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Assessment of the Effects of Land Use/Land Cover Changes on Soil Loss and Sediment Yield Using WaTEM/SEDEM Model: Case Study of Ziz Upper Watershed in SE-Morocco

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Abstract

Water erosion and sediment production rates are closely related to land use and land cover (LULC). A spatially distributed soil erosion and sediment delivery model can be used as a good tool to assess the effects of changes in land use/land cover on erosion processes. However, the calibration of such a model requires a lot of data, which is sometimes non-existent. In this work, WaTEM/SEDEM model of spatial distribution of sediments and their delivery to rivers was applied to the large Ziz basin (4,435 km^2) in south-eastern Morocco. Model calibration and validation were carried out based on recorded sediment yield during the period from 1973 to 2009 at Hassan Eddakhil dam in the catchment outlet. Thereafter, three LULC scenarios were modeled by reproducing land use/land cover in 1936 and in 1957 and then a hypothetical future scenario. The results of LULC dynamics revealed that degraded forest drastically declined while rangeland substantially increased between 1936 and 2017. These changes in LULC can be explained by the interactions between bioclimatic factors and ecologically inadequate and ultimately destructive human interventions (overgrazing, deforestation). The comparison of WaTEM/SEDEM simulations for these scenarios with the current situation of LULC shows that sediment yield has increased from 1.5 million to 2.2 million ton/year and an increase in specific sediment yield from 3.37 to 5.6 t/ha/year. For soil erosion classes, the results show a trend of slight to moderate class from 1936 to current situation. The present study has shown that the great anthropogenic pressure on the natural resources of the Ziz upper watershed ended by the outcropping of pavements of soils exposed directly to the erosive processes.

Keywords: LULC change; WaTEM/SEDEM; GIS; sediment yield; Ziz; SE Morocco
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1. Introduction

The world's population is projected to reach10 billion by 2056, and this increase will lead to substantial increases in demand for natural resources (water, air, soil) [1]. For soil resources, research did not start until the middle of the 20th century, and it was focused on the physico-chemical and biological properties, the genesis, and the geographic distribution of soils [2].The degradation of the soil resource has had a negative impact on the well-being of at least 3.2 billion people and caused a massive extinction affecting one sixth of all species on the planet [3]. The United Nations Sustainable Development Goals explicitly identify soil resources as being of crucial importance and promote soil resources' protection in order to achieve the ambitious goal of Zero Land Degradation by 2030 [4]. These goals provide good opportunities for soil erosion modelers to respond with more specific assessments and solutions on how to reach these goals.

In Europe, water erosion is the most serious danger to soils [5]. Accelerated water erosion affects one sixth of land surface [6] and mountainous regions are among the high-risk areas due to steep slopes that increase soil erosion and sediment redistribution rates [7].

Recently, many studies have demonstrated that land cover/land use (LULC) is among the main drivers of soil erosion intensity, and historical LULC changes have affected soil erosion rates and sediment yields in many watersheds around the world [7].

A quantitative assessment of the impact of LULC changes on soil loss and sediment export can be conducted in various ways: in the field by suspended sediment measurement, and in experimental watershed by long-term monitoring. Nowadays, geographic information systems (GIS) techniques and remote sensing data (RS) can be used successfully to enable rapid and detailed soil erosion assessment. Thus, these useful techniques provide effective methods of measuring, analyzing and managing soil erosion from the scale of the plot to the regional. Therefore, spatial and quantitative information on soil erosion at the watershed scale can contribute significantly to soil conservation planning.

In Morocco, according to the national watershed management plan [8], soil erosion has affected a large part of the national territory (75%). The cumulative annual soil losses are estimated at 100 million tones [9], with 50 million m^3 of water loss each year by siltation in large dams. These results have triggered alerts for urgent intervention and monitoring of soil losses for better decision-making with regard to the conservation of soil and water resources.

To assess and predict soil erosion under different conditions and to develop management plans, soil erosion models are good tools for assessing soil erosion rates for the current LULC conditions with a number of alternative LULC scenarios. Spatially distributed erosion and sediment transport models allow the assessment of both the differences in total sediment yield, differences in sediment sources, and the existence of sedimentation traps within catchments. Empirical models such as USLE (Universal Soil Loss Equation) were the first introduced, followed by physical models. Among these models, there was WaTEM/SEDEM (Water and Tillage Erosion Model [10] and SEdiment DElivery Model [11]), a spatially-distributed soil redistribution rates and sediment delivery model, based on RUSLE (Revised Universal Soil Loss Equation) and equipped with a sediment transport equation to predict sediment supply in a drainage network at regional scale [7]. The first modelling of soil erosion on European scale using WaTEM/SEDEM model indicates that sediments delivery towards fluvial system were 15.3% of total eroded soils [6].

The main objective of the present study was to assess soil redistribution rates and sediment supply to a stream network under current, past and future conditions of LULC in a semi-arid context using WaTEM/SEDEM model, calibrated and validated by recorded sediment yields at the catchment outlet. The study area (Ziz upper watershed in southeast Morocco) is a large catchment with poorly developed soils [12] for which a good amount of sediment yield data was recorded during 1973 to 2009 at the Hassan Eddakhil dam, the only hydraulic structure built in 1971 with an initial water capacity of 380.10^6 m^3 [13]. It was built with two objectives: to protect the Tafilalet plain against floods and to provide the water needs for irrigation and for the use of the population.

2. Materials and Methods

2.1 Study area

Ziz upper watershed is located in the oriental region of Moroccan High Atlas (Figure 1). It is a large mountainous watershed in Ziz at Draa-Tafilalet region and covers a total area of approximately 4,435 km^2. It borders central High Atlas to the West, upper Moulouya to the North and Anti Atlas to the south. Ziz upper watershed topography is very rugged, and the altitude varies from 1,023 m a.s.l. (above sea level) to 3,687 m a.s.l. in the north-west part with an average altitude of 1,812 m. The dominant slope class that occupies more than 80% of the Ziz upper watershed area is between 0 and 15°.

This basin experiences a semi-arid climate characterized by a harsh winter and a moderate summer with mean annual temperatures ranging from 10.2°C to 19.2°C [2]. The annual rainfall ranges from 119 mm to 377 mm and falls in spring and autumn. The Ziz catchment is crossed by national road 13 and regional road 706, which connect the center of Imilchil to the center of Er-Rich. The 2014 census reported the population of Draa-Tafilalet region at 1,635,008, compared to 149,580 in 2004 [14]. Most people live in rural areas on the banks of Oued Ziz where they predominantly practice subsistence farming of cereals and legumes, and their farms are concentrated along the riverbanks. The center of Er-Rich is the largest agglomeration located at the point where two major Oueds branches, that drain the upstream western and northern parts of Ziz valley, meet. The soils represented are poorly developed, and are alluvial or colluvial contributions in the deposition areas, or even raw minerals have not yet developed [15].

According to the geological map [16, 17] of the study area, Jurassic formations largely dominate and occur in two main levels of limestone: The Upper Aalenian and the Dogger. Triassic formations occur in small areas and include marls and dolomitic clays with salt levels and basalts [15]. The dominant LULC features include: poorly vegetated areas or rangelands (64%), degraded forest (25%), agricultural fields (10.1%), and water bodies (0.6%).

2.2 WaTEM/SEDEM model

In this work, we used WaTEM/SEDEM model to estimate soil loss and sediment transport in a large mountain watershed, under current, past and future conditions. This model has been applied in different conditions including Spanish catchments [18-20], Australian catchments [21], Slovenian landscapes [22], European scale [23] and recently in Czech watersheds [24].

WaTEM/SEDEM model is based on RUSLE equation and a transport capacity equation (TC) to predict sediment delivery in a drainage network [10, 11, 25]. This model comprises three components; the first is used to calculate annual soil erosion using the RUSLE approach as shown in equation 1 [26].

$$A = \mathrm{R} * \mathrm{K} * \mathrm{LS}_{2\mathrm{D}} * \mathrm{C} * \mathrm{P} \tag{1}$$

Where A is the mean annual soil loss (kg/m^2/year), R is a rainfall erosivity factor (MJ mm/m^2/h/year), K is a soil erodibility factor (kg h/MJ/mm), C is a dimensionless cover and management factor, P is a dimensionless erosion control practice factor, and LS_{2D} is a slope-length factor [27]. The second is used to estimate sediment flux from slopes to the stream network (equation 2) [11].

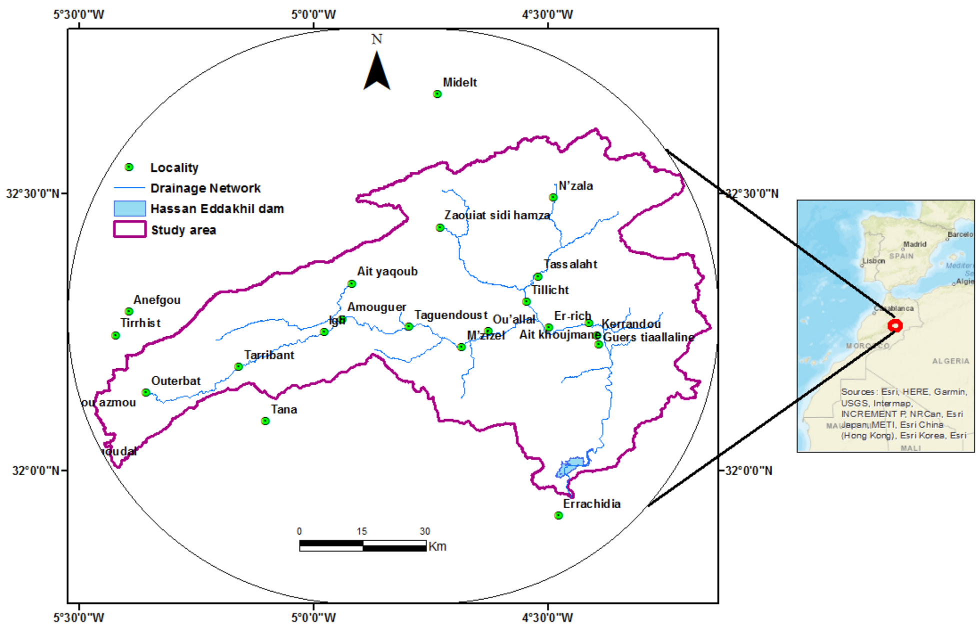

Figure 1. Location of the Ziz upper watershed in southeast Morocco

$$TC = ktc * R * K * (LS_{2D} - 4{,}1s^{0,8}) \quad (2)$$

Where TC is the annual transport capacity (kg/m/year) and R, K, and LS factors are the same as in equation 1, s is the local slope (m/m) and ktc is a transport capacity parameter (m). The third is tillage erosion which represents the net soil flux caused by tillage on a hillslope of infinitesimal length and unit width and is proportional to the local slope gradient (equation 3) [28]:

$$Qs,t = ktill\ s = -ktill\ dh/dx \quad (3)$$

Where Qs,t is the net downslope flux due to tillage translocation (kg/m/year), ktill is the tillage transport coefficient (kg/m/year), s is the local slope gradient (m/m), h is the height at a given point of the hillslope (m) and x is the horizontal distance (m)[28].

2.2.1 Model inputs

WaTEM/SEDEM model requires that input parameter files must have the same resolution. The topographic data and the river topology/flow were derived from SRTM-DEM (main input). The C factor was estimated using the regression relation of Van der Knijff [29], The K factor was estimated using the Wischmeier monogram and the results of soil studies of the national watershed management plan for the adjacent Assif Melloul watershed [15]. The R factor was calculated using rainfall data available from meteorological stations. Road and ponds maps were produced using satellite images and available topographic maps of the study area.

The inputs layers were generated in IDRISI GIS software (Clark Labs, Clark University) with a horizontal resolution of 30 * 30m. This resolution was choosed to keep the same DEM's resolution. The input layers consisted of R factor, K factor, C factor and Parcel map. The P factor was fixed to be 1 in WaTEM/SEDEM.

2.2.2 Model calibration

WaTEM/SEDEM calibration was conducted by adjusting its parameters (ktc and ktill). Then, the simulation results were compared with observed results in the Hassan Eddakhil dam. Recorded sediment data from 1973 to 1990 were used for model calibration and those recorded from 1991 to 2009 were used for model validation. To assess model results efficiency, we used The Nash–Sutcliffe equation 4 [30].

$$NS = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - Omean)^2} \tag{4}$$

Additionally, the relative root mean square error (RRMSE) was used as an estimate of the model accuracy according to equation 5.

$$RRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(Oi - Pi)^2}}{\frac{1}{n}\sum_{i=1}^{n}Oi} \tag{5}$$

Where n is the number of observations, Oi is the observed value, Omean is the mean observed value, and Pi is the predicted value. The closer the value of NS is to 1, the more efficient is the model. Details of the calibration procedure are given in the studies of Mohamed *et al.* [31].

2.3 LULC change detection

The detection of LULC changes in the Ziz upper watershed was carried out using the overlay operation of three parcel maps obtained from georeferenced maps (1936 and 1957) and from the Landsat 8 images acquired in March 2017 for the same geographical area. LULC change was very pronounced during the period from 1936 to 2017. Figures 2 and 3 present LULC dynamics in the study area and a probable future situation.

During the period of 1936 to 2017, the Ziz upper watershed was dominated by degraded forest and followed by poorly vegetated areas. Meanwhile, agricultural fields and water bodies were the least land use types. The results show that degraded forest consistently underwent serious decrease. On the contrary, poorly vegetated areas kept on increasing. The decrease of degraded forest from 1936 to 2017 reflected the great pressure of deforestation and overgrazing undertaken by the population. Figure 3 shows more details about the dynamic LULC change in the Ziz upper watershed.

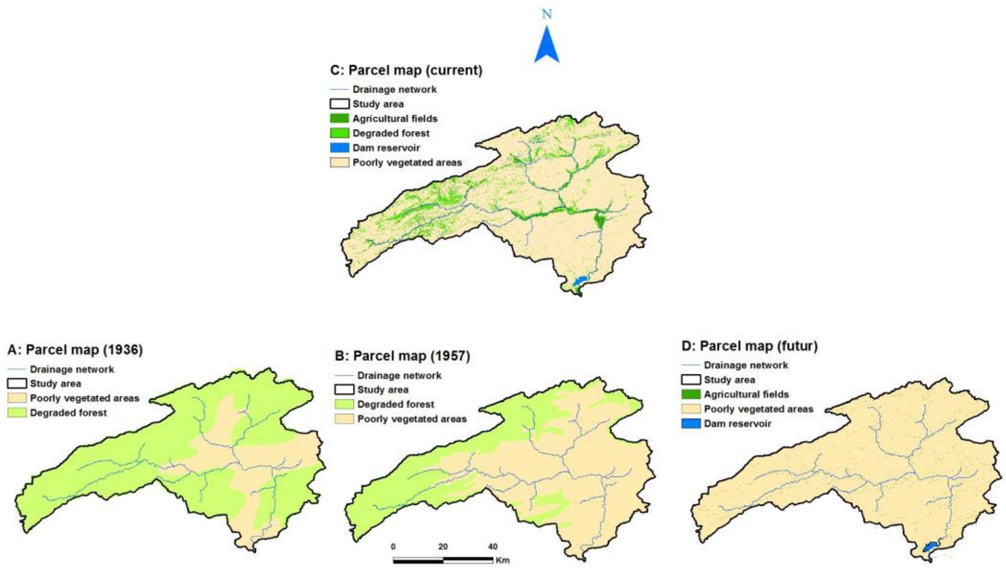

Figure 2. Dynamic change of parcel maps of the Ziz upper watershed under past (A:1936, B:1957), current (C) and likely future conditions (D)

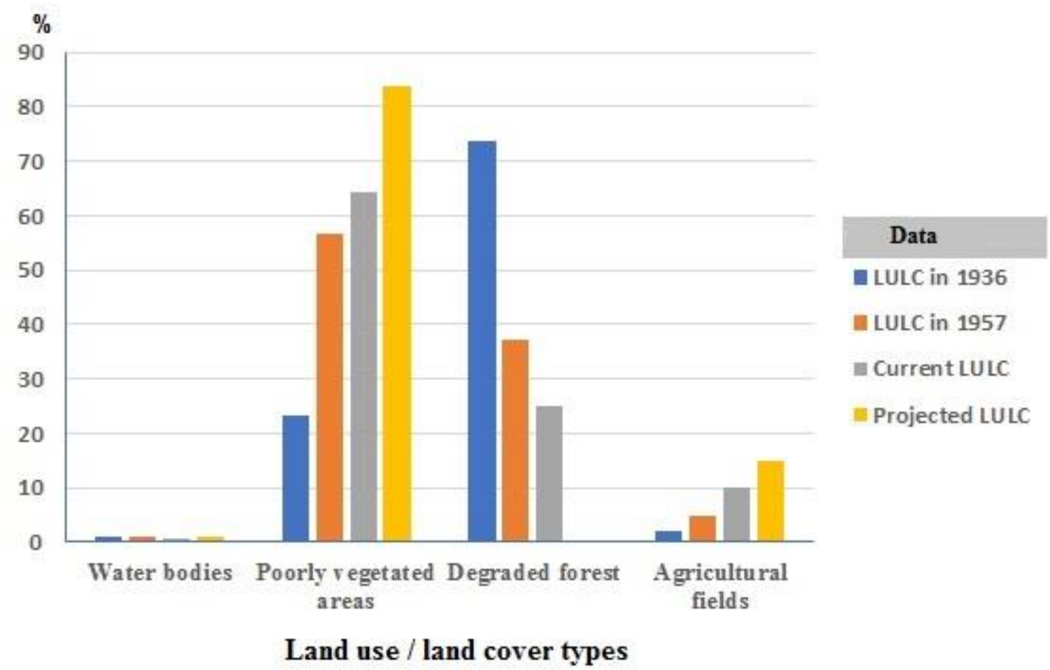

Figure 3. Diagram of Land Use/Land Cover (LULC) dynamic in the Ziz upper watershed under past, current and future conditions

3. Results and Discussions

3.1 WaTEM/SEDEM calibration and validation

Optimal parameters found in the model calibration were ktcmax = 477m and ktill = 0m. This ktcmax seems at first to be high in comparison with those found by Verstraeten [32] in Belgium watersheds (ktcmax = 250m), by Haregweyen *et al.* [33] in Ethiopian catchments (ktcmax = 110m), by Syahli [34] in Merawu watershed in Indonesia (ktcmax = 297m), and by Konecna *et al.* [24] in Czech watershed (ktcmax = 55m). These comparisons should be taken very carefully since the environmental conditions are not similar and the resolution of the Digital Elevation Models (DEMs) used is different in all these studies. With reference to the tillage transport coefficient (ktill) that controls the intensity of tillage erosion, in the case of our study: agricultural fields which occupy 10% of the total area in the Ziz upper watershed, are very narrow and distributed along the banks of the Ziz valley. They are generally small flat areas and plowing there is done by conventional tools such as the wood plow. So, the contribution of tillage to soil redistribution was almost negligible. Also, in comparison with the WaTEM/SEDEM application made by Quijano *et al.* [20], ktill was fixed at the value of 0 knowing that in their study area (Ebro basin, NE Spain) the plowing was done by modern mechanical tools. The application of the WaTEM/SEDEM model using optimal parameters allowed us to predict the annual sediment yield and the predicted soil loss map. The comparison of simulated results with those measured at the catchment outlet shows a good correlation (65%). The Relative Root Mean Square Error (RRMSE) of the model's accuracy found in this simulation was approximately 2.6%. For more details, we refer to the studies of Mohamed *et al*. [31].

3.2 Sediment main sources and deposition areas

To simplify the reading of the predicted soil loss map, the Ziz upper catchment was subdivided into 27 sub-basins (Figure 4A and Table 1). In all the pixels of each sub-basin, GIS Idrisi calculates soil losses and deposits. If the losses are greater than the deposits, we have a negative balance which means erosion and if the losses are less than the deposits, we will have a positive balance, which means deposition. The results show that the sub-basins n° 1, 20, 21, 22, 23 and 24 display positive values, which means that they are intermediate locations of sedimentation. The other sub-basins show negative values, which means that they are hotsspot of sediment generation.

The sub-basins n°3, 4 and 5 are the most sediment producing. However, n° 22 is the site receiving the highest sediment deposit. For other LULC situations, Figure 4 and Table 2 illustrate the spatial distribution of soil erosion and deposition in the Ziz upper watershed.

Table 2 showed that soil erosion affected about 9/10 of the study area under different LULC situations, and it was only approximately 1/10 of the catchment area that experienced deposition. The areas affected by erosion increased slowly. On the contrary, those where the deposition occurred decreased slightly. Figure 4 shows that the steeply sloped parts were the areas that experienced the worse erosion. However, deposition occurred in the southern parts of the catchment and in the areas where the topography was relatively flat.

3.3 Results of WaTEM/SEDEM application for different LULC situations

LULC change dynamic from 1937 to 2017 indicates a reduced area occupied by degraded forest at the expense of poorly vegetated areas (rangelands). The results show a reduction of about 2/3 in degraded forest (73.6% to 25%) over the last decades. This occurred as a result of the deforestation

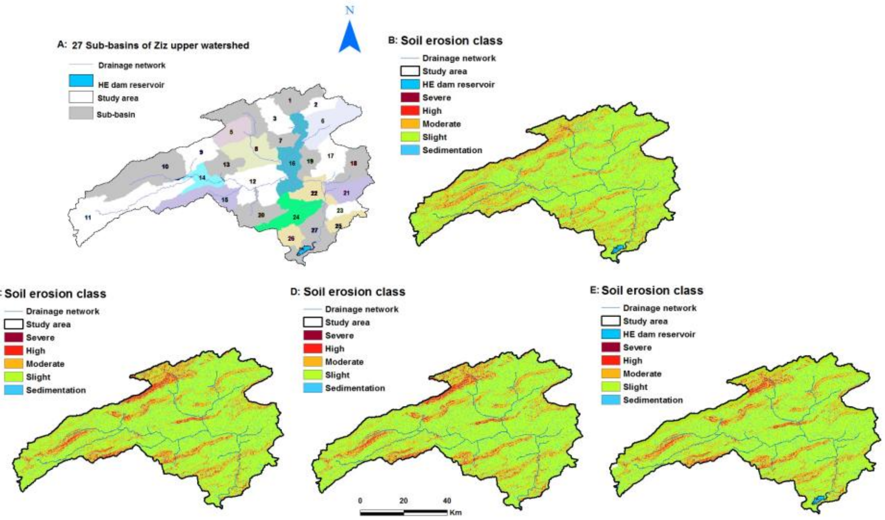

Figure 4. The 27 sub-basins (A) and predicted soil loss map of the Ziz upper watershed under past (C:1936, D:1957), current (B) and a likely future Land Use/Land Cover (E)

Table 1. Distribution of sediment budgets and water erosion factors values by sub-basin in the Ziz upper watershed for the current LULC conditions

Sub-basin	Area (ha)	Area (%)	R factor	K factor	LS factor	C factor	Sediment budget (t/year)
1	14457.7	3.3	0.0038	0.072	12.2	0.79	347.52
2	6547.1	1.5	0.0037	0.080	11.7	0.82	-6010.53
3	13244.4	3.0	0.0037	0.077	13.7	0.83	-37205.12
4	17442.8	4.0	0.0039	0.107	24.7	0.84	-46342.52
5	11812.1	2.7	0.0038	0.116	26.0	0.83	-31054.55
6	22775.2	5.2	0.0036	0.108	11.0	0.83	-3722.84
7	6915.7	1.6	0.0035	0.115	10.3	0.84	-745.65
8	21023.7	4.8	0.0036	0.094	12.6	0.83	-5460.84
9	13725.4	3.2	0.0038	0.101	20.3	0.84	-24213.46
10	38278.8	8.8	0.0044	0.072	20.5	0.80	-20352.4
11	46372.6	10.7	0.0050	0.069	18.9	0.82	-7749.95
12	27139.6	6.2	0.0036	0.080	9.3	0.83	-436.52
13	10869.1	2.5	0.0038	0.067	11.4	0.86	-6640.84
14	8994.3	2.1	0.0038	0.061	15.6	0.84	-4651.29
15	8254.7	1.9	0.0034	0.068	10.3	0.87	-912.82
16	21920.5	5.0	0.0034	0.091	10.2	0.83	-4485.32
17	16244.8	3.7	0.0034	0.086	11.6	0.86	-1595.33
18	13752.5	3.2	0.0034	0.066	8.9	0.87	-2214.26
19	17608.7	4.0	0.0039	0.115	14.1	0.86	-21532.94
20	15649.9	3.6	0.0036	0.080	20.1	0.81	284.53
21	12206.1	2.8	0.0033	0.094	10.1	0.84	179.94
22	12465.9	2.9	0.0033	0.087	11.6	0.79	3243.93
23	18098.8	4.2	0.0033	0.110	16.9	0.83	450.66
24	6831.7	1.6	0.0033	0.059	14.3	0.81	102.42
25	6641.9	1.5	0.0032	0.053	15.9	0.79	-37.87
26	7469.8	1.7	0.0031	0.072	22.8	0.80	-655.62
27	18238.7	4.2	0.0030	0.077	21.4	0.82	-25418.36

Table 2. Spatial distribution of soil erosion and deposition in the study area under past, current and future condition of Land Use/Land Cover (LULC)

Year	1936 (%)	1957 (%)	Current (%)	Projected (%)
Erosion	88.12	88.54	90.5	91.2
Deposition	11.47	11.45	9.5	8.2

(to ensure the wood used for heating and cooking) and overgrazing (mostly herds of goats). As a result, the increase of poorly vegetated areas (rangelands) caused the appearance of bare soil that were exposed directly to erosive agents that increased water erosion rates and sediment yields. The WATEM/SEDEM model allowed the prediction of sediment delivery maps for the three LULC scenarios, which was interesting for comparing the effect of LULC changes on soil erosion and sediment yields. Table 3 provides more details.

Table 3. Summary of the WaTEM / SEDEM model results for different LULCs scenarios in the Ziz upper watershed

WaTEM/SEDEM results	For 1936	For 1957	Current	Projected
Total sediment production (t/year)	52831150.3	44772374.3	23135015.6	37125431.9
Total sediment deposition (t/year)	51328083.7	43257181.9	21105686.6	34885858.6
Total river export (t/year)	1495651.6	1507824.3	2027095.5	2229264.9
Sediment yield (t/year)	1503066.6	1515192.4	2029328.9	2239573.3
Specific sediment yield (t/ha/year)	3.37	3.57	4.58	5.6

For the current LULC situation, the specific sediment yield is 4.58 t/ha/year, while for 1936, 1957 and a likely future condition the specific sediment yields are 3.37, 3.57 and 5.6 t/ha/year, respectively. These results show that the transition of degraded forest areas from steeply sloped to poorly vegetated areas caused high rate of soil loss and sediment yield. These results revealed that sediment yield at the catchment outlet of the Ziz upper watershed follows the LULC change.

According to the predicted map of soil erosion classes, the results show an increasing trend from slight to moderate (from 1936 to current situation) and slight erosion classes increased slowly while areas in the high soil severity class decreased. Meanwhile, other soil erosion classes had mix increase and decrease trends, such as high class that increased from 1936 to 1957 and decreased from 1957 to 2017. Table 4 presents more details about the dynamic of erosion classes.

Table 4. Distribution of soil erosion classes in the Ziz upper watershed under current, past and future conditions

Soil loss (t/ha/year)	Erosion class	Area (%) for 1936	Area (%) for 1957	Area (%) for current	Area (%) for future
>70	Severe	0.17	0.16	0.18	0.14
20 to 70	High	5	5.1	1.9	4.6
7 to 20	Moderate	17.6	17.6	19.4	16.8
0 to 7	Slight	77.1	77	78.5	78.3

The results of the spatial distribution of soil erosion classes showed that the highest rate of slight erosion class occured in the current situation (78.5%) and the lowest occured in 1936 and 1957. Meanwhile, the lowest high class and the highest moderate class are occured in the current LULC. İn 1936 and 1957 conditions, the spatial distribution of soil erosion classes looked similar. The diagram in Figure 5 gives a description of the distribution of erosion classes and depositions in (ha) for the different scenarios.

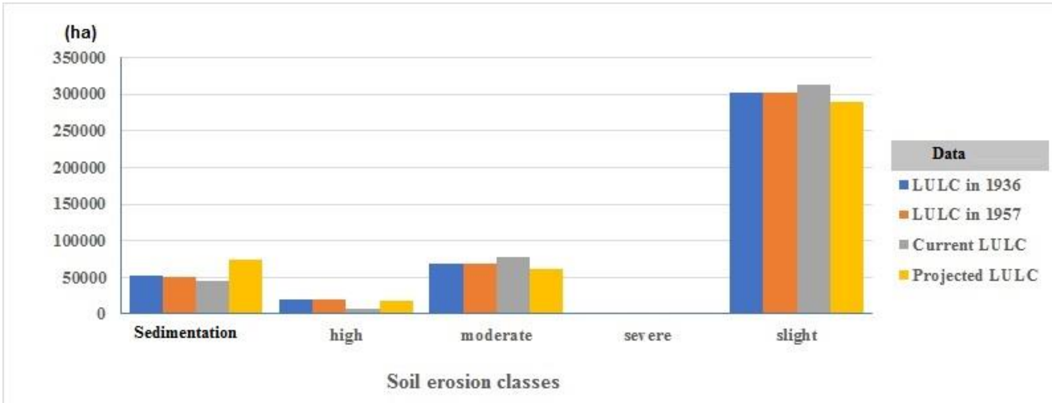

Figure 5. Diagram of soil erosion classes composition in the Ziz upper watershed under past, current and future conditions of LULC

3.4 Sediment yield at the Hassan Eddakhil dam

For the current LULC situation, the total sediment production is 23,135,015.6 ton/year, which represents significant soil erosion, and this quantity is directly linked to the effect of soil erosion on-site. However, during the transportation process, the amount of eroded soil available as suspended sediment that can reach the catchment outlet called "sediment yield" is about 2,029,328.9 ton/year. This large quantity of suspended sediment leads to off-site problems related to the supply of sediment to the rivers which lead to the early siltation of the Hassan Eddakhil dam, the only hydraulic infrastructure in the study area. On the other hand, based on Ghorbel and Claude's work [35] for converting sediment densities, it was found that "one cubic meter of mud with an apparent density (da) = 1.7 contains 1.2 tons of solids (sediments)". So, considering this average value, the sediment load arriving at the Hassan Eddakhil dam can as well be expressed as 1,691,107.4 m^3/year.

Given that the dam reservoir has an initial water capacity of 380 million cubic meters, the sediment yield calculated according to the WaTEM/SEDEM model contributes annually 4% of the dam siltation, which gives the dam an estimated lifespan of 22.7 years. This estimate omits other sediment sources (river bank erosion, permanent gully erosion and fluvial transport) and assumes that suspended sediment does not leave the dam during dredging operations and flood evacuation.

The results showed that the sediment delivery ratio has increased from past to current LULC situation. Moreover, it is expected to decrease under future LULC conditions. Table 5 presents more details about the dam siltation rate and lifespan for the differents LULCs scenarios.

Table 5. Simulated gross erosion, sediment yield (SY), sediment delivery ratio (SDR), dam siltation (%) and dam lifespan (year) under current and three LULCs scenarios (1936, 1957 and future) in the Ziz upper watershed

Period	Gross erosion (Mt/year)	SY (Mt/year)	SY (Mm^3/year)	SDR (%)	Dam siltation (%)	Dam life time (year)
LULC in 1936	52.8	1.5	1.25	2.84	-	-
LULC in 1957	44.8	1.5	1.26	3.34	-	-
Current LULC	23.1	2.03	1.69	8.79	4.4	22.7
Projected LULC	37.1	2.24	1.87	6.04	4.9	20.4

3.5 Impact of each factor on water erosion according to the WaTEM / SEDEM model

To identify the factors most pertinent to water erosion in the study area, we used the principal component analysis (PCA). The results presented in Figure 6 show that for the current LULC situation, there are negative correlations varying from 66 to 91% between water erosion and most factors: R^2 = 82.95% for the topographic factor (LS); R^2 = 91.6% for the crop managment factor (C); R^2 = 89.7% for the rainfall erosivity factor (R) and finally R^2 = 66.12% for the soil erodibility factor (K).

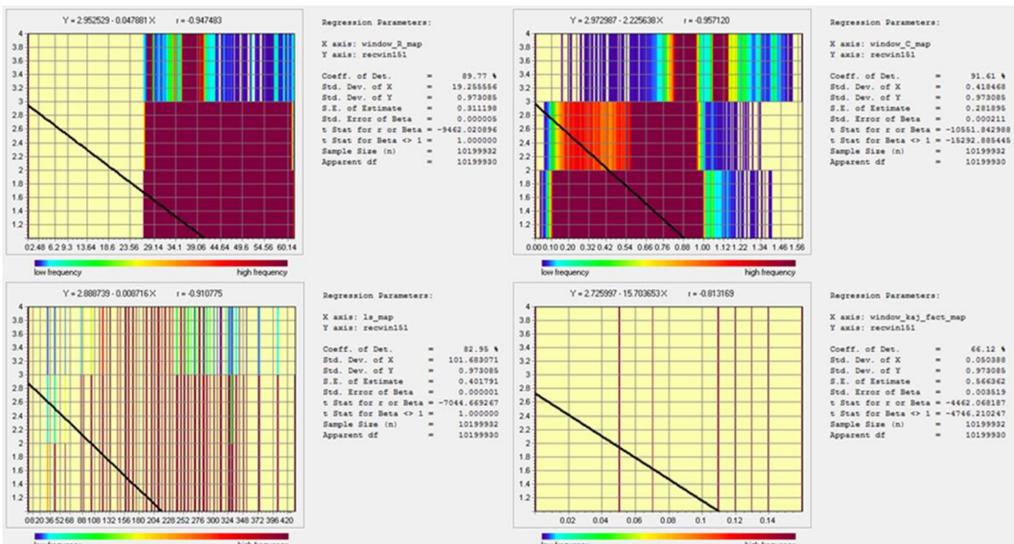

Figure 6. Statistical analysis of erosion production factors according to WaTEM/SEDEM model

The PCA results show that we must grant more importance to the two factors (C) and (LS). Suggested actions might involve more reforestation to protect land surface and to improve land cover, and the adoption of land conservation practices such as limiting the lengths of slopes so they generate less runoff. Spatially, we recommend these actions firstly, in sub-basins n°3, 4 and 5, where the (LS) factor is very important and conservation practices are rare, and secondly, in sub-basin n°27, an area which generates most of the sediment contributing to the dam siltation.

4. Conclusions

In this work, sediment yield data derived from the bathymetrical surveys conducted over 37 years (1973 to 2009) of suspended sediments at the Hassan Eddakhil dam in the Ziz upper catchment outlet were used to calibrate and validate WaTEM/SEDEM model. Model simulations for both the sediment yield (SY) and the specific sediment yield (SSY) were in good agreement with measured data. The NS and RRMSE were 0.65 and 0.026, respectively.

Based on the WaTEM / SEDEM results for the current LULC situation in the Ziz upper watershed, the sediment yield is 1.6 million ton/year and the specific sediment yield is 4.58 t/ha/year. A large proportion of the sediment comes from the sub-basins n°3, 4 and 5 in the northern upstream parts and hilly landscape (steep slopes) of the Ziz watershed. The sediment budget results showed that these three sub-basins contributed approximately 46% of sediment production. Application of the calibrated WaTEM/SEDEM model to the Ziz upper watershed under past and future condition of LULC enabled an estimation of the impact of LULC change on soil erosion and sediment yield. The results revealed that soil erosion rates and sediment yield are influenced by LULC change. Furthermore, the decrease in degraded forest and corresponding increase in poorly vegetated areas (barren land) led to increased soil erosion rates and sediment yield. Mean sediment yields were 3.37, 3.57, 4.58 and 5.6 t/ha/year for the LULCs scenarios in 1936, 1957, current and future conditions, respectively.

This study has demonstrated that the WaTEM/SEDM model can be used for assessing sediment budget under current and alternative LULC scenarios. We evaluated changes in the sediment yield and changes in the main sediment sources and sedimentation areas as a result of past and future condition of LULC. So, these results can be used to implement some measures to prevent soil erosion.

The spatial-temporal distribution of soil erosion classes under different scenarios show the trend of slight to moderate class over the period of 1936 to 2017. For performing a good calibration of the WaTEM/SEDEM model, the use of recorded sediment yield at the catchment outlet and soil redistribution rates is required for further application of such models. The use of isotopic techniques such as the 137 Cs can also provide a robust model calibration.

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