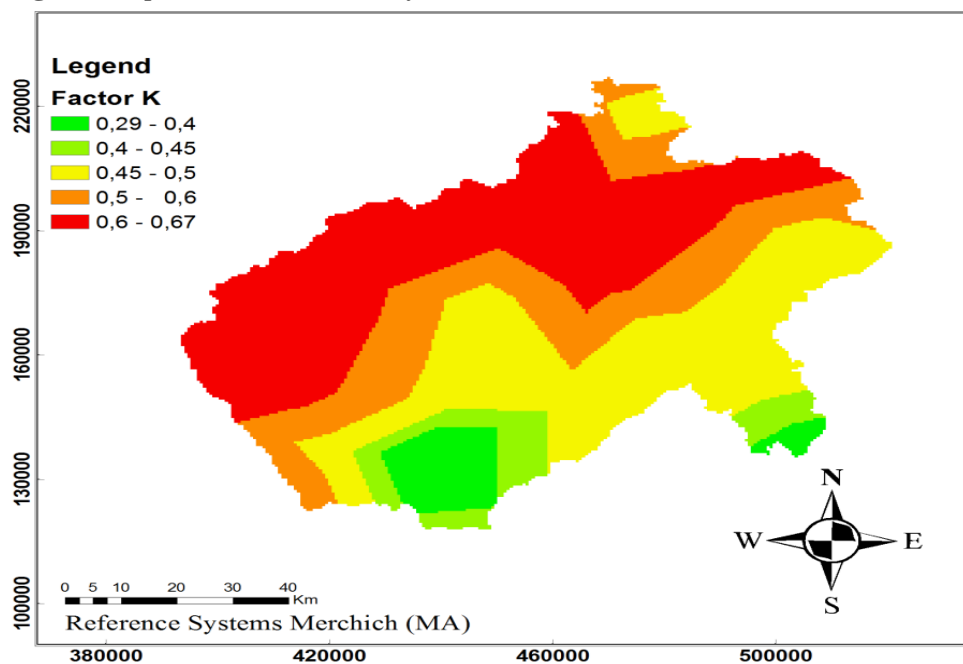


We see that the high value of precipitation coincides with areas covered, the thing which reduces the erosion affect.

Soil Erodibility Factor K

The values of the factor K, located between 0.29 and 0.67 show a marked fragility of soils and their susceptibility to erosion (see Figure 7).

Figure 7. Spatial Distribution of K Factor



The bare soil has a lower erodibility value than covered soil but it is still a region which promotes the erosion phenomenon.

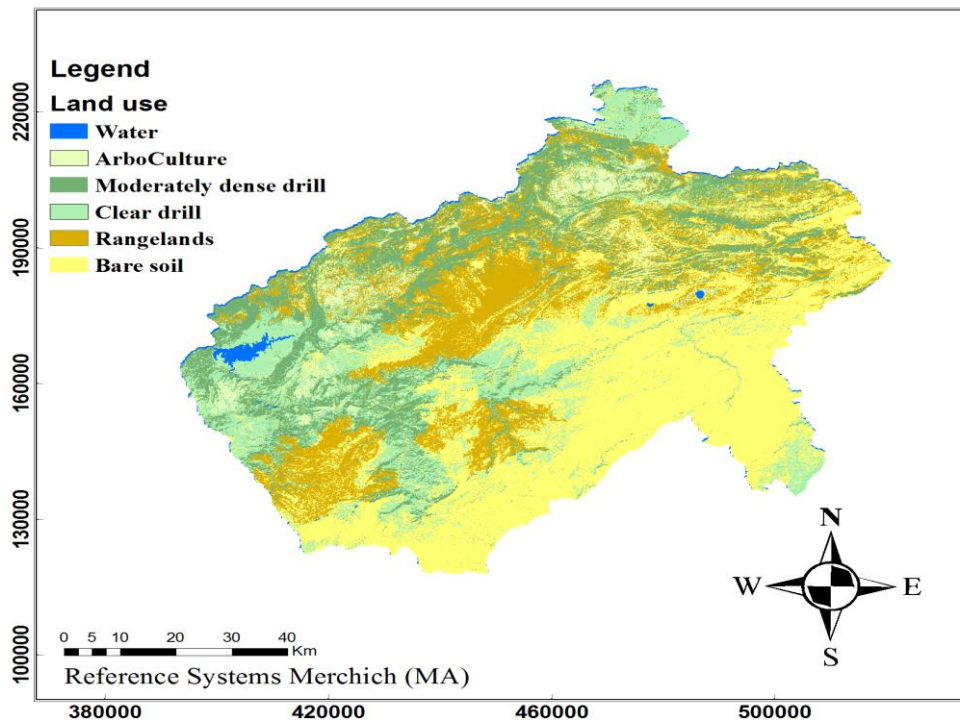
Vegetation Cover Factor C

The major lands used are the forest formations, rangelands, arboculture, water and bare soil (see Figure 8). View the kappa coefficient value which found equal to 0.96 the results of supervised classification are acceptable (Rawat, 2015) (see Table 4).

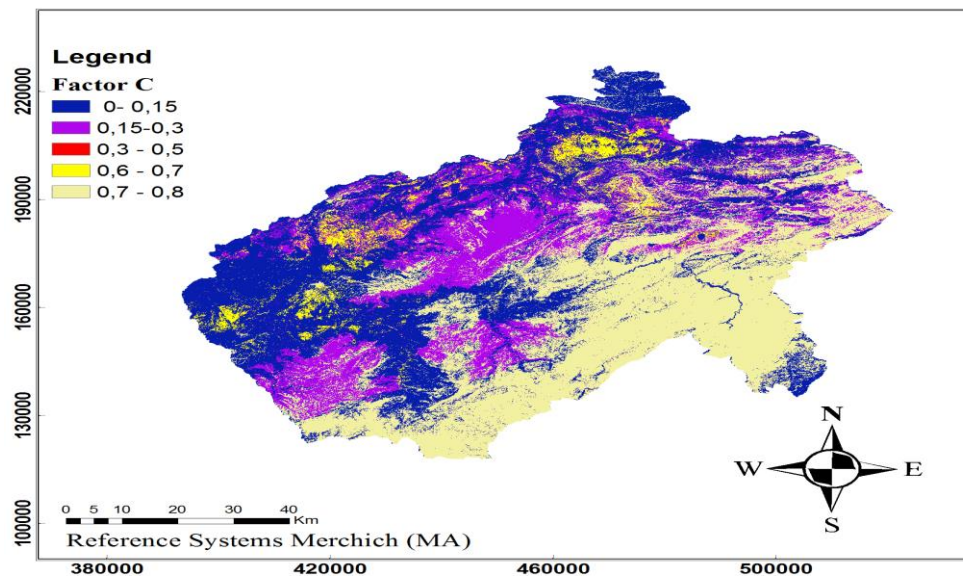
Table 4. Confusion Matrix: Truth Ground (Percent)

	Sparse forest	Arboculture	Range land	Bare soil	Water	Moderately dense forest	T
Sparse forest	94.36	0	2.31	0.36	0	0	17.84
Arboculture	0	100	0	0	0	0	0.24
Range land	2.26	0	95.18	0	0	0	9.23
Bare soil	3.38	0	2.51	99.64	0	0	67.18
Water	0	0	0	0	100	0	3.35
Moderately dense forest	0	0	0	0	0	100	2.15
T	100	100	100	100	100	100	100

Figure 8. The Occupation of Land Use Map



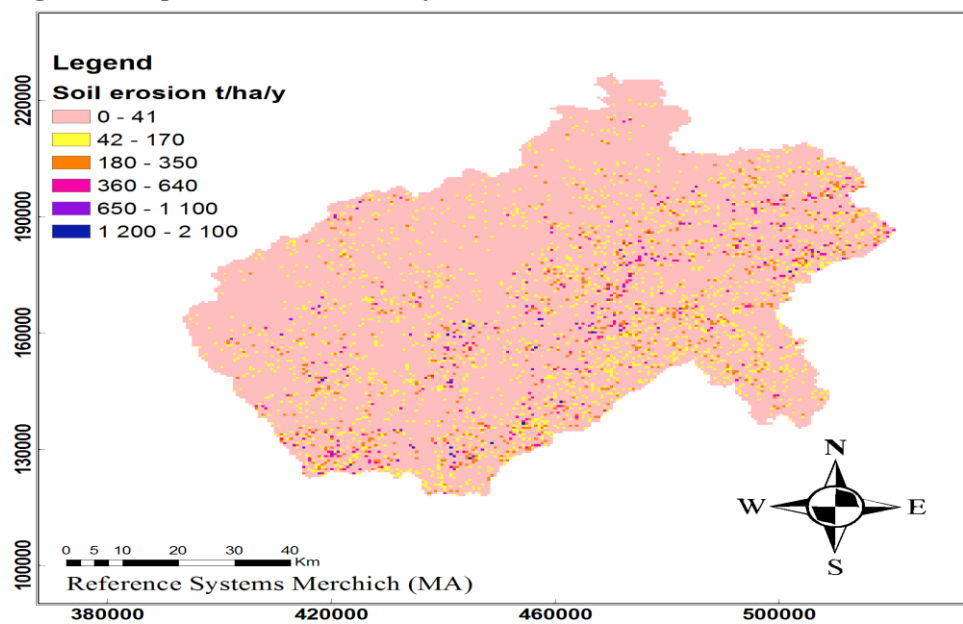
The results show that the C factor value range from 0 in water plan to 0.8 in bare soil (see Figure 9).

Figure 9. Spatial Distribution of C Factor*Soil Conservation Factor P*

The inspection of the property shows the absence of erosion control practice, thus a value of "1" is attributed to this factor.

Soil Loss

After we combine all these five factors we got the soil loss in t/ha/year (see Figure 10).

Figure 10. Spatial Distribution of Soil Loss

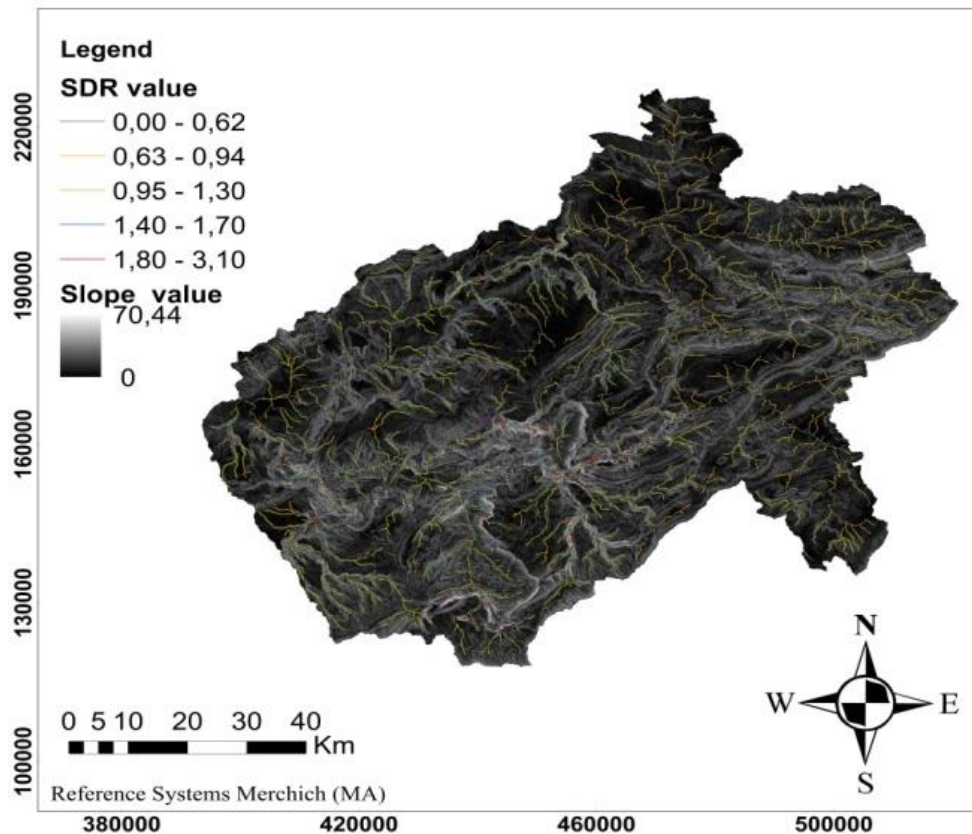
The results show that the commune called *Agoudim* is the most degraded with 77.66 t/ha/y (see Table 5).

Table 5. Soil Loss in Each Commune

Commune	Area (ha)	Min (t/ha/y)	Max (t/ha/y)	Mean (t/ha/y)
Aghbala	44895.74	0	977.55	18.59
Tizi N'isly	34590.77	0	515.62	7.38
Timouilt	1633.71	0	101.88	2.39
Naour	2576.24	0	161.47	6.88
Ait Ouqbili	10524.89	0	195.00	4.71
Tounfit	6723.37	0	405.93	34.88
Tanougha	2293.48	0	275.38	7.72
S.Y.Oyoussef	24411.47	0	1069.95	17.82
Ouaouizeght	20201.51	0	977.07	13.53
Tabaroucht	13666.65	0	814.63	20.52
T. N. Hamza	19667.41	0	548.89	6.93
Anemzi	31951.69	0	1065.81	43.32
B.El Ouidane	8545.59	0	149.58	2.46
Ait Yahia	10713.40	0	1067.44	64.89
Isseksi	6346.35	0	206.92	9.84
Tagleft	38455.14	0	573.29	12.78
Outerbat	1759.39	0	1144.26	53.73
Boutferda	73045.91	0	1032.11	24.56
Anergui	22872.01	0	1306.91	24.00
A.N'lkhair	14703.43	0	669.56	12.71
Tilouguite	46843.63	0	1196.28	24.88
Ait Mazigh	18567.80	0	1028.00	16.59
Imilchil	55923.32	0	2100.00	37.92
Bou Azmou	67453.58	0	802.15	31.81
Ayt mhamed	13383.90	0	889.08	19.88
Agoudim	6566.28	0	1338.53	77.66
Zaouit Ahnsal	98745.50	0	1611.09	26.28

Sdr and Net Soil Loss

The SDR value at the outlet of Oued El Abid watershed is estimated at 0.65 (see Figure 11) then the sediment yield was found to be 12.74 million t/a.

Figure 11. *Sediment Delivery Ratio*

The analysis of soil samples showed a mean soil density of 2.45 t/m^3 (see table 5), thus the sediment yield is estimated at $5.2 \text{ Mm}^3/\text{year}$.

Discussion

The results presented suggest that taking the sediment delivery ratio into account greatly reduces the total sediment output compared to what is calculated from the USLE.

In the North-Morocco many studies performed by (Rahhou, 1999; Al Karkouri, 2003; Aroussi et al., 2011) had focused on erosion phenomenon, but they had not addressed the sedimentation delivery phenomenon. (El Garouani et al. 2008) have used a sedimentation model based on the revised universal soil loss equation and the spatial variability of the field to estimate the amount of soil load for the Tlala watershed outlet. Recently (El Gaatib and Erraji, 2014) did a study in the Oued el Beht watershed based on the USLE model. They coupled the rainfall and flow rate in order to estimate the transport of sediment to the El Kansra dam.

(Lahlou, 1982) used practical methods (bathymetry, topography survey, turbidimetry measurement, emptying and filling of dam) in order to estimate the silting rate in 27 dams across Morocco, the annual silting rate was estimated to

be between 1,35 and 10 million m³. As regard the Bin El Ouidane dam the author used the curve extrapolation of specific degradation of watershed surface based on measurements from watersheds. The annual silting rate was estimated to be 1, 5 millions m³.

The bathymetric measurement between the years 1953 and 2008 showed a sediment yield rate of 5 million m³/year (see table 6).

Table 6. Bathymetric Results

Year	Volume (Mm ³)	Sediment yield (Mm ³)	Annual lose (Mm ³ /Y)	Sediment yield rate (Mm ³ /Y)
1953	1507.5			5
1991	1320.6	186.9	4.9	
1994	1302.8	17.8	5.9	
1996	1265.5	37.2	18.6	
2000	1254.6	10.9	2.7	
2003	1242.7	11.9	4.0	
2008	1233.1	9.6	1.9	

The differences between the result obtained by the dual focus on erosion and deposition and this given by the specific degradation (Lahlou, 1982) are due to the global warm which was expected to conduct to a moderate hydrological cycle, with high rainfall totals.

The new proposed method in Morocco gives results are acceptable compared to those given by validation methods that are more accurate and expensive with a slight overestimation does not exceed 0.04% maximum. This method is also applicable on all watersheds regardless the superficies, then it can be considered technically a reliable method and deserves to be applied instead of the commonly used.

The Erosion values obtained by the application of this method may vary significantly due to different weather conditions. By against the long term, the mean values obtained by USLE and its rectified version RUSLE represent the soil losses more accurately (Stone and Hilborn, 2012).

Indeed, the confidence for the factors values cannot be defined by lack of validation on the parcels for calibration. Custom field will be the subject of our next step in our project.

Conclusions

Taking into account the variability of erosion and deposition processes at the same time resulted in reducing the estimated soil erosion values calculated by the USLE model. Although the results obtained by this study are questionable because of probability of error in the data used and the limits of the USLE model when applied to the large watershed, this method provides an important support to decision makers and planners to simulate scenarios for the evolution of the region and plan interventions against erosion. It also helps to monitor the impact of land use and development on the quality of soil resources.

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