

**Original Scientific paper**  
10.7251/AGRENG1701099S  
UDC 551.435.1(64)

**MODELLING RESERVOIR SEDIMENTATION AT BIN EL OUIDANE  
DAM, MOROCCO**

El Moutassime SABRI<sup>1\*</sup>, Ahmed BOUKDIR<sup>1</sup>, Rachid EL MASLOUHI<sup>2</sup>,  
Mustapha MABROUKI<sup>1</sup>, Abdellah EL MAHBOUL<sup>3</sup>, Vivien Romaric EKOUELE  
MBAKI<sup>1</sup>, Abdelhamid ZITOUNI<sup>1</sup>, Wissal BAITE<sup>1</sup>, Zhou ECHAKRAOUI<sup>1</sup>

<sup>1</sup>Department of industrial engineering, Faculty of sciences and technical, University of  
sultan Moulay Slimane, Beni Mellal, Morocco

<sup>2</sup>Oum Er B'IA Hidrological basin Agency, Beni Mellal, Morocco

<sup>3</sup>The Delegate Ministry in Charge of Water, Morocco

\*Corresponding author: sabri.elmoutassime@gmail.com

**ABSTRACT**

This study was conducted in the Oued El Abid watershed upstream of the Bin El Ouidane dam, in Tadla-Azilal province (Morocco) 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 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:** *soil, erosion, USLE, GIS, SDR.*

**INTRODUCTION**

Soil erosion is a complex dynamic process by which productive soil particles are detached, transported and accumulated in a distant place. This results in exposure of subsurface soil and sedimentation in reservoirs(Jain et al., 2001). In Morocco, the dam siltation retained annually reduces the storage capacity of 75 million m, 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 Km<sup>2</sup> of Morocco, it is estimated that about 150 000 km is affected by serious water and wind erosion (Namr and Mrabet, 2004).

The entire downstream area of 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 m<sup>3</sup> between 1954 and 2008 with an average shortfall of 5 million m<sup>3</sup> per year.

However, it is difficult to model soil erosion because of the complexity of the interactions of factors that influence the erosion process (Lufafa et al., 2003). 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 functionally more powerful than the empirical models, but those models often need lots of data and are computationally intensive to use in many circumstances, particularly with respect to modelling 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 (Maidment, 2002).

## **MATERIALS AND METHODS**

### **Study area**

The watershed of Oued El Abid with an area of 7686 km<sup>2</sup> is the upper part of the great Oum Er Rabia drainage basin of 50,000 km<sup>2</sup> (see Figure 1. A). 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 1. B).

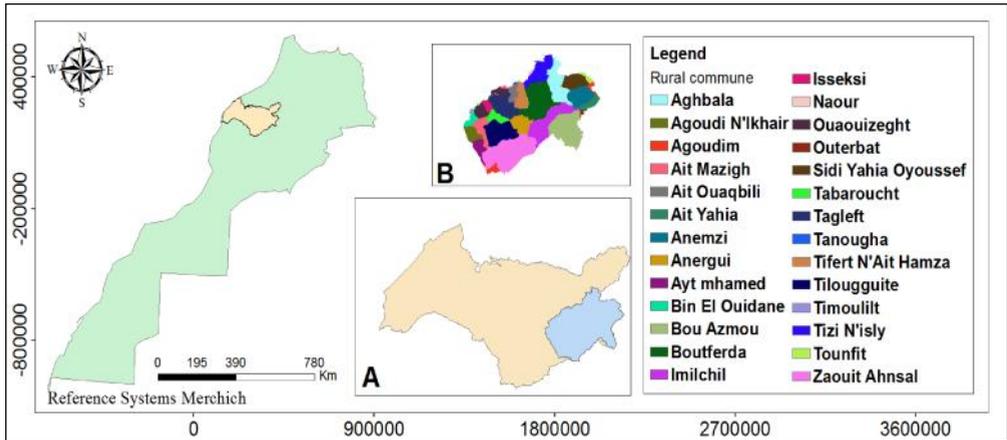


Figure 1. Localisation of study area

### 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.

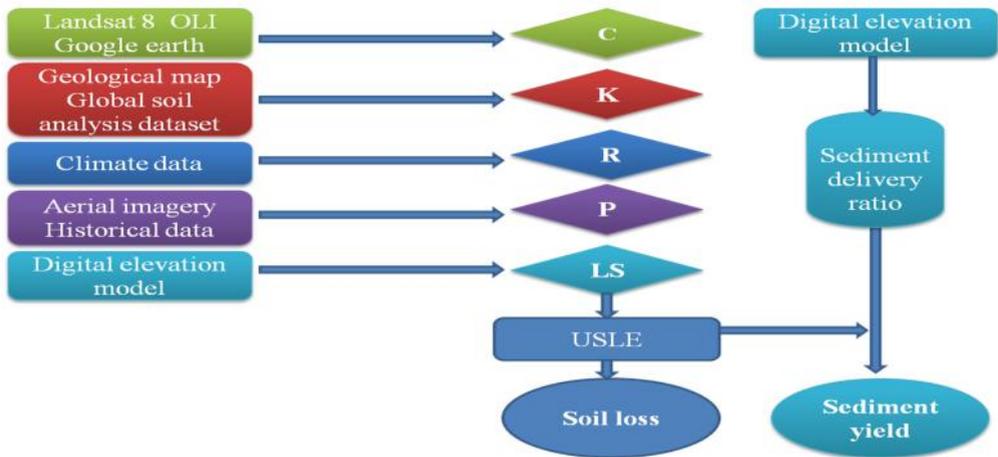


Figure 2. Schematic of the approach used

The sediment yield was calculated using the sediment delivery ratio (SDR) based on river gradient extracted from ASTER satellite imagery using arc hydro tools (Maidment, 2002).

### 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.

#### 1. Topographic Factor LS

The LS factor was calculated using the following equation (see Equation 1) (Bizuwerk et al., 2003; Stone and Hilborn, 2012):

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

Where:

Slope = slope steepness in %

Slope length = (flow accumulation \* cell resolution) in m (Van Remortel et al. 2004)

The slope was extracted from SRTM with 30 m resolution using arc hydro extension.

#### 2. Rainfall Erosivity Factor R

To estimate this factor we have used the equation provided by (Arnoldus, 1977) (see Equation 2) which was used by FAO in Morocco to develop an iso-erodent (Hui et al., 2010). The equation expressed as follows (see Equation 2):

$$R = 0.1714 F^2 \quad (2)$$

F is the Fournier index modified expressed as follows (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.

#### 3. Soil Erodibility Factor K

Erodibility (K) is a function of the organic material and texture of soil, the permeability and the profile structure. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff (Wischmeier and Smith, 1978). 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 and aggregate data of 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).

#### **4. 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 Google earth image has brought more details especially for forests classes. The kappa coefficient calculated from confusion matrix is used to determine the accuracy of the supervised classification(Ruiz-Luna and Berlanga-Robles, 2003).

#### **5. 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 (Roose, 1996).

#### **Sediment Delivery Ratio Module**

The sediment delivery ratio is affected by many highly variable physical characteristics of a watershed. It varies with the drainage area, slope, relief-length ratio, runoff-rainfall factors, land use/land cover and sediment particle size, etc . The empirical equations relating SDR with one or more factors are still useful tools to estimate SDR (Ouyang and Bartholic, 1997).

(Jimmy R. Williams, 1972) used slope of the main stream channel to predict sediment delivery ratio.

The model is written as follow (see Equation 4):

$$SDR = 0. \times SLP^{0.0} \quad (4)$$

SLP: is slope of drainage line in degree.

RESULTS AND DISCUSSION

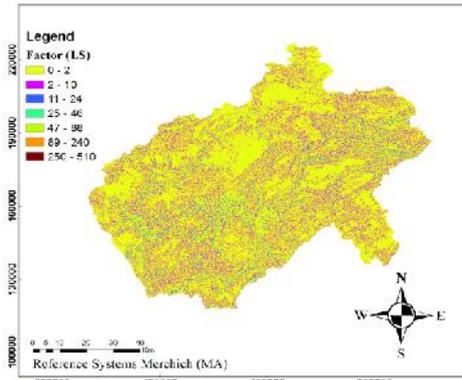


Fig. 3 Spatial distribution of LS factor

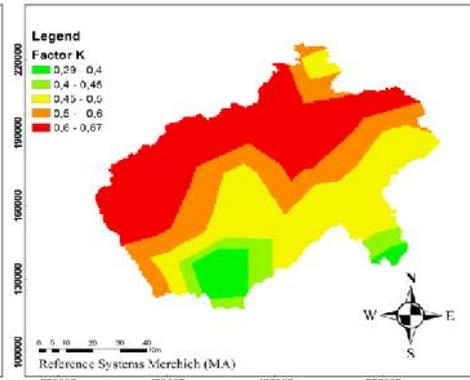


Fig. 4 Spatial distribution of K factor

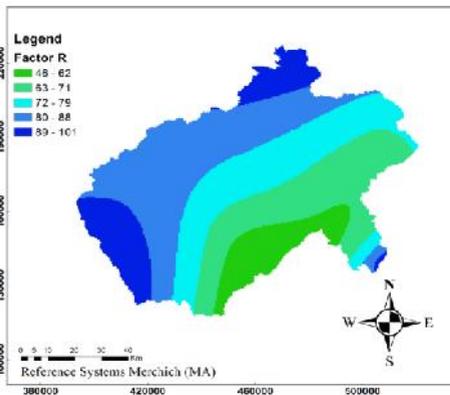


Fig. 5 Spatial distribution of R factor

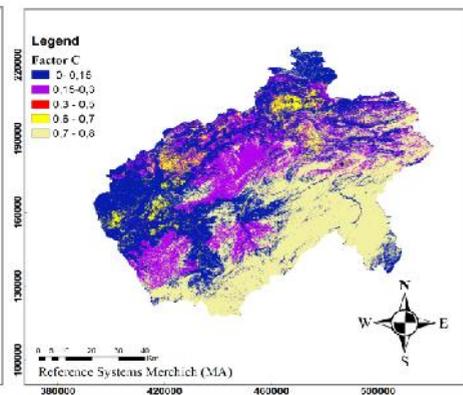


Fig. 6 Spatial distribution of C factor

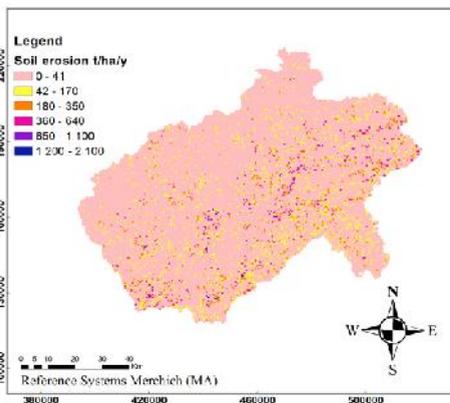


Fig. 7 Spatial distribution of soil loss

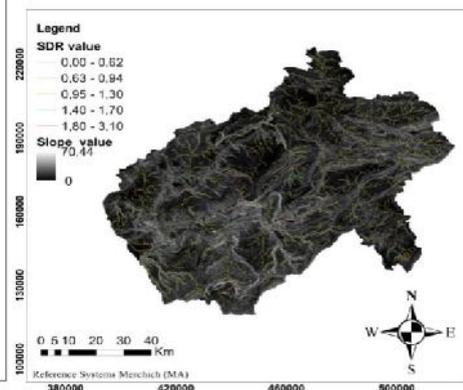


Fig. 8 Sediment delivery ratio

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

After we combine all these five factors (see Figure 3; 4; 5; 6) we got the soil loss in t/ha/year (see Figure 7).

The results show that the commune called *Agoudim* is the most degraded with 77, 66 t/ha/y (see Table 1).

**Tab. 1** 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
Timoulilt	1633, 71	0	101, 88	2, 39
Naour	2576, 24	0	161, 47	6, 88
Ait Ouaqbili	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. Oyousséf	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'khair	14703, 43	0	669, 56	12, 71
Tilougguite	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

The SDR value at the outlet of Oued El Abid watershed is estimated at 0. 65(see Figure 8) then the sediment yield was found to be 12. 74 million t/a.

The analysis of soil samples showed a mean soil density of 2. 45 t/ m, thus the sediment yield is estimated at 5. 2Mm/year.

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 (Dahman, 1994; 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 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, turbidity measurement, emptying an 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 m. 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 million m.

The bathymetric measurement between the years 1953 and 2008 showed a sediment yield rate of 5 million m/year.

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 lead to a more vigorous hydrological cycle, including more total rainfall and more frequent high intensity rainfall events.

The new proposed method in Morocco gives results are acceptable compare 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.

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.

**REFERENCES**

- Al Karkouri, J. (2003) Dégénération du milieu naturel dans le bassin de Beni Boufrah (Rif Central - Maroc): analyse des facteurs. Doctoral thesis. University of Mohamed V.
- Arnoldus, H. M. J. (1977) Methodology Used to Determinate the Maximum Potential Average Soil Loss due to Sheet and Rill Erosion in Morocco. Assessing Soil Degradation. pp. 8–9.
- Aroussi, O. El. Mesrar, L. Garouani, A. El. Lahrach, A. Beaabidate, L. Akdim, B. (2011) Predicting the Potential Annual Soil Loss Using the Revised Universal Soil Loss Equation ( Rusle ) in the Oued El Malleh Catchment (Prerif,Morocco). *J. Present Environment and Sustainable Development*. 5, pp. 5 – 16.
- Bizuwerk, A. Taddese, G. Getahun, Y. (2003). Application of GIS for Modeling Soil loss rate in Awash River Basin, Ethiopia. In *International Livestock Research Institute(ILRI)*, Addis Ababa, Ethiopia.
- Dahman, H. (1994). Utilisation des SIG et des télédétections dans l'étude de l'érosion hydrique: application au bassin versant de Tleta. Doctoral Thesis. National Forestry Engineering School.
- Dewitte, O. Jones, A. Spaargaren, O. Breuning-Madsen, H. Brossard, M. Dampha, A. Deckers, J. Gallali, T. Hallett, S. Jones, R. Kilasara, M. Le Roux, P. Michéli, E. Montanarella, L. Thiombiano, L. Van Ranst, E. Yemefack, M. Zougmore, R. (2013). Harmonisation of the soil map of africa at the continental scale. *J. Geoderma* . 211, pp. 138–153. Doi: 10. 1016/j. geoderma.. 07. 007
- El Gaatib, R. Erraji, A. Abdelkader, L. (2014). Impact des processus d'érosifs sur les ressources naturelles des bassin hydrographiques et sur l'état d'envasement des retenues des barrages : Application au bassin versant de Oued Beht en amont du barrage El Kansra Maroc. *J. Geo Observateur*. 21, pp. 35–45.
- El Garouani, A. Chen, H. Lewis, L. Tribak, A. Abharour, M. 2008 Cartographie De L'Utilisation Du Sol Et De L'Érosion Nette À Partir D'Images Sa Litaires Et Du Sig Idrisi Au Nord-Est Du Maroc. *J. Télédétection*. 8, pp. 193–201.
- Flanagan, DC. Gilley, JE. Franti, T. 2007 Water Erosion Prediction Project (WEPP): Development History, Model Capabilities and Future Enhancements. *J. Asabe*. 50, pp. 1603–1612.
- Hui, L. Xiaoling, C. Lim, KJ. Xiaobin, C. Sagong, M. (2010) Assessment of soil erosion and sediment yield in Liao watershed, Jiangxi Province, China, Using USLE, GIS, and RS. *J. Earth Science* . 21, pp. 941–953. Doi: 10. 1007/s12583-010-0147-4
- Jain, S; Kumar, S. Varghese, J. (2001). Estimation of soil erosion for a Himalayan watershed using GIS technique. *J. Water Resources Management*. 15, pp. 41–54. Doi: 10. 1023/A:1012246029263
- Williams, J. R. (1972). Sediment Yield Computed with Universal Equation. *J. Hydraulics Division*. 98, pp. 2087–2098.

- Lahlou, A. (1982). La dégradation spécifique des bassins versants et son impact sur l'envasement des barrages. In Proceedings of the Exeter Symposium. (July 1982). Exter. IAHS Pub. n. 137.
- Lufafa, A. Tenywa, M. M. Isabirye, M. Majaliwa, M. J. G; Woomer, P. L. (2003). Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. *J. Agricultural Systems*. 76, pp. 883–894. Doi: 10.1016/S0308-521X(02)00012-4
- Maidment, D. R. (2002). *Arc Hydro: GIS for water resources*. ESRI press
- Morgan, R. P. C. Quinton, J. N. Smith, R. E. Govers, G. Poesen, J. W. A. Chisci, G. Torri, D. (1998). The EUROSEM model. Modelling soil erosion by water. In Proceedings of the NATO Advanced Research Workshop “Global change: modelling soil erosion by water”. (September, 1995). University of Oxford. UK. 389–398.
- Namr, K. Mrabet, R. (2004). Influence of agricultural management on chemical quality of a clay soil of semi-arid Morocco. *J. African Earth Sciences*. 39, pp. 485–489. Doi: 10.1016/j.jafrearsci.2004.07.016
- Ouyang, D. Bartholic, J. (1997) predicting sediment delivery ratio in saginaw bay watershed. In the 22nd National Association of Environmental Professionals Conference Proceedings . (19–23 May 1997 ). USA. Pp. 659–671.
- Rahhou, M. (1999). L'érosion dans le Préfif central, zone interfluviale Leben-Sebou-Ouergha, un prolongement de l'évolution naturelle, une production sociale. Doctoral thesis. University of Mohammed V.
- Renard, K. Foster, G. Weesies, G. McCool; D. Yoder, D. (1997) Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). In *Agricultural Handbook No. 703*. Department of Agriculture, Washington DC.
- Roose, E. 1996 Land husbandry - Components and strategy by Director of Soils Research. In *Fao Soil Bulletin*. 70, p. 380.
- Ruiz-Luna, A. Berlanga-Robles, C. A. (2003) Land use, land cover changes and coastal lagoon surface reduction associated with urban growth in northwest Mexico. *J. Landscape Ecology*. 18, 159–171. Doi: 10.1023/A:1024461215456
- Stone, R. P. Hilborn, D. 2012 Universal Soil Loss Equation (USLE). (Octobre 2012). Ontario. pp. 1–8.
- Van Remortel, R. D. D. Maichle, R. W. W. Hickey, R. J. J. (2004). Computing the LS factor for the Revised Universal Soil Loss Equation through array-based slope processing of digital elevation data using a C++ executable. *J. Computers & Geosciences*. 30, pp. 1043–1053. Doi: 10.1016/j.cageo.2004.08.001
- Wang, G. Hapuarachchi, P. Ishidaira, H. Kiem, A. S. Takeuchi, K. (2009). Estimation of Soil Erosion and Sediment Yield During Individual Rainstorms at Catchment Scale. *J. Water Resources Management*. 23, 1447–1465. Doi: 10.1007/s11269-008-9335-8
- Wischmeier, W. H. Smith, D. D. (1978). Predicting Rainfall Erosion Losses. In *Agriculture Handbook*. p. 537. Department of Agriculture, Washington DC.