International Soil and Water Conservation Research 4 (2016) 177–185

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Original Research Article

Assessing sediment yield in Kalaya gauged watershed (Northern Morocco) using GIS and SWAT model

Hamza Briak [a,b,*], Rachid Moussadek [b], Khadija Aboumaria [a], Rachid Mrabet [b]

[a] Department of Earth Sciences, Faculty of Sciences and Techniques (FST), Abdelmalek Essaadi University, Postal Box 416, 90000 Tangier, Morocco
[b] Department of Environment and Natural Resources, Scientific Division, National Institute for Agricultural Research (INRA), Postal Box 415, 10000 Rabat, Morocco

ARTICLE INFO

Article history:
Received 25 March 2016
Received in revised form
4 August 2016
Accepted 16 August 2016
Available online 7 September 2016

Keywords:
Erosion-control
SWAT model
Simulation
Watershed
Northern Morocco

ABSTRACT

An efficient design for erosion-control structures of any watershed in the world is entrusted with the delicate forecasting of sediment yields. These outlook yields are usually inferred by extrapolations from past observations. Because runoff, as the transporting vehicle, is more closely correlated with sediment yields than any other variable. So, calibration as well as validation of process-based hydrological models are two major processes while estimating the sediment yield in watershed. The actual survey is fulfilled with the aim of developing a trustworthy hydrologic model simulating stream flow discharge and sediment concentration with least uncertainty among the parameters picked out for calibration so as to verify the effect of the scenarios on the spatial distribution of sediment yield (sediments transported from sub-basins to the main channel during the step of time). Soil and Water Assessment Tool (SWAT, version 2012) model integrated with Geographic Information System (GIS, version 10.1) was used to simulate the stream flow and sediment concentration of Kalaya catchment situated in north of Morocco for the period from 1971 to 1993. Model calibration and validation were performed for monthly time periods using Sequential Uncertainty Fitting 2 (SUFI-2, version 2) within SWAT-CUP using 16 parameters. Our calibration outputs for monthly simulation for the period from 1976 to 1984 showed a good model performance for flow rates with NSE and PBIAS values of 0.76 and −11.80, respectively; also a good model performance for sediment concentration with NSE and PBIAS values of 0.69 and 7.12, respectively. Nonetheless, during validation period (1985–1993) for monthly time step, the NSE and PBIAS values were 0.67 and −14.44, respectively for flow rates and these statistical values were 0.70 and 15.51, respectively for sediment concentration; which also means a good model performance for both. Following calibration, the inclusive effect of each parameter used was ranked using global sensitivity function in SWAT-CUP. From our analysis, the effective hydraulic conductivity in main channel alluvium (CH_K2), USLE support practice factor (USLE_P) and manning's "n" value for the main channel (CH_N2) were found to be the most sensitive parameters during different iterations with different number of simulation but with the same inputs. The least sensitive parameter were found to be different in either cases unlike the most sensitive parameters. As a result, the global evaluated soil erosion rate in the study area varied from 20 to 120 t/ha/yr. It was summarized that the entire knowledge of the hydrologic processes happens within the watershed and the consciousness about acceptable meaningful range of the parameters is crucial while developing reliable hydrologic model.

1. Introduction

Of all the gifts of nature, none is more essential to man than soil (Singh & Saika, 1990; Singh, 2002). The soils play a major role in the provision of services and goods provided by ecosystems to humans. Located at the interface between the atmosphere, lithosphere, hydrosphere and biosphere, they participate in great cycles necessary for life on Earth: the water cycle and major nutrients (carbon, nitrogen, phosphorus…). They support most agricultural, forestry and pastoral production systems and contribute to climate regulation (controlling emissions of greenhouse gases and carbon sequestration). Meanwhile, they have always faced the problem of erosion which is a process of the surface soil alteration and relief

* Corresponding author at: Department of Earth Sciences, Faculty of Sciences and Techniques (FST), Abdelmalek Essaadi University, Postal Box 416, 90000 Tangier, Morocco.
E-mail address: hamza.briak@gmail.com (H. Briak).

Peer review under responsibility of International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

http://dx.doi.org/10.1016/j.iswcr.2016.08.002
2095-6339/

modifications successively involving the detachment of soil particles, their transportation by the action of various agents (water, wind, work tools ground, gravity, glaciers…) and then, their deposition at a distance varying from less than a meter to several thousand kilometers. Critical environmental, ecological and economic troubles worldwide can be caused by soil erosion (Pimentel et al., 1995; Portenga & Bierman, 2011; Wu & Chen, 2012; Yang, Kanae, Oki, Koike, & Musiake, 2003) and has become a challenging issue, menacing chiefly the Mediterranean territories (Grimm, Jones, & Montanarella, 2002; Yaalon, 1997) especially in north of Morocco (Briak, Moussadek, Derradji, Aboumaria, & Mrabet, 2016; Raclot, Inoubli, Moussa, Habaieb and Bissonnais, 2015). In fact, Mediterranean climate is identified by seasonal contrast, where the soil erodibility can be affected by the dry and warm summer climate (Le Bissonnais et al., 2007), and where the soil erosion can be affected by the concentration of precipitation events, particularly in the fall (Ramos & Martínez-Casasnovas, 2009). This event may lead to serious degradation of the hill slopes with further negative damage on natural resources (Cerdà & Robichaud, 2009; Smith, Sheridan, Lane, Nyman, & Haydon, 2011; Stoof et al., 2015). Yet, both climate changes and also human interventions are responsible for the dramatic reductions in runoff and sediment load (Gao, Mu, Wang, & Li, 2011; Zuo et al., 2016).

To predict reliable quantity and rate of sediment transport from land surface into streams, rivers and water bodies, to identify erosion problem areas within a watershed and to propose the best management practices to reduce erosion impact, models are used (Yesuf, Assen, Alamirew, & Melesse, 2015). In this paper, Soil Water Assessment Tool model (SWAT; Arnold, Srinivasan, Muttiah, & Williams, 1998) has been applied to simulate the performance of a small-scale in the Kalaya river catchment in north of Morocco. The agro-hydrological model SWAT was used because it is a continuous-time, daily-based and semi-distributed watershed simulation model developed to predict hydrological and water quality processes (Arnold, Allen, & Bernhardt, 1993; Yen et al., 2014) and to seek good planning strategies, which strongly depend on integrated basin models (Collins & McGonigle, 2008; de Vente et al., 2013; Rickson, 2014). The definition and the quantification of uncertainty calibration in distributed hydrological modeling have become the subject of much research in recent years (Abbaspour, 2005). Multi-variable and multi-site approaches to calibrate and validate SWAT have been used through trial-and-error processes. Not only internal hydrological processes in the model have been evaluated, but also a number of subcatchments have been used in this calibration (Cao, Bowden, Davie, & Fenemor, 2006). Several worldwide studies have been done using the SWAT model, for example in America (Arnold et al., 2012; Havrylenko, Bodoque, Srinivasan, Zucarelli, & Mercuri, 2016; Jha & Gassman, 2014; Mbonimpa, Yuan, Mehaffey, & Jackson, 2012… etc.), but only a few studies have been realized by this model in Morocco (Fadil, Rhinane, Kaoukaya, Kharchaf, & Alami Bachir, 2011; Kharchaf, Rhinane, Kaoukaya, & Fadil, 2013). In this context, the interest of this approach lies in having a good spatialized hydrological stock of the basin which could be extended to similar watersheds where there is a lack of data in north of Morocco, knowing that it has never been sampled owing to the shortage of the stations scale in the studied area.

2. Methods and materials

2.1. Study area

The research area is the 3838 ha Kalaya catchment in north of Morocco (Fig. 1) located in the southern part of Tangier city. The study area has a Mediterranean climate sub-humid to wet, characterized by wet winters and dry summers. The annual average precipitation is 667 mm, while the annual average temperature is about 18 °C (Briak et al., 2016). The hydrological monitoring is ensured by the hydrometric station located at the outfall Kalaya (reservoir). The representation of relief chosen for this study is the ASTER - GDEM satellite with a spatial resolution of 30 m. Use of this resolution in watershed modeling is widely demonstrated (Hirt, Filmer, & Featherstone, 2010). Surroundings for the most part formed of little rough hills with comparatively low height.

2.2. SWAT model

Widely used over the world, Soil and Water Assessment Tool (SWAT) is a hydrological model to assess sediment, impact of land use, in-stream water quality, climate change and, water quality and quantity variation. SWAT can determine as well as river basin-scale, continuous-time model that operates on a daily or sub-daily time step, computationally efficient, and able to estimate long-term yields in large watersheds. The model is physically-based and uses readily available temporal and spatial data. It simulates water flows in soil and groundwater, crop growth, nutrient cycling, erosion, pesticides, bacteria, sediments, nutrients, and environmental impact of climate change (Arnold et al., 1998). The impact of climate change or land management practices on sediment transport and surface hydrological response over long periods of time for large complex watersheds that have differed soils, land use and management practices is anticipated by this model (Neitsch, Arnold, Kiniry, Williams, & King, 2005). Associated by a stream network, in the swat model the basin is subdivided into multiple sub-basins, each sub-basin is divided into hydrological response units (HRUs) that consist of unique combinations of homogenous soil and land use properties in each sub-basin (Arnold et al., 2012). The hydrological cycle is simulated by SWAT model according to the equation below of water balance (Neitsch et al., 2005):

$$SW_t = SW_0 + \sum_{n=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \quad (1)$$

where SW_t is the soil water content (mm), SW_0 is the water available to plants (mm), R_{day} is the precipitation (mm), Q_{surf} is the surface runoff (mm), E_a is the evapotranspiration (mm), W_{seep} is the percolation (mm), Q_{gw} is the low flow (mm) and t is the time (days).

2.3. SWAT-CUP model

The SWAT-CUP tool (SWAT Calibration and Uncertainty Procedures) is a program that interfaces with ArcSWAT, to perform calibration, validation and sensitivity analysis of the SWAT model. It was designed to bring more flexibility and performance as to the calibration of SWAT model to face out the limits of ArcSWAT calibration functions in the ArcGIS environment. Thus, the advantage of the application is its ability to give a large choice of functions and wider and generous interfaces for parameterization, calibration and validation of the model. The execution of the SWAT-CUP model involves the use of output files generated by SWAT model in ArcSWAT (Abbaspour, 2011). Five different algorithms procedures are associated to SWAT such as Generalized Likelihood Uncertainty Estimation "GLUE" (Beven & Binley, 1992), Particle Swarm Optimization "PSO" (Eberhart & Kennedy, 1995), Parameter Solution "ParaSol" (Alamirew, 2006), Mark chain Monte Carlo "MCMC" (Kassa & Foerch, 2007) and Sequential Uncertainty Fitting "SUFI-2" (Abbaspour et al., 2007; Abbaspour, Johnson, & van Genuchten, 2004). The SUFI-2 strategy is applied in this research since it can supply the widest marginal parameter uncertainty intervals of model parameters among the five approaches. The goodness of fit

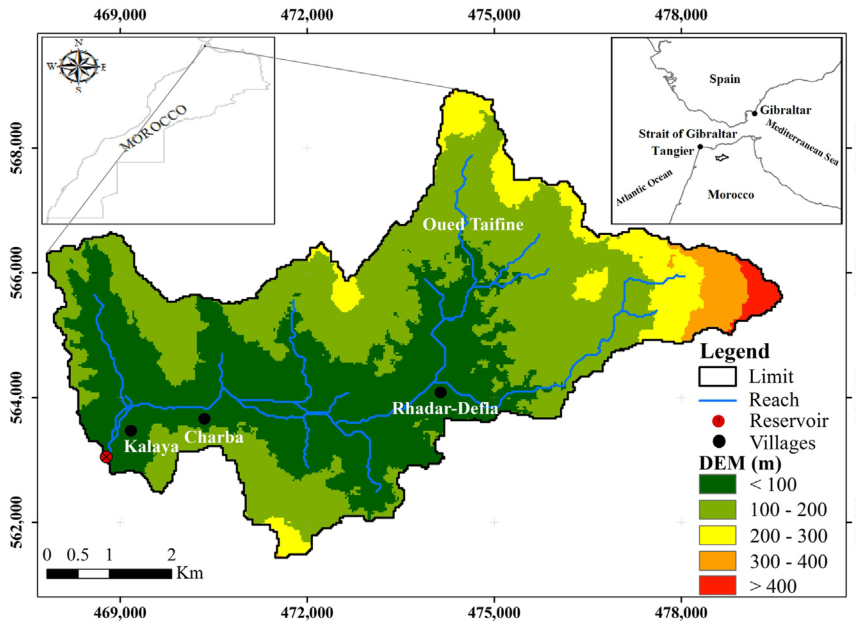

Fig. 1. Digital elevation model (DEM) of the zone studied (Kalaya catchment).

in SUFI-2 is quantified by the coefficient of linear correlation (R^2), the coefficient of Nash-Sutcliffe efficiency (NSE) and the coefficient of Percent bias (PBIAS) between the observed data and the best simulation. The formulas of these coefficients are given in the following equations:

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n} (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n} (Y_i^{obs} - Y^{mean})^2} \quad (2)$$

$$\text{PBIAS} = \frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i=1}^{n} (Y_i^{obs})} \quad (3)$$

NSE is a normalized dimensionless statistic that implement the comparative size of the residual distinction compared to the measured data variance (Nash & Sutcliffe, 1970). It show how well the plot of observed versus simulated data fits the 1:1 line. *PBIAS* measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta, Sorooshian, & Yapo, 1999). It is the perversion of information being evaluated, expressed as a percentage. In addition, Yi^{obs} is the *i*th observation for the constituent being evaluated, Yi^{sim} is the *i*th simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and *n* is the total number of observations.

2.4. Input data

The preparation of input data will be implemented in a tool GIS "version 10.1" and SWAT "version 2012" has an expansion on ArcMap "ArcSWAT2012" which simplifies the usage of prepared data. The following basic data were selected as SWAT model

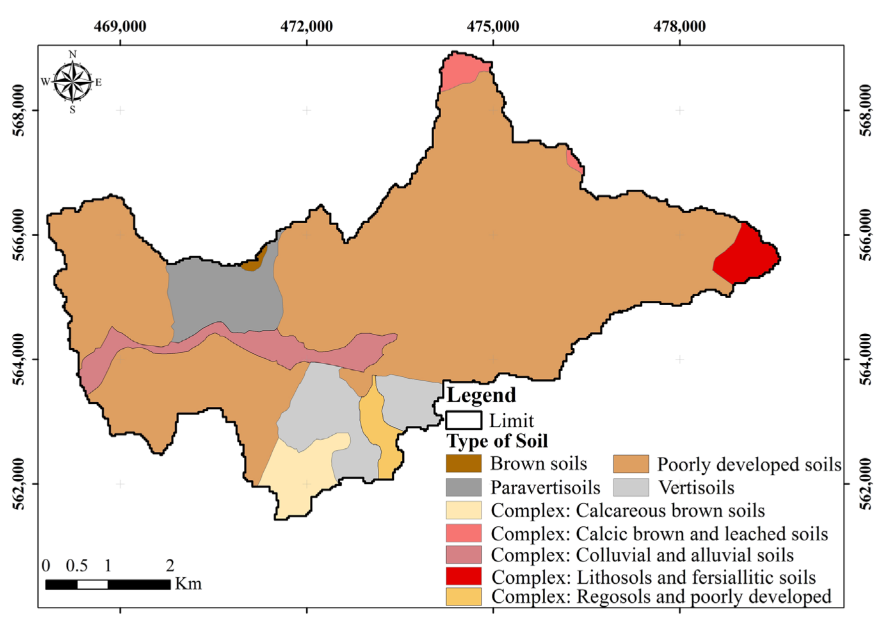

Fig. 2. Soil map of the Kalaya basin.

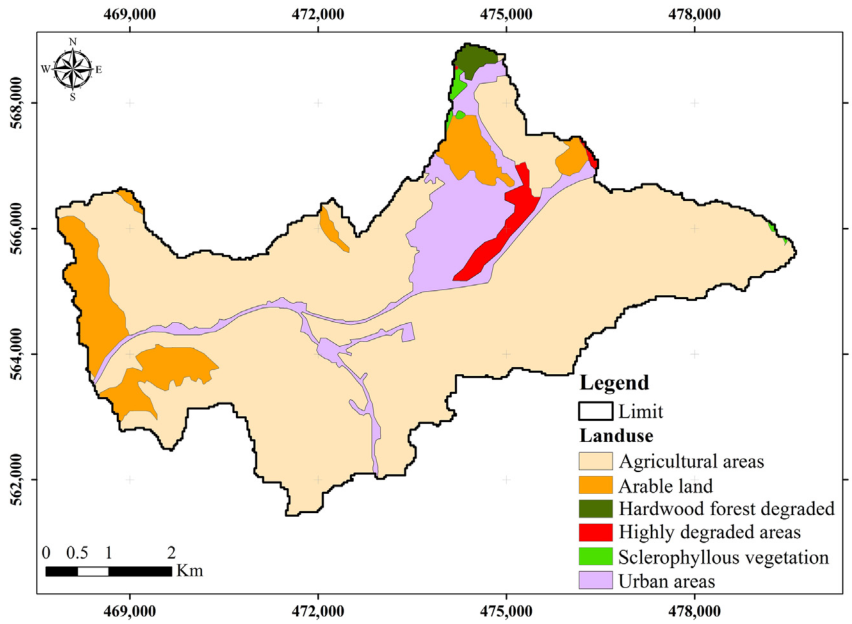

Fig. 3. Land use map of the Kalaya basin.

inputs:

(A) **DEM:** it describes the topography and the geometry of the basin and sub-basins; it is extracted from the ASTER - GDEM satellite with a spatial resolution of 30 m (Fig. 1).
(B) **Climate:** 23 years (1/1/1971–12/31/1993) of daily weather gauge and river discharge data. The first 5 years (1971–1975) for initialization of the model (warm-up of the model run), 9 years (1976–1984) for calibration and 9 years (1985–1993) for validation. These hydrological and meteorological data are collected from the Moroccan General Hydraulic Direction.
(C) **Soil map:** it determines the different types of soil in the study area; it is associated with all the information describing the physical and chemical properties of the soil. This map is obtained from the National Institute for Agronomic Research (Fig. 2).
(D) **Land use map:** it defines the standing sorts of land use in the basin; almost all the surface of Kalaya basin is covered by the agricultural areas, this result from the very pronounced human activity in the zone. This map is obtained from the High Commission for Water, Forests and Desertification Control (Fig. 3).
(E) **Slope map:** it is deducted from DEM, explains that the Kalaya watershed consists essentially of the plains, and the majority of this basin has low slopes (Fig. 4).

2.5. Delineation basin and HRU definition

The map of the spatial distribution of the generated sub-basins is showed by the Fig. 5. 27 sub-basins have been generated by the discretization of watershed Kalaya, defined primarily by reference to the confluence of the drainage system and hydrometric station. This segmentation will permit to simulate the main operations in

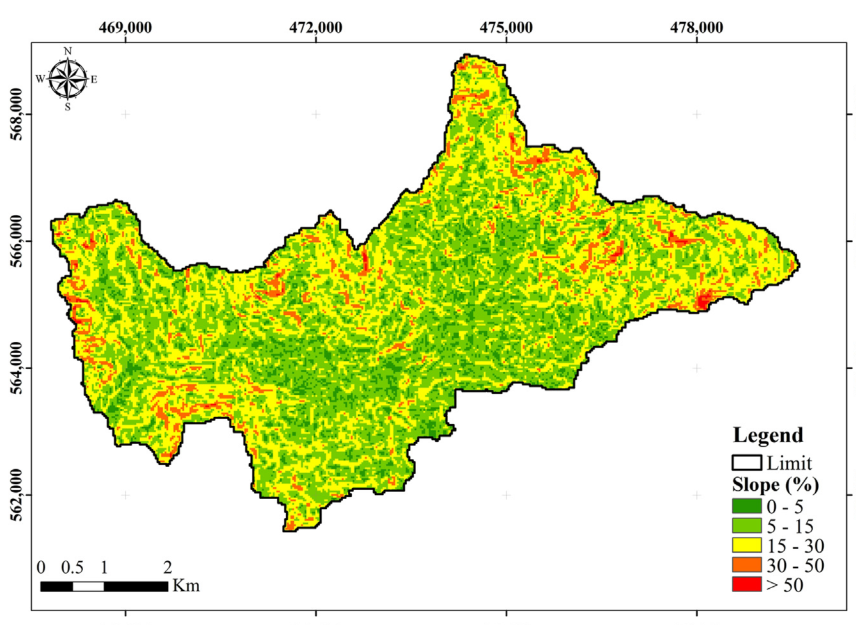

Fig. 4. Slope map of the Kalaya basin.

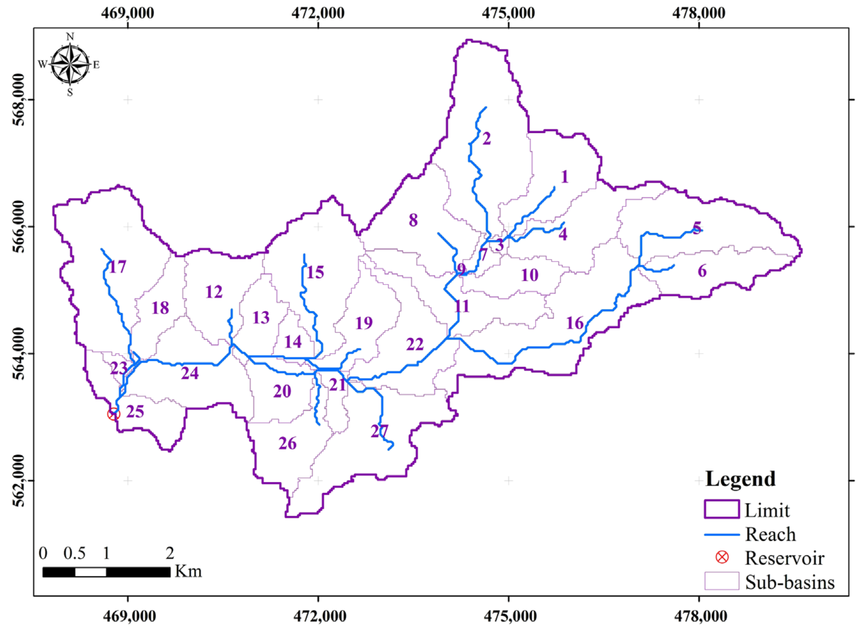

Fig. 5. Delineation of sub-basins of the Kalaya basin.

these basins and to estimate the contribution of each of these entities. On the other hand, analysis the watershed is allowed by SWAT as a whole or by subdividing it into sub-basins containing the same portions called Hydrological Response Units (HRU) where the dominant land use, soil and slope within the basin are regarded to be the land use, soil and slope of each sub-basin (Arnold et al., 2011). All processes modeled by SWAT are simulated at the locative measure of these units. A better estimation of stream flow and sediment concentration is given by the multiple scenarios that account for 10% land use, 10% soil and 10% slope threshold combination. The Kalaya river basin results in 161 HRUs in the whole basin. This scenario results in the detailed land use, soil and slope database, containing many HRUs, which in turn represent the heterogeneity of the study area. However, the features of HRUs are the key factors impacting the stream flow and sediment concentration.

3. Results and discussion

In this research, the relative sensitivity values have been evaluated and found in the parameter estimation process. Sixteen parameters are found to be sensitive with the relative sensitivity values such as runoff curve number (*CN2*), USLE support practice factor (*USLE_P*), Plant uptake compensation factor (*EPCO*), soil evaporation compensation factor (*ESCO*), Average slope length (*SLSUBBSN*), available water capacity of the soil layer (*SOL_AWC*), moist bulk density (*SOL_BD*), saturated hydraulic conductivity (*SOL_K*), erosion (*USLE_K*), Peak rate adjustment factor for sediment routing in the sub-basin (tributary channels) (*ADJ_PKR*), Linear parameter for calculating the maximum amount of sediment that can be retrained during channel sediment routing (*SPCON*), Exponent parameter for calculating sediment retrained in channel sediment routing (*SPEXP*), Surface runoff lag time (*SURLAG*), effective hydraulic conductivity in main channel alluvium (*CH_K2*), Manning's "n" value for the main channel (*CH_N2*) and groundwater "revap" coefficient (*GW_REVAP*). The global effect of each used parameter was classified using total sensitivity function in SWAT-CUP. The capability of a hydrological model to adequately simulate stream flow and sediment concentration typically counts on the precise calibration of parameters (Xu, Pang, Liu, & Li, 2009). In fact, model calibration and validation are indispensable for simulation process, which are used to estimate model expectation results. Calibration of flow and sediment concentration was performed in the same time period with 7 iterations and each iteration has many simulations. The model has calibration period (1976–1984) and validation period (1985–1993). A simulation is considered adequate if NSE >0.5 and PBIAS $< \pm 25\%$. The details, model evaluation and discussions are given as follows.

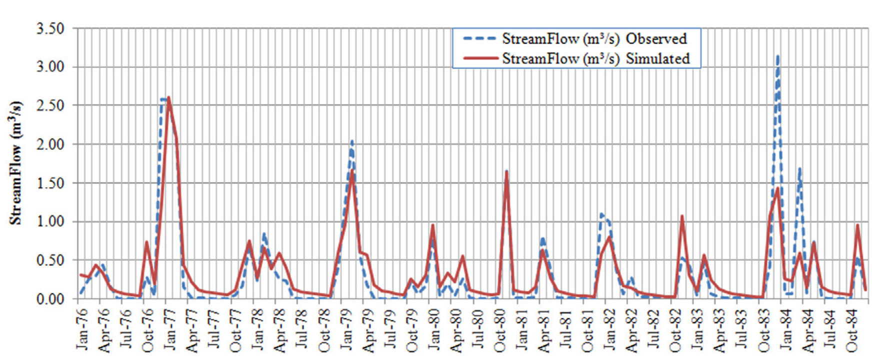

Fig. 6. Observed and simulated monthly stream flow for model calibration (1976–1984).

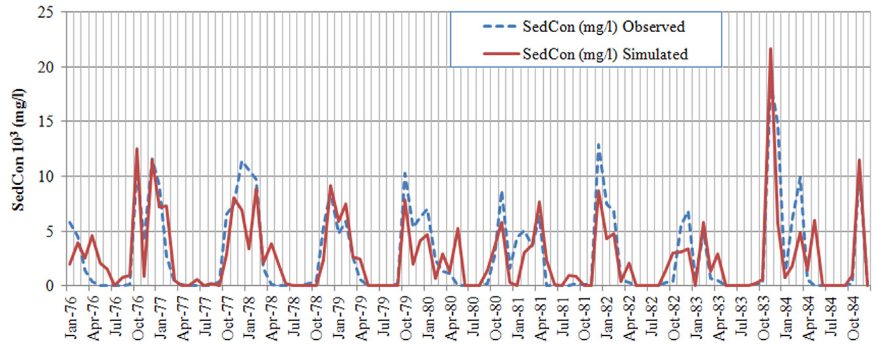

Fig. 7. Observed and simulated monthly sediment concentration for model calibration (1976–1984).

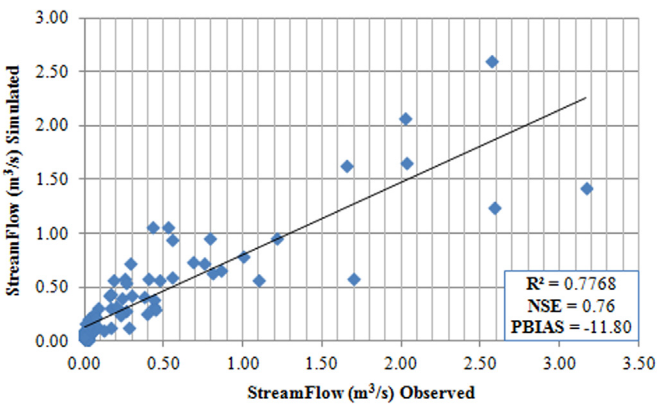

Fig. 8. Scatter plot of monthly stream flow for calibration period (1976–1984).

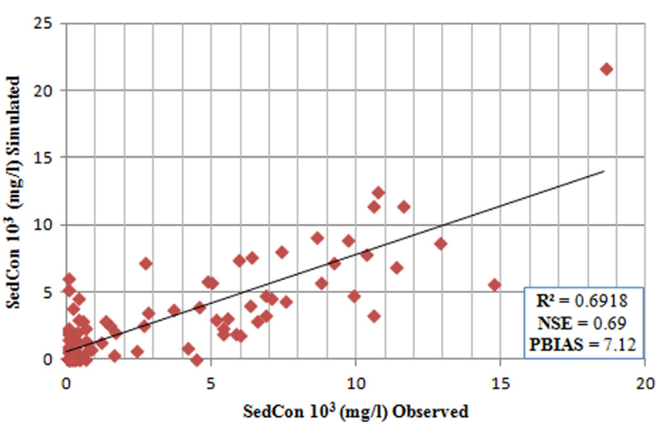

Fig. 9. Scatter plot of monthly sediment concentration for calibration period (1976–1984).

3.1. Model calibration

The calibration of a conceptual model consists of setting the model input variables to make correspond maximally the response of the model to measured observations representing the reality on the ground deliberate with the purpose of defining the values or desirable ranges of the model parameters that depend broadly on the nature and specific properties of the study area. In fact, calibration of SWAT model in the Kalaya basin through the SUFI-2 method was performed over a period of 9 years by comparing the flow rates and sediment concentration of measured at flow rates and sediment concentration simulated in hydrometric station considered (Figs. 6 and 7). These figures show that the variation of flow and sediment concentration in the station is simulated successfully by the model; it represents the monthly peaks marking these two states. According to the performance assessment criteria of the model recommended for a monthly time step (Moriasi et al., 2007), the calibration allowed us to get a good model performance for flow rates with a coefficient of NSE of the order of 0.76 and PBIAS of the order of −11.80, and also a good model performance for sediment concentration which NSE of the order of 0.69 and PBIAS of the order of 7.12 (Figs. 8 and 9). This decreases the doubts associated with this calibration and what's more, it provides a better estimate of the studied process.

3.2. Model validation

A model is valid when he allows reproducing the observations in a proper and satisfactory manner. Any calibration procedure of a model should be put necessarily to the control for testing its reliability and performance. Validation of SWAT model was performed over other period of calibration (9 years) by comparing the flow rates and sediment concentration of measured at flow rates and sediment concentration simulated in hydrometric station considered (Figs. 10 and 11). According to the performance assessment criteria of the model recommended for a monthly time

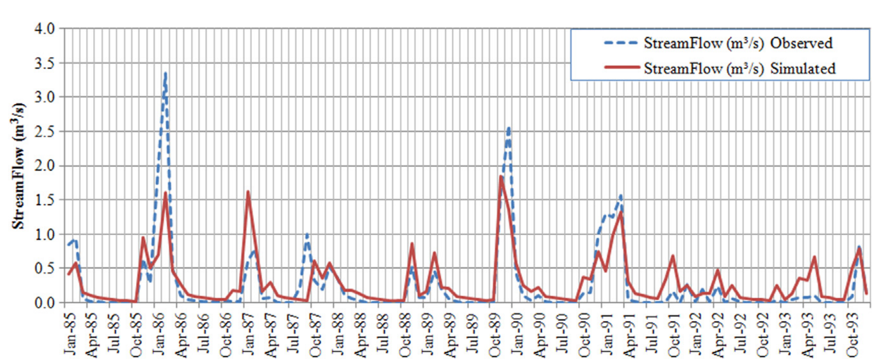

Fig. 10. Observed and simulated monthly stream flow for model validation (1985–1993).

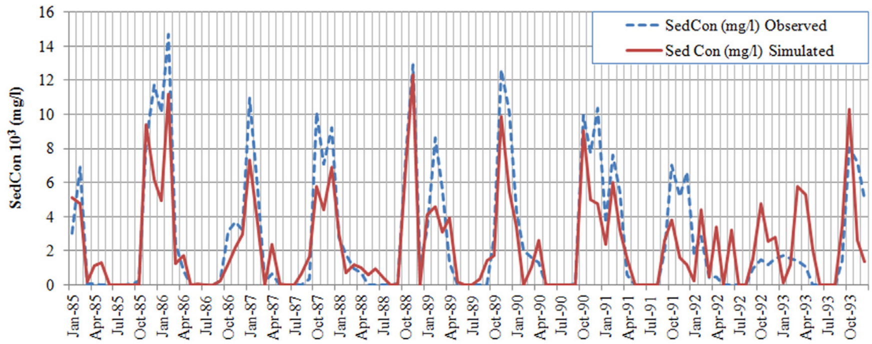

Fig. 11. Observed and simulated monthly sediment concentration for model validation (1985–1993).

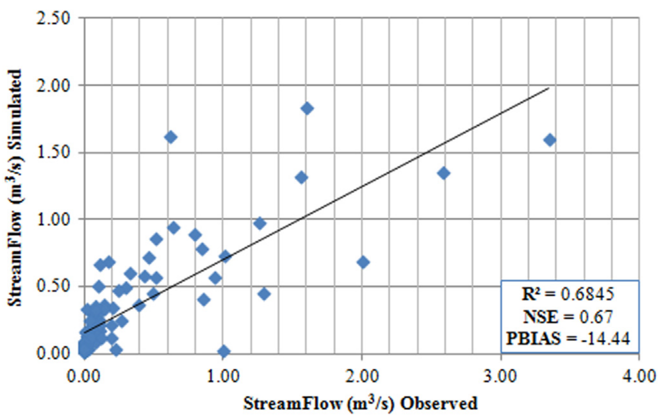

Fig. 12. Scatter plot of monthly stream flow for validation period (1985–1993).

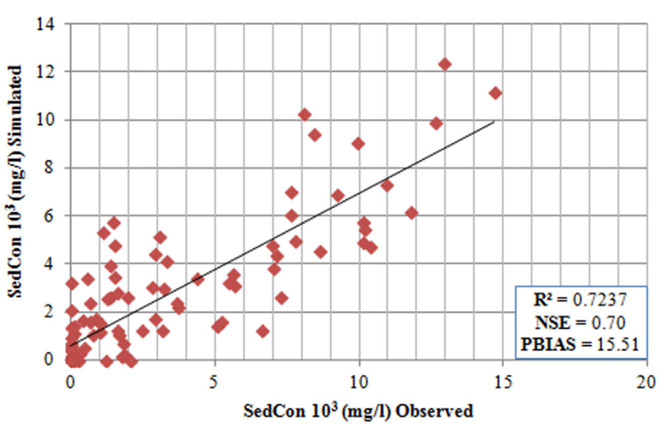

Fig. 13. Scatter plot of monthly sediment concentration for validation period (1985–1993).

step (Moriasi et al., 2007), the validation allowed us to obtain a good model performance for flow rates with a coefficient of NSE of the order of 0.67 and PBIAS of the order of −14.44, and also a good model performance for sediment concentration which NSE of the order of 0.70 and PBIAS of the order of 15.51 (Figs. 12 and 13). The good agreement between simulations and observations through the validation phase also shows the good performance of the model calibration and ability to represent various climatic situations.

3.3. Uncertainty analysis

The optimum values found by the SUFFI method for the calibrated parameters are shown in Table 1:

In the sensitivity analysis, 16 parameters related to stream flow and sediment concentration were initially selected. After the first

Table 1
Sensitive parameters, fitted values and P values after calibration using SUFI-2.

Parameter Names	Rank	Fitted_Value	Min_Value	Max_Value	P_Value
R__CN2.mgt	1	0.004	−0.063	0.234	0.87
R__SLSUBBSN.hru	2	0.110	0.078	0.194	0.35
R__SOL_AWC().sol	3	−0.005	−0.014	0.100	0.22
R__SOL_BD().sol	4	0.116	−0.760	0.139	0.97
R__SOL_K().sol	5	−0.120	−0.150	−0.015	0.35
R__USLE_K().sol	6	0.608	0.178	0.699	0.42
V__ADJ_PKR.bsn	7	0.647	0.537	1.167	0.36
V__CH_K2.rte	8	17.961	−0.010	239.609	0.01
V__CH_N2.rte	9	0.051	0.027	0.091	0.12
V__EPCO.hru	10	0.205	0.193	0.641	0.78
V__ESCO.hru	11	0.869	0.652	1.000	0.70
V__GW_REVAP.gw	12	0.133	0.052	0.171	0.90
V__SPCON.bsn	13	0.007	0.005	0.011	0.91
V__SPEXP.bsn	14	1.001	0.753	1.151	0.40
V__SURLAG.bsn	15	4.786	1.813	6.218	0.19
V__USLE_P.mgt	16	0.356	0.130	0.562	0.02

V: means the existing parameter value is to be replaced by a given value;
R: means an existing parameter value is multiplied by (1+ a given value).

iteration, 5 parameters which are CH_K2, USLE_P, CH_N2, SURLAG and SOL_AWC have been revealed most sensitive parameters for modeling of Kalaya basin. A P-stat value is used to identify the relative significance among these 5 parameters. A value close to zero has more significance. Defining the optimal values of model variables automatically is time consuming but it was assured more functional and reliable than the procedure which is done with one's hand (Fadil et al., 2011). The sensitivity analysis of the model to sub-basin delineation and HRU definition thresholds show that the flow is more sensitive to the HRU definition thresholds than sub-basin discretization effect. The results in this basin are 161 HRUs in the whole basin. The good simulation results of monthly time steps are produced by the SWAT model, which are useful for the water resources management in the Kalaya basin.

3.4. Sediment yield

The erosion is simulated by SWAT in the watershed using MUSLE that combines a variety of factors: runoff, soil type, land use, topography and land management practices. An estimate of soil particles can be provided by this equation may be torn away and delivered to streams, and spatialize the most erosion-sensitive zones (Kharchaf et al., 2013). In addition, the amount of sediment eroded and conveyed to the hydrographic network at each spatial unit can be estimated by the SWAT model (Neitsch et al., 2005). The quantity of sediment supplied by the various units space of watershed Kalaya varies between 20 and 120 t/ha/yr, with an average rate of around 55 t/ha/yr (Fig. 14). These values that have been estimated by the SWAT model are identical with those of previous studies that have been done also for analyzing the

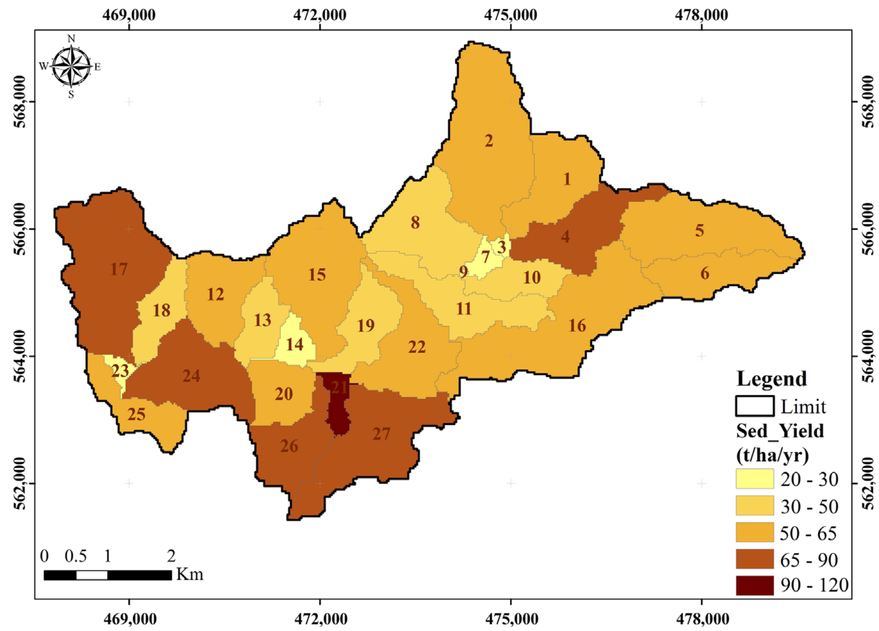

Fig. 14. Sediment Yield of the Kalaya basin.

problems of erosion and identify areas for large risk of erosion in northern Morocco (Benmansour et al., 2002; Benmansour et al., 2014; Damnati et al., 2004; El Garouani et al., 2008; Merzouk & Dahman, 1998; Zouagui et al., 2012). This delivery allowed us to identify parts where soil losses are very high. The highest sedimentation rates (particularly at sub-basins 4, 17, 21, 24, 26 and 27) are located in agricultural and arable lands on steep slopes. This is probably due to the influence of tillage practices on soil loss because they increase soil erosion rate and sediment losses (Moussadek et al., 2011; Mrabet, 2008). Generally, the sediment rates are very high in almost all the distributions; this indicates that the watershed Kalaya has different areas where soil erosion is so substantial (Briak et al., 2016).

4. Conclusion

The model used was successfully calibrated and validated on watershed Kalaya with a spatial approach and it has generated a set of results on the hydrological functioning of the basin and its spatial units, also the processes of production and transfer of sediments within the study area. During the calibration period, the monthly results of NSE and PBIAS are respectively 0.76 and −11.80 for flow rates, also 0.69 and 7.12 for sediment concentrations. On the other hand and during the validation period, the results of NSE and PBIAS are 0.67 and −14.44 for flow rates, also 0.70 and 15.51 for sediment concentrations. The total estimated soil erosion rate in the study area differed from 20 to 120 t/ha/yr. This work has helped to highlight the contribution of the spatial approach to modeling the watershed by building on the advantages offered by new technologies in spatial reference for the supply of models in entry of data (Remote Sensing Space Systems) and for the treatment and the crossing of the different layers of information (GIS Techniques). Furthermore, the calibrated model can be well used in Kalaya watershed to assess and treat other watershed components such as the analysis of the impacts of land use and climate changes on the water resources as well as the water quality and the sediment yield. Thereafter, the modeling conducted with the SWAT model allowed to determine precisely the evolution of some parameters for planning of dam construction in the future and flood disaster risk management, which will contribute to the water resources management in the Kalaya river basin, and thereby is advantageous for the sustainable development of the country.

References

Abbaspour, K. C. (2011). *User manual for SWAT-CUP, SWAT calibration and uncertainty analysis programs* (p. 103) Duebendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology, Eawag.

Abbaspour, K. C., Johnson, C. A., & van Genuchten, M. T. (2004). Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure. *Vadose Zone Journal*, *3*(4), 1340–1352.

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., et al. (2007). Spatially distributed modelling of hydrology and water quality in the Pre-Alpine/Alpine Thur watershed using SWAT. *Journal of Hydrology*, *333*, 413–430.

Abbaspour, K. C. (2005). Calibration of hydrologic models: When is a model calibrated? In Zerger, A., Argent, R. M. (Eds.), *Modeling and simulation society of Australia and new Zealand* (pp. 2449–12455). Melbourne, Australia.

Alamirew, C. D. (2006). *Modeling of hydrology and soil erosion in Upper Awash river basin* (p. 235) University of Bonn, Institut für Städtebau, Bodenordnung und Kulturtechnik.

Arnold, J. G., Allen, P. M., & Bernhardt, G. (1993). A comprehensive surface-ground water flow model. *Journal of Hydrology*, *142*, 47–69.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large-area hydrologic modeling and assessment: [part I] model development. *Journal of American Water Resources Association*, *34*, 73–89.

Arnold, J. G., Kiniry, J. R., Srinivasan, R., Williams, J. R., Haney, E. B., & Neitsch, S. L. (2011). *SWAT input/output file documentation, version 2009*. Temple, Texas, USA: Grassland Soil and Water Research Laboratory.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., … Jha, M. K. (2012). SWAT: model use, calibration, and validation. *Transactions of the ASABE*, *55*, 1491–1508.

Benmansour, M., Amenzou, N., Zouagui, A., Marah, H., Sabir, M., Nouira, A., … Taous, F. (2014). Assessment of soil erosion and sedimentation rates in My Bouchta watershed in north Morocco using fallout radionuclides and stable isotopes In: L. K. Heng, K. Sakadevan, G. Dercon, & M. L. Nguyen (Eds.), *Managing soils for food security and climate change adaptation and Mitigation* (pp. 113–118). Rome: FAO.

Benmansour, M., Ibn Majah, M., Marah, H., Marfak, T., Walling, D.E. (2002). Use of the 137Cs technique in soil erosion in Morocco – case study of the Zitouna basin in the north. In *International Symposium on Nuclear Techniques in Integrated Plant Nutrients, Water and Soil Management. IAEA Publication* (pp. 308e315). IAEA e CSP-11/C.

Beven, K., & Binley, A. (1992). The Future of Distributed Models – Model Calibration & Uncertainty Prediction. *Hydrological Processes*, *6*(3), 279–298.

Briak, H., Moussadek, R., Derradji, A., Aboumaria, K., & Mrabet, R. (2016). Effect of vegetation types on highway erosion in Kalaya basin (North Morocco). *Journal of Materials and Environmental Science*, *7*(2), 605–612.

Cao, W., Bowden, W. B., Davie, T., & Fenemor, A. (2006). Multi-variable and multi-site calibration and validation of SWAT in a large mountainous catchment with high spatial variability. *Hydrological Processes*, *20*, 1057–1073.

Cerdà, A., & Robichaud, P. (2009). *Fire effects on soils and restoration strategies. Land reconstruction and management series*. 5. Enfield, NH, USA: Science Publishers.

Collins, A. L., & McGonigle, D. F. (2008). Monitoring and modelling diffuse pollution from agriculture for policy support: UK and European experience. *Environmental Science and Policy*, *11*, 97–101.

Damnati, B., Ibrahimi, S., & Radakovitch, O. (2004). Utilisation du 137Cs pour l'estimation des taux d'érosion dans un bassin versant du nord du Maroc. *Sécheresse*, *15*(2), 195–199.

Eberhart R.C., Kennedy J. (1995). A new optimizer using particle swarm theory. In *Proceedings of the sixth international symposium on micro machine and human science*, IEEE service center (pp. 39–43), Piscataway, NJ, Nagoya, Japan.

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 satellitaires et du SIG Idrisi au Nord-Est du Maroc. *Teledetection, Editions Scientifiques GB*, *8*(3), 193–201.

Fadil, A., Rhinane, H., Kaoukaya, A., Kharchaf, Y., & Alami Bachir, O. (2011). Hydrologic modeling of the bouregreg watershed (Morocco) using GIS and SWAT model. *Journal of Geographic Information System*, *3*, 279–289.

Gao, P., Mu, X. M., Wang, F., & Li, R. (2011). Changes in streamflow and sediment discharge and the response to human activities in the middle reaches of the Yellow River. *Hydrology Earth System Sciences*, *15*(1), 1–10.

Grimm, M., Jones, R., & Montanarella, L. (2002). *Soil erosion risk in Europe*. Luxembourg: Office for Official Publications of the European Communities.

Gupta, H. V., Sorooshian, S., & Yapo, P. O. (1999). Status of automatic calibration for hydrologic models: comparison withmultilevel expert calibration. *Journal of Hydrology Engineering*, *4*(2), 135–143.

Havrylenko, S. B., Bodoque, J. M., Srinivasan, R., Zucarelli, G. V., & Mercuri, P. (2016). Assessment of the soil water content in the Pampas region using SWAT. *Catena*, *137*, 298–309.

Hirt, C., Filmer, M. S., & Featherstone, W. E. (2010). Comparison and validation of the recent freely available ASTER-GDEM ver1, SRTM ver4.1 and GEODATA DEM-9S ver3 digital elevation models over Australia. *Australian Journal of Earth Sciences*, *57*(3), 337–347.

Jha, M. K., & Gassman, P. W. (2014). Changes in hydrology and streamflow as predicted by a modelling experiment forced with climate models. *Hydrological Processes*, *28*(5), 2772–2781.

Kassa, T., & Foerch, G. (2007). Impacts of land use/cover dynamics on streamflow: The case of hare watershed, Ethiopia. In *Proceedings of the 4th International SWAT2005 Conference*.

Kharchaf, Y., Rhinane, H., Kaoukaya, A., & Fadil, A. (2013). The contribution of the geospatial information to the hydrological modeling of a watershed with reservoirs: Case of Low Oum Er Rbiaa Basin (Morocco). *Journal of Geographic Information System*, *5*, 258–268.

Le Bissonnais, Y., Blavet, D., Noni, G., Laurent, J., Asseline, J., & Chenu, C. (2007). Erodibility of mediterranean vineyard soils: relevant aggregate stability methods and significant soil variables. *European Journal of Soil Science*, *58*, 188–195.

Mbonimpa, E. G., Yuan, Y., Mehaffey, M. H., & Jackson, M. A. (2012). SWAT model application to assess the impact of intensive corn-farming on runoff, sediments and phosphorous loss from an agricultural watershed in Wisconsin. *Journal of Water Resource and Protection*, *4*, 423–431.

Merzouk, A., & Dahman, H. (1998). Shifting land use and its implication on sediment yields in the Rif Mountains (Morocco). *Advanced in Geoecology*, *31*, 333–340.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & et Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, *50*(3), 885–900.

Moussadek, R., Mrabet, R., Dahan, R., Douaik, A., Verdoodt, A., Van Ranst, E., & Corbeels, M. (2011). Effect of tillage practices on the soil carbon dioxide flux during fall and spring seasons in a Mediterranean Vertisol. *Journal of Soil Science and Environmental Management*, *Vol. 2*(11), 362–369.

Mrabet, R. (2008). No-tillage systems for sustainable dry land agriculture in Morocco In: Fanigraph (Ed.), Rabat, Maroc: INRA Publication.

Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models, part I: A discussion of principles. *Journal of Hydrology*, *10*(3), 282–290.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2005). *Soil and water assessment tool theoretical documentation—version 2005. Soil and water research laboratory, agricultural research service*. Temple: US Department of Agriculture.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., et al. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science*, *267*, 1117–1123.

Portenga, E. W., & Bierman, P. R. (2011). Understanding earth's eroding surface with 10Be. *GSA Today*, *21*, 4–10.

Raclot, D., Inoubli, N., Moussa, R., Habaieb, H., Bissonnais, Y. L. (2015). Soil cracking effects on hydrological and erosive processes in Mediterranean cultivated vertisols. In *Proceedings of the 1St International Conference Afro-Mediterranean Soils: Constrains and Potentialities for Durable Management.* At Marrakech (Morocco).

Ramos, M. C., & Martínez-Casasnovas, J. A. (2009). Impacts of annual precipitation extremes on soil and nutrient losses in vineyards of NE Spain. *Hydrological Processes*, *23*, 224–235.

Rickson, R. J. (2014). Can control of soil erosion mitigate water pollution by sediments? *Science Total environment*, *468–469*, 1187–1197.

Singh, B., & Saika, B.P. (1990). Water table control through pipe drains in tea soils, in: *Tea Research Global Perspective*, (Proc Int Conf Res Dev Tea), 74.

Singh, R.K. (2002). Soil conservation measures in agricultural land. In *Integrated Watershed Management for Sustainable Development*, (ICAR Research complex for NEH region, Umiam, Meghalaya), 104.

Smith, H. G., Sheridan, G. J., Lane, P. N. J., Nyman, P., & Haydon, S. (2011). Wildfire effects on water quality in forest catchments: a review with implications for water supply. *Journal of Hydrology*, *396*(1–2), 170–192.

Stoof, C. R., Ferreira, A. J. D., Wouter Mol, den Berg, J. V., Kort, A. D., Drooger, S., Erik, C. S., … Ritsema, C. J. (2015). Soil surface changes increase runoff and erosion risk after a low–moderate severity fire. *Geoderma*, *239–240*, 58–67.

de Vente, J., Poesen, J., Verstraeten, G., Govers, G., Vanmaercke, M., Van Rompaey, A., … Boix-Fayos, C. (2013). Predicting soil erosion and sediment yield at regional scales: Where do we stand? *Earth Science Reviews*, *127*, 16–29.

Wu, Y., & Chen, J. (2012). Modeling of soil erosion and sediment transport in the East River Basin in southern China. *Science of the Total Environment*, *44*, 159–168.

Xu, Z. X., Pang, J. P., Liu, C. M., & Li, J. Y. (2009). Assessment of runoff and sediment yield in the Miyun Reservoir catchment by using SWAT model. *Hydrological Processes*, *23*, 3619–3630.

Yaalon, D. (1997). Soils in the Mediterranean region: what makes them different? *Catena*, *28*, 157–169.

Yang, D. W., Kanae, S., Oki, T., Koike, T., & Musiake, K. (2003). Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes*, *17*, 2913–2928.

Yen, H., Ahmadi, M., White, M. J., Wang, X., & Arnold, J. G. (2014). C-SWAT: The Soil and Water Assessment tool with consolidated input files in alleviating computational burden of recursive simulations. *Computers & Geosciences*, *72*, 221–232.

Yesuf, H. M., Assen, M., Alamirew, T., & Melesse, A. M. (2015). Modeling of sediment yield in Maybar gauged watershed using SWAT, northeast Ethiopia. *Catena*, *127*, 191–205.

Zouagui, A., Benmansour, M., Amenzou, N., Nouira, A., Sabir, M., Benjelloun, H., … Benkadad, A. (2012). Application de la technique de 137Cs à l'estimation de l' érosion hydrique dans le bassin versant de Moulay Bouchta, Rif occidental, Maroc. *Rev mar Sci Agron Vétérinair*, *1*, 53–58.

Zuo, D., Xu, Z., Yao, W., Jin, S., Xiao, P., & Ran, D. (2016). Assessing the effects of changes in land use and climate on runoff and sediment yields from a watershed in the Loess Plateau of China. *Science of the Total Environment*, *544*, 238–250.