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MODELLING AND MAPPING OF SOIL EROSION ON THE OUED EL MALLEH CATCHMENT USING REMOTE SENSING AND GIS

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Abstract: In Morocco, the spectacular expansion of erosive processes shows increasingly alarming aspects. Due to the considerable costs of detailed ground surveys for studying this phenomenon, remote sensing is an appropriate alternative for analyzing and evaluating the risks of the expansion of soil degradation. According to an FAO study (2001), Erosion threatens 13 million ha of cropland and rangeland in northern Morocco and induces an estimated average water storage capacity loss of 50 million m3 each year through dam silting. The lost water volume could potentially be used to irrigate 5000 to 6000 ha/year. This study analyses soil erosion on the Oued El Malleh catchment, a 34 km² catchment located in the north of Fez (Morocco). This contribution aims at mapping the spatio-temporal evolution of land use and modelling the erosion and sedimentation processes using the well known RUSLE model. Land use changes were assessed using Landsat-5 TM and Landsat-7 ETM+ images, from the 1987-2011 periods which were validated by field studies. The images were first georeferenced and projected into the Moroccan coordinate system (Merchich North) then processed to evaluate soil loss through a GIS package (Idrisi Andes Software). These static assessments of soil loss were then used in a deposition/sedimentation algorithm to model soil loss propagation to the downstream. The soil loss averages determined by the model vary between 1.09 t/ha/yr as a minimum value for the reforested lands and 169.4 t/ha/yr as a maximum value for the uncultivated lands (badlands). The latter generally correspond to Regosols or low protected soils located on steep slopes. In comparison with RUSLE, the sedimentation model yields lower values of soil losses; only 97.3 t/h/year for the uncultivated lands, and -0.34 t/ha/year in the reforested land, indicating an on-going sedimentation process. By taking into account the temporal variability of erosion and deposition jointly lower values of soil erosion are calculated by the RUSLE model. However, despite this decline, land degradation problems are still important due to the combination of land use and local lithology. The results of this study were used to indentify areas where interventions are needed to limit land degradation processes.

Keywords: Soil erosion; RUSLE; sedimentation; remote sensing; El Oued Mellah; Morocco.

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INTRODUCTION

Recent studies on the vulnerability to climate change in the Mediterranean region show a trend toward increasing aridity which accelerates soil erosion (De Ploey *et al.*, 1991). Soil erosion by rainfall and runoff is a widespread phenomenon in Mediterranean countries (Bou Kheir *et al.*, 2001), she continues to take a considerable extent, especially on slopes, because of the nature torrential rains, the high vulnerability of land (soft rock, fragile soils, steep slopes and degradation of vegetation cover) and the unfavorable impact human activities (deforestation, fire, misconduct farming, urban extension, exploitation of quarries, etc). According to an FAO study (1990), the situation continues to deteriorate: 40% of land in Morocco is threatened by soil erosion.

Remote sensing and geographic information systems (GIS) are increasingly used for the study of surface phenomena and are essential tools in support systems and operational decision-making for operations risk management (Lee, 2004; Bou Kheir *et al.*, 2006). The implementation of effective soil conservation must first be preceded by assessment in the space erosion risk (Moussa *et al.*, 2002; Souchère *et al.*, 2005).

To estimate the rate or the state of erosion, several methods are adopted, the most used are: the universal equation of soil loss (Wischmeier & Smith, 1978), as amended (Foster *et al.*, 1996) and the technique for predicting water erosion (Laflen *et al.*, 1991). The choice of model depends on the variability of the basin area, the availability of point data and rainfall data (Bonn, 1998). However, when these methods for calculating soil loss, which are established on a piecemeal basis, are extrapolated to larger scales, it usually results in some usage constraints that are not always respected (Chakroun, 1993).

The objectives of this study are: (a) Mapping spatio temporal land use from remote sensing data (Landsat) over a period of 24 years (1987–2011); (b) Estimation of soil loss by RUSLE model integrated into the GIS Idrisi Andes; (c) Identification of areas across the basin where interventions are needed to limit the process of soil degradation.

Framework Physics

The study field is the watershed of Oued El Maleh, It extends over an area of 34 km², is located north of the Fez city in the boundary between the southern Rif wrinkles (Zalagh and Tghat) and Saiss plain, It is bounded on the west and north by the Oued Mekkés watershed, to the south by Saiss plain to the east by the Oued Sebou valley (**Fig. 1**).

The study of climate in the study area is based on the use of rainfall and temperature data from the Fez Saïss station. This study allowed us to identify

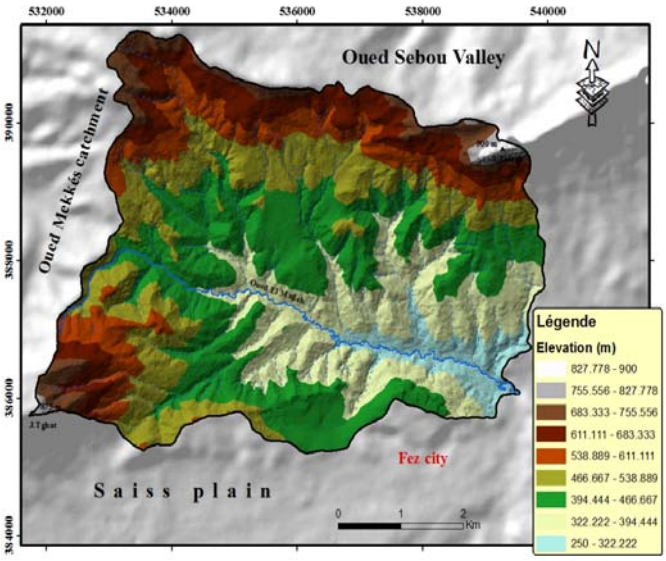

Fig. 1 Localisation and Digital Elevation Model of Oued El Malleh catchment.

a certain number of climatic characteristics. Precipitation collected in the station are different from one year to another, with an annual average of 484.75 mm. The average monthly precipitation is 40.36 mm. December is the wettest month, while July is the driest month. The annual average temperature is 17.76°C. The calculation of the index of aridity (annual and monthly) indicates that the study area has a semi arid climate.

Several geological formations occur throughout the watershed. We observe different deposition of different ages: Triassic gypsiferous clays in the Northwest sandstone limestone Liassic age at Jbel Tghat and Jbel Zalagh, marl Miocene sandstones, conglomerates of Pliocene and Quaternary travertines (Essahlaoui *et al.*, 2001).

Given the complexity and diversity of geological facies several types of soils are found in this region. There are six soil units: a raw mineral soils, poorly developed soils, Vertisols, calicimagnésiques soil, isohumic soil and mixed complexes of soil units.

Mapping the occupation of land and water erosion

Studies on the change in the land use are of great importance because they can know the current trends in the process of deforestation, degradation, desertification and loss of biodiversity in a given area.

The identification of spatio temporal variation of land use in the study area was carried out from the ground reality and visual interpretation of satellite images Landsat-5 and Landsat-7 ETM + (between 1987 and 2011). It is based on radiometric values of the image data and various parameters specific to the technique of photo-interpretation namely the texture and structure of the image, then we georeferenced images using the projection system Merchich North. Thus, we conducted a cutting of images by selecting parts that correspond to the same portion of space from the coordinates of our study area.

Unsupervised classification

Unsupervised classification is intended to provide the samples and taxonomy to initialize the supervised classification. Training plots were demarcated according to their local homogeneity apparent. Their size is small, of the order of 30 pixels on average because the images have not extensive and heterogeneous units. The choice of training areas was made according to the color ranges of homogeneous observations in the field and the visual interpretation of the color composition. Were selected at least four plots per class. Learning is achieved by the function of IDRISI ANDES MAKESIG. The latter has also helped create files of spectral signatures of each class defined theme.

Supervised classification

Supervised classification is to assign a thematic class pixels that belong to a class defined by the spectral plots workout. This is a step that requires the choice of a classification algorithm is best suited to the processed data. Supervised classification was launched with the function of IDRISI ANDES MAXLIKE. It uses the maximum likelihood algorithm based on spectral signature files. It is assumed that all classes have the same a priori probability. Pixels are assigned to the class to which they have the highest probability of belonging. MAXLIKE also has the option to reject a certain number of pixels that the possibility of belonging to a class is very low.

All images are taken in the dry season not to compare images from different seasons, which could lead to not comparable results. The visual interpretation of satellite images was performed by the image processing software IDRISI Andes have a comprehensive series of modules for both digital and analog methods.

RESULTS

The analysis of satellite data has identified five main types of land use (badland, reforestation, urban area, a mixture of olive and cereal and irrigated crops). Subsequently, soil losses were estimated by RUSLE model integrated into the GIS Idrisi Andes. The results allow the identification of areas across where interventions are needed to limit the process of land degradation.

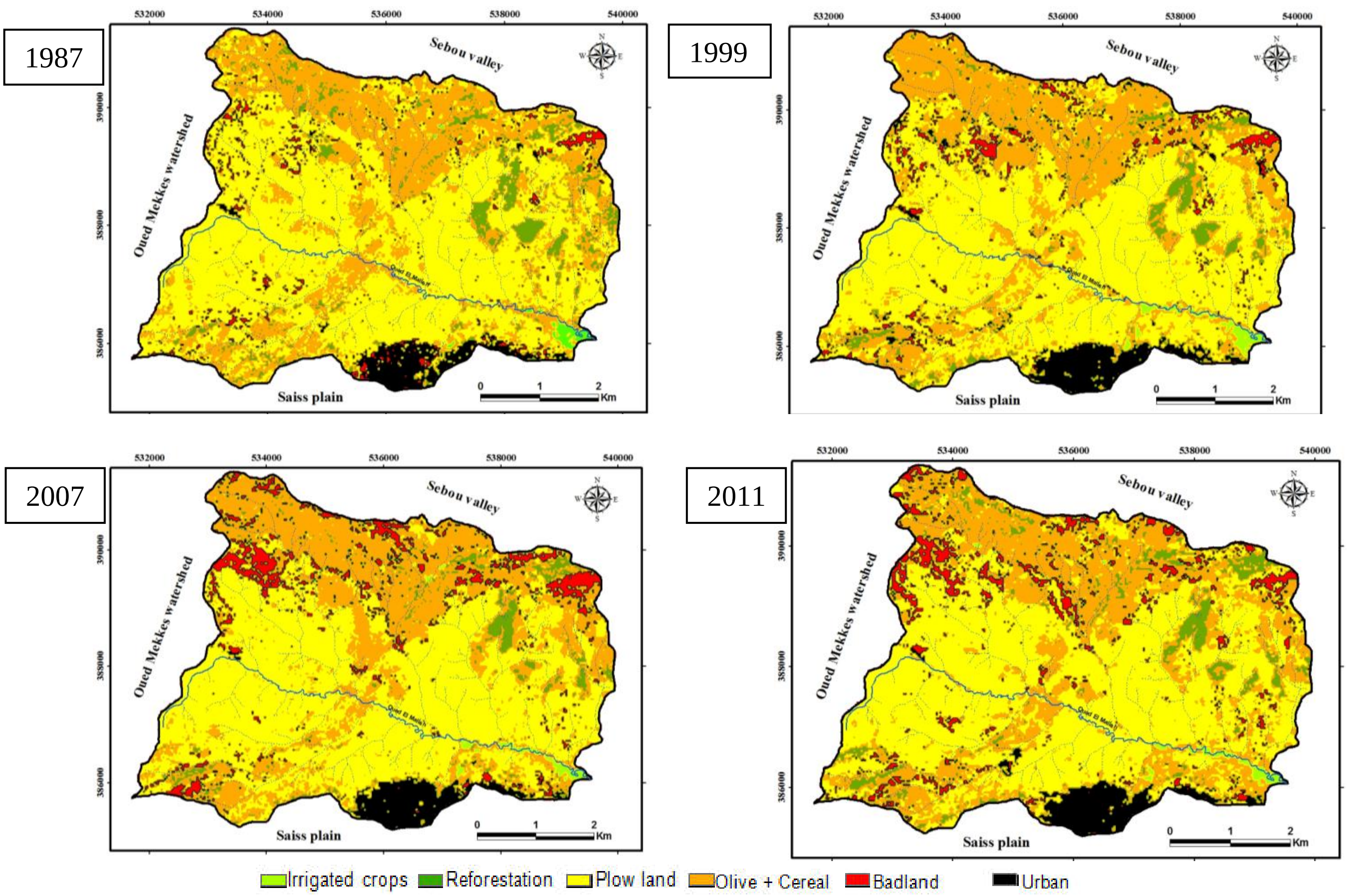

Fig 2.

In general more than 90% of the total area of Oued El Mellah catchment is covered by cereals, olives, or a mixture of both cultures, while other land (Badland, irrigated crops, and reforestation) does not exceed 7% of the area of the basin (**Fig. 2**).

Table 1. Changes in land use over time (%)

Land use	1987	1999	2007	2011	%
Badland	3,58	4,74	7,85	7,90	54,75
Reforestation	6,75	3,65	3,18	4,75	-42,17
Olive+Cereal	26,84	30,02	31,31	28,99	7,41
Plowland	58,65	56,06	53,31	53,90	-8,81
Irregated crops	0,62	0,95	0,77	0,74	15,91

The diachronic study of the land shows a modification of the natural environment with an increased the area of badlands (+54.75%), an extension of irrigated crops (+15.91%), a reduction in the reforested area (-42.17%), a slight extension of the land occupied by olive trees (+7.41%) in favor of plowland (-8.81%), while the urban area have not undergone significant change (+4.34%) (**Table 1**).

The land use dynamics showed that the study area experiencing expansion in favor of wasteland reforestation and plowland. The presence of urban areas in the fields of agriculture shows an intrusion of the local population with the consequent degradation of natural resources.

MAPPING SOIL EROSION

The RUSLE Model

Despite the criticism of the misuse of the USLE model in conditions other than those in which it was developed, it seems in practice that the modeling approach by using the USLE factors remains a strategy acceptable to assess soil erosion, especially considering the recent progress in RUSLE model, Revised USLE (Renard *et al.*, 1997). It is an empirical model in which erosion (A), expressed in t/ha/yr is the product of six factors:

$$A = R \times K \times LS \times C \times P \quad (1)$$

R = rainfall erosivity, K = soil erodibility, LS = slope length and slope of C = P = cover anti-erosion practices (**Fig. 3**).

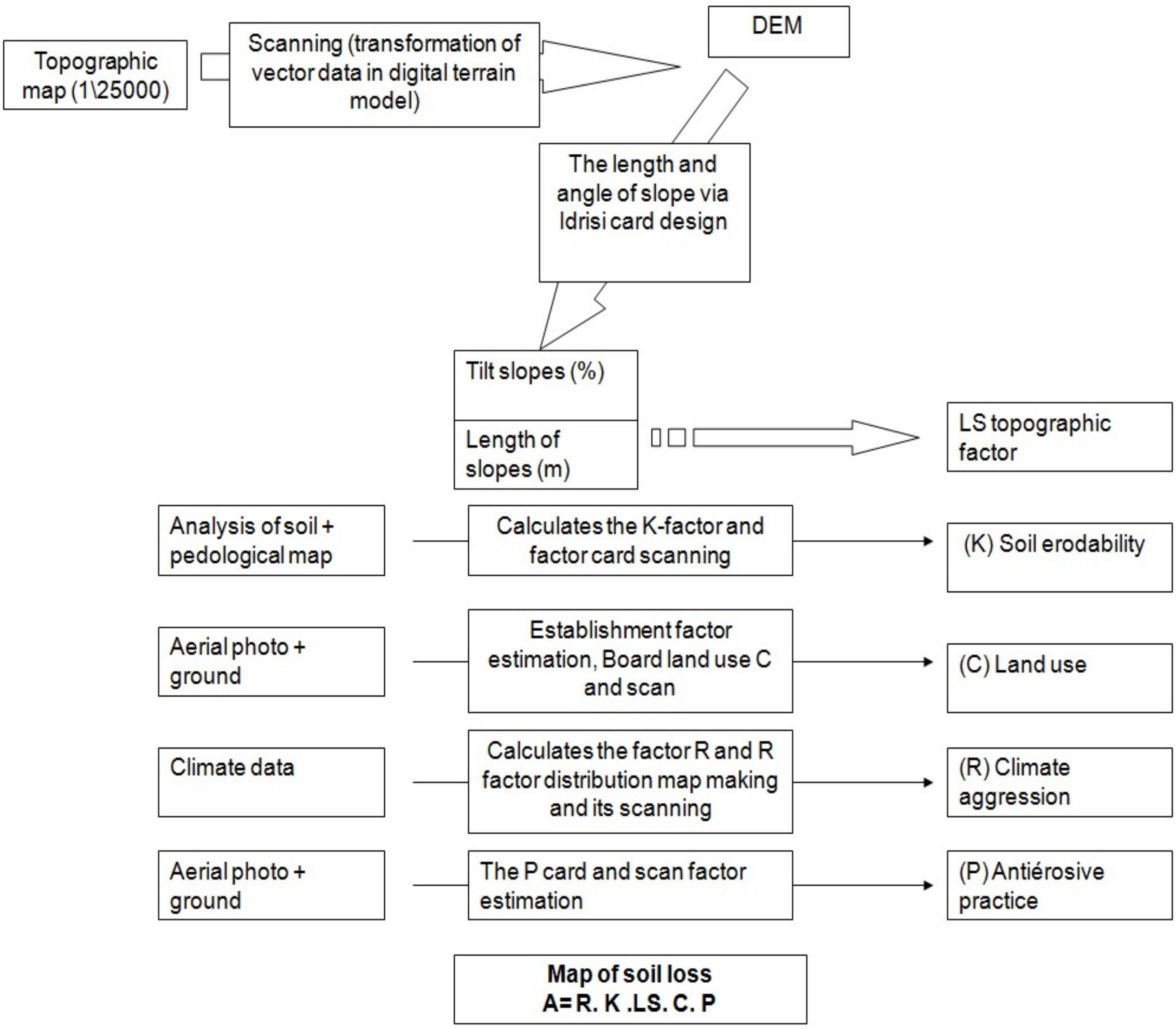

Fig. 3 Schematic representation of the approach used (El Garouani et al., 2007).

Table 2. values of soil loss (RUSLE model)

	RUSLE (t/ha/yr)			
	1987	1999	2007	2011
Bandland	150.206	159.845	177.45	190.17
Reforestation	0.72	1.181	0.698	1.789
Olive+cereal	5.048	18.115	10.149	14.473
Plowland	9.2	13.109	13.42	20.091
Cultures irrigées	13.385	0.111	0.044	0.06

After the land use mapping, soil losses were estimated by RUSLE module integrated into the GIS Idrisi. This module calculates not only the soil loss for each pixel in the grid, but also group the pixels into homogeneous polygons based on the criteria of slope orientation and slope length as they may be adjusted by the user (**Fig. 4**).

The averages of soils Losses determined by RUSLE by type of land use vary between 1.09 t/ha/year as the minimum value in the reforestation area, and 169.41 t/ha/yr as the maximum value recorded at the badlands. These generally correspond to Regosols or soils little protected located on steep slopes, the area occupied by annual crops (plowland) also show a average susceptibility to erosion with annual losses of 13.95 t/ha/year.

The sedimentation model

These static assessments of soil losses were then used in an algorithm deposition (sedimentation) which models the movement of the soil loss to the downstream. Sedimentation model is based on the RUSLE model results to calculate the erosion assessment in each elementary plot considered homogeneous. It uses homogeneous polygons resulting from the RUSLE model calculation to assess the net movement of soil (erosion or deposition) in plots or sub-watersheds (Lewis *et al.*, 2005).

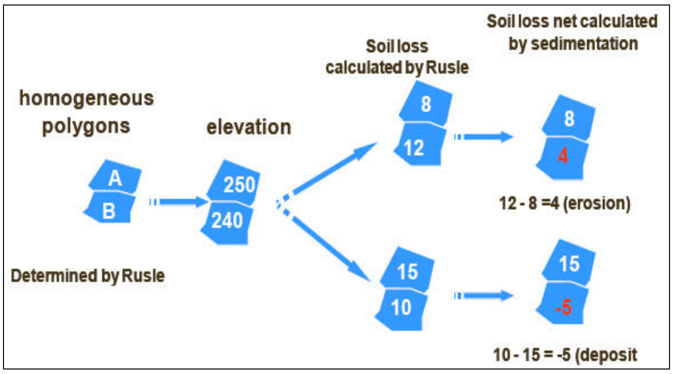

Fig. 4 Principle model of deposition: Sedimentation (El Garouani, 2007).

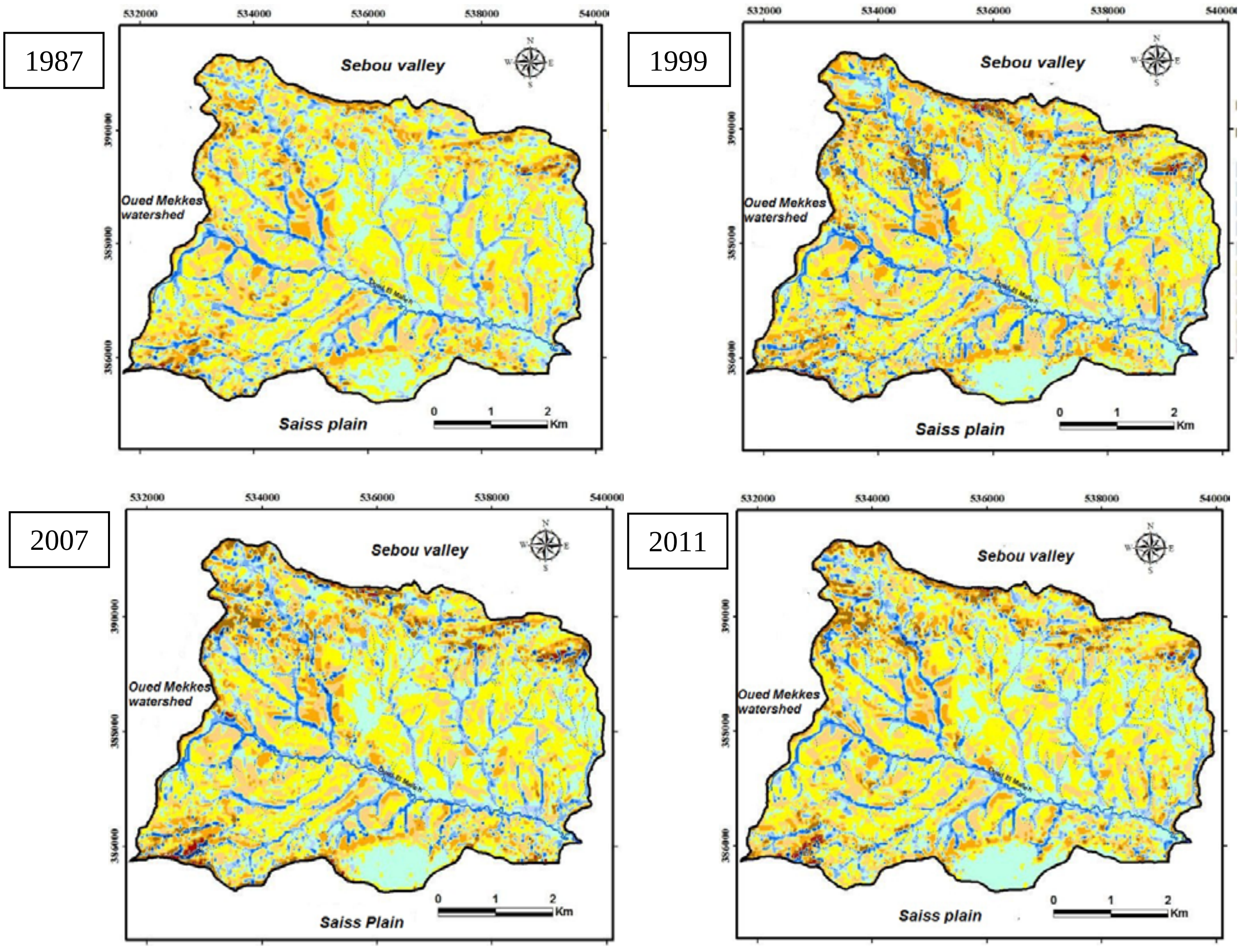

Fig. 5 Map of spatial distribution of net soil loss (t/ha/yr)

Table 3. values of net soil loss (Sidementation model)

	Sedimentation (t/ha/yr)			
	1987	1999	2007	2011
Badlands	79.04	90.84	104.13	115.48
Reforestation	-0.42	-0.26	-0.08	-0.63
Olive + Cereal	0.51	1.59	0.09	-1.05
Plow land	0.88	0.89	0.16	0.96
Irregated crops	-30.91	-0.26	-0.08	-0.33

Taking into account the temporal variability of erosion and deposition at the same time led to lower values of soil erosion calculated by the RUSLE model (e.g. only 97.37 t/h/year as results for the model sedimentation in the badland). Despite this decline, there is still a problem of soil degradation due to the type of land use and local lithology (**Table 3**). This therefore shows the severity of land degradation due to the type of land use and the local lithology that promotes soil erosion.

CONCLUSION

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