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Review article

Soil water erosion assessment in Morocco through modeling and fingerprinting applications: A review

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ABSTRACT

During the last century, a great deal of effort has been directed toward determining soil erosion rates using various methods under a wide range of climatic conditions, soil types, land uses, topography, and among others. Therefore, to better understand soil erosion studies in Morocco, a country with diverse physiography and climatic variations we undertook an analysis of national data of several soil erosion modeling and fingerprinting. The approach used for this research is a review of scientific articles, conference papers and thesis on soil erosion, focusing more on categorization of the different soil erosion models and other methods applied. The results reveal very interesting information as follows: (i) the distribution and frequency level of modeling and fingerprinting applications; the focus was on the north of the country: (Rif 32.89%, High Atlas 32.89%, Occidental Meseta 18.43% and Middle Atlas 10.53%), (ii) The (R) USLE models remain the most widely used models (51,32%) in Morocco, (iii) The support practice factor was severely lacking across the country, (iv) the highest erosion rate is concentrated in the Atlas and Rif mountains; and (v) a positive relationship between erosion rate and geological features, slope, climate, land use and cover, plus other environmental characteristics, as well as measurement and modeling conditions, and a negative relationship with the study areas size and scale. Even though the overall results show a high degree of variability, which cannot be explained by this combination of factors, but is at a minimum partly related to the experimental conditions. This overview research and database are designed to assist in the future assessment of soil erosion and to help define priorities for soil erosion research by providing a state of art for future focused and comprehensive analyses to address this issue of soil erosion in Morocco.

1. Introduction

Soil degradation due to water erosion processes poses a series of threats to terrestrial ecosystems (Han et al., 2016; Borrelli et al., 2020; Li et al., 2022). This phenomenon is one of the most serious problems in the world, which influenced by both natural and human factors (Shougang and Ruishe, 2014). It has become one of the global environmental hazards that affects human survival and restricts global socio-economic sustainable development (Han et al., 2016).

Soil erosion and its impacts are one of the main concerns of watershed managers and policy makers. They are increasingly seeking data on soil erosion and its effects on water quality at the watershed scale (Merritt et al., 2003), addressing the spatial distribution of soil erosion risk and the absolute value of soil erosion losses. The soil erosion model is playing an important role in the design and implementation of soil management and conservation strategies (Panagos et al., 2015). Furthermore, models vary significantly in their application, requirements, expected use, and their outputs (Merritt et al., 2003). Effective modelling can provide information about current erosion, its trends and scenario analysis (Ganasri and Ramesh, 2016). In effect, soil erosion models are important for estimating rates of soil loss and runoff from agricultural land, for planning land use policies, generating relative indices of soil loss, and

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providing guidance for government policy and strategy on soil and water conservation (Smith, 1999). Although modeling is an effective and valuable tool for decision support (Cerdan et al., 2002), its application is not an easy task. Indeed, the natural complexity of landscape systems, spatial heterogeneity and insufficient of available data are the main difficulties in water erosion modeling (Merritt et al., 2003). A challenge for basin management decision makers is to identify models that accurately simulate the complexity of basin processes using available data (Nguyen et al., 2019).

Due to its position in the northwest of Africa, Morocco presents a good example of a country with great diversity terms of climate, vegetation, morphology, and geology; Classified as a semi-arid Mediterranean country in development (Gourfi et al., 2018), nevertheless that have commonly suffered from land degradation and mismanagement (Jazouli et al., 2019). Over the past decades, Morocco has implemented a strategy of surface water mobilization through the construction of dams; it is one of the most powerful countries in the field of dams in Africa (Gourfi et al., 2021). Nowadays, according to water department of Morocco, 149 dams were built and operational with a total storage capacity up to 22 billion m^3 to supply water demand about 11 billion m^3. However, it is impacted by the sedimentation problem caused by soil erosion upstream (Gourfi et al., 2021). The reservoir siltation leads to an overall decrease in reservoir capacity of about 70 hm^3/year, or 0.4% each year, with a large regional variability, and much higher values in certain areas, such as the north of the country (Ezzaouini et al., 2022). Therefore, developing and applying different models and fingerprintings to evaluate the soil erosion at watershed scales could be valuable to manage and reduce the impacts of this issue.

In this perspective, the main objective of this study is to provide a review of research on soil water erosion modeling and fingerprinting studies in Morocco. From this general objective, stems a set of specific objectives which are (i) analysis of geographical distribution and frequency of modeling applications, (ii) evaluate models and fingerprintings most commonly presented in the Moroccan literature, (iii) percent distribution of soil erosion rate estimates by geologic domain and (iv) highlight the factors controlling soil erosion in the different structural zones. To achieve these objectives, we have constructed a database founded on academic articles, thesis, bulletins, conference papers, textbooks, research reports and publicly available materials relating to soil water erosion models conducted in Morocco, which cover its main structural domains. This review provides an insight into the national status of soil water erosion model applications in Morocco and summarizes information on the processes and regions that have been most evaluated and that require increased attention in the future.

2. Methods

2.1. Study area

The kingdom of Morocco covering about an area of 710 850 km^2, has a special location in the northwest corner of the African continent (21N–36N, 1W–17W). It is surrounded by the moving plates of the Mediterranean Sea to the north and the Atlantic Ocean to the west. Indeed, during its long geological history conditioned by this hinge position, between the African, European and American continents. Several orogenic cycles have succeeded each other, each contributing, by its geodynamic context and its magnitude, to shape the major structural areas of Morocco (Piqué and Knidiri, 1994).

Morocco is a country of contrasts, it is a fact that the differences in relief, the diverse nature of forms and its geographical location yields highly variable climatic conditions converge to individualize structural areas and landscapes very different from one end of the country to the other, and is divided geologically into four major structural domains (Piqué and Knidiri, 1994). These structural domains distributed into seven diferent areas as illustrated in Figure 1: Rif, Middle Atlas, High Atlas, Anti Atlas, Occidental Meseta, Oriental Meseta and Sahara. Rifan domain to the north consists of the inner zones, the flyshield zone and the outer zones; that includes friable rocks of various types and ages, the soil is highly developed undergoing a very high loss of soil due to landslides experienced by the region, the climate is humid ($P > 500$ mm), the vegetation cover is arable land type and contains permanent crops mainly located along the rivers in the coastal plains. Middle and High Atlas mountains (where the Jebel Toubkal is located is the highest point of the High Atlas as well as Morocco and North Africa with 4167m) are formed by a covering of essentially carbonate, Mesozoic and Cenozoic terrains and characterized by high altitudes and steep slopes, a semi-arid climate with precipitation between 100 and 500mm, medium vegetation cover and poorly developed soils. Meseta domains are formed by a Paleozoic basement of Cambrian to Carboniferous age and consist mainly of sedimentary terrain with intense bimodal volcanic activity in the Visean; it is

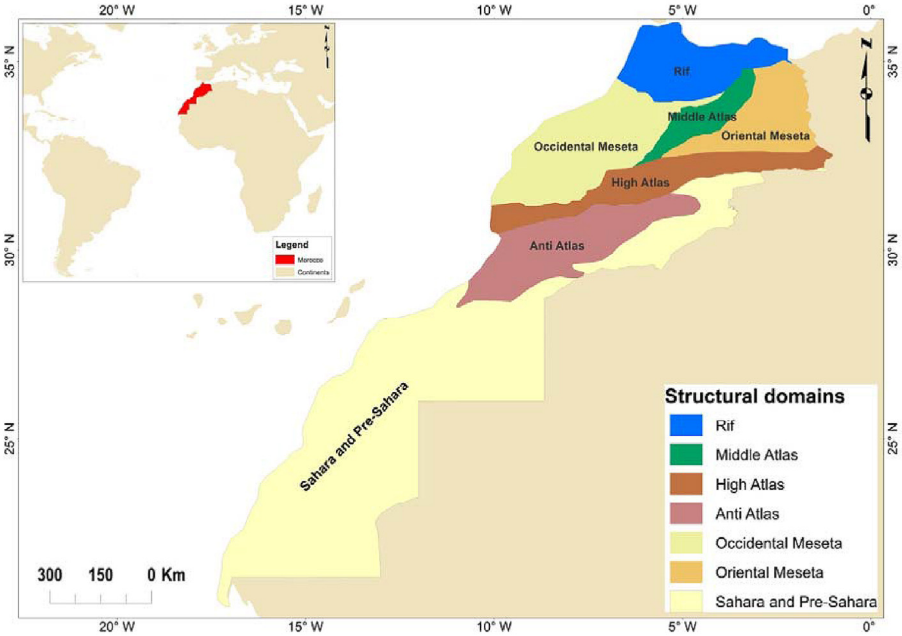

Figure 1. Situation and structural domains of Morocco.

generally characterized by low to moderate relief, well-developed soils and a semi-arid to mediterranean climate. The domain of Anti-Atlas and Sahara (where is the lowest point of the country, at 55 meters below sea level) which is formed by a Proterozoic basement and characterized by a desert climate (P < 100 mm), a vegetation cover dominated essentially by bare areas and sparse desert steppes, and very poor soils (Gourfi et al., 2020; Verner et al., 2018; Michard et al., 2008). Namely, in a semi-arid environment in northwest Morocco that is affected by the formation of severe gullies, where the effects of extreme rainfall are clearly demonstrated (Shrestha and Jetten, 2018). Indeed, precipitation has decreased significantly, and temperature has increased markedly during these years to indicate the possibility of dry periods (Beroho et al., 2020), which can turn into an acceleration of extreme events (Ouraich and Tyner, 2018), e.g. droughts and floods.

2.2. *Data collection using meta-analysis*

A dataset of erosion rate measurements in Morocco was collected from thesis, scientific articles and conference paper published in international journals between 1970 (Heusch, 1970) when the first studies of soil erosion started till date 2021 (Elmalki et al., 2021; Farah et al., 2021b, 2021a; Labbaci et al., 2021; M'Barek et al., 2021; Tahouri et al., 2021; Tairi et al., 2021; Taleb et al., 2021; Eloudi et al., 2021; Acharki et al., 2022) and were collected, classified and evaluated. This research was performed on "Science direct", "Springer", "Google", "Google scholar", "Researchgate" and academic libraries. To search for articles related to this statistical study, we selected the keywords: soil erosion and model or model name in Morocco, water erosion modeling in Morocco, water erosion assessment methods in Morocco; emphasizing those indexed by Web of science and Scopus. The articles matching the selected keywords were downloaded and examined. The study approach consisted of two main phases. The first of the data collection process consisted of three main steps: test the relevancy of the articles to the purpose of the synthesis study, entry data recording and retrieve all the necessary data listed in Table 1 for each relevant article. The second phase is to assess the accuracy of the documentation. We eliminated approximately 19.15% of the items reviewed and checked for completeness and considered 80.85% of the records that met the criteria; we have specifically selected articles dealing with the quantitative or qualitative assessment of soil erosion by modeling or fingerprinting in a given region of Morocco. This process identified a total of 76 articles. Then, we reviewed the database to identify and correct inconsistencies, misclassifications, and obvious typos.

2.3. *Statistical analysis*

This research provides an overview of soil water erosion assessment through model and fingerprinting applications in Morocco and led to the creation of a multi-source database of soil erosion model and fingerprinting predictions applied in different regions of Morocco, covering a wide range of publication periods as shown in Table 2. A dataset with extensive inputs including the following information was collected (if available): type of model, estimated soil erosion rates (in units of mass per area and time), geographic coordinates (longitude and latitude), author(s) and year of application, study area size (ha) and the main factors controlling water erosion. These inputs yielded statistical information on soil erosion patterns and predictive trends in space and time.

Table 1. List of information collected for each entry in the database.

Group	Entry	Types of data
Bibliography	Title	Open (alphanumeric)
Study area	Author(s)	Open (alphanumeric)
Setting	Year of publication	Open (numeric)
Modelling outcomes	Journal	Open (alphanumeric)
	Geological domain	Open (alphanumeric)
	Name of the watershed	Open (alphanumeric)
	Latitude (decimal degrees)	Open (numeric)
	Longitude (decimal degrees)	Open (numeric)
	Surface (ha)	Open (numeric)
	Dam	Open (alphanumeric)
	Main factors	Open (alphanumeric)
	Management factor (P)	Open (alphanumeric)
	Model developed/applied	Open (alphanumeric)
	Estimated soil erosion rate (t/ha/year)	Open (numeric)
	Conclusion	Open (alphanumeric)
	Recommendation	Open (alphanumeric)

Diagrams and maps were used to provide the frequency of study in each structural domain, a visual relationship between the soil erosion rate and these areas with environmental factors. Also an analysis of model and fingerprinting used to predict soil erosion in Morocco, from the most used to the least ones.

3. Results and discussion

According to the first step of literature download, we observe a limited number of articles indexed on Scopus which are interested in soil erosion in Morocco despite the interest of this topic. An analysis of the relevant documents (65 articles, 8 conferences and 3 thesis) reveals a great deal of useful information to get an overview of the geographic location of modeling applications, the area most vulnerable to erosion, the models most used to predict soil erosion, how and where these models are used the distribution and frequency level of modeling applications and rate of erosion in each structural area. Thus, this study revealed some contradictions, both in the use of certain models and in the results obtained in certain studies.

3.1. *Geography and frequency of modeling applications*

The geographic distribution of the modeling applications was clustered with ArcGIS software using a shade of color to optimally visualize the density of observations, as shown in Figure 2. Consider that Morocco has been divided into different structural zones in which there are no study areas that overlap two geographical zones. As the map and statistics clearly indicate, the studies were concentrated in the northern part of the country; the Rif and the High Atlas (area containing the highest peaks of North Africa) were the major themes of the publications representing more than 65% of the total documents published. Numerically (Figure 2), the Rif mountains ($n = 25$; 32.89%) and the High Atlas mountains ($n = 25$; 32.89%) with the highest density of modeling applications, followed by Occidental Meseta ($n = 14$; 18.43%), Middle Atlas mountains ($n = 8$; 10.53%), Anti-Atlas domain ($n = 2$; 02.63%), Oriental Meseta ($n = 2$; 02.63%) and zero application density observed in Sahara domain ($n = 0$; 0%).

Even though the problem of soil erosion is severe, only a few studies have been carried out to characterize and evaluate soil erosion in Morocco. This gap in studies is mainly due to the absence of recurrent data (Gourfi et al., 2018). Indeed, a primary difficulty for Morocco was the lack of data on parental material (Hessel et al., 2014). In particular, there is a total absence of studies on this phenomenon in the Saharan region which represents a vast part of Moroccan territory; this remark should therefore be taken into consideration.

3.2. *Applied soil erosion prediction model and fingerprinting*

In recent decades, there has been an increase in the application of soil erosion assessment model and fingerprinting for large areas, including Morocco. This evolution is explained by an increased political need for more information on land degradation. Those models were progressively linked to GIS interfaces during the last decades. The models most applied in Morocco, according to this study (Table 3), are members of the universal soil loss equation family: RUSLE (Revised Universal Soil Loss Equation) (Renard et al., 1997) ($n = 27$; 35.53%) and USLE (Universal Soil Loss Equation) ($n = 12$; 15.79%); (Wischmeier and Smith, 1978). In

Table 2. Main characteristics of the studied watershed.

Zone	Watershed/Area	Watershed characteristics				Model	Erosion rate (t/ha/year)	Paper type	Reference
		Area (ha)	Latitude	Longitude	Dam/Outlet				
Rif	Arbaa Ayacha	19900	31°–31°21′N	7°30′-7°60′O	___	RUSLE	25.77	Article	(Ouallali et al., 2016a)
	Arbaa Ayacha	19900	31°–31°21′N	7°30′-7°60′O	___	PAP/RAC	Map	Article	(Ouallali et al., 2016b)
	Asfalou	81023	___	___	Asfalou	PAP/RAC	Map	Article	(Tahouri et al., 2021)
	Boussouab	25220	34°30′-34°35′N	3°35′-3°40′W	___	USLE	55.35	Article	(Sadiki et al., 2014)
	El Hachef	23000	___	___	El Hachef	^{137}Cs and^{210}Pb	20 to 32	Article	(Damnati et al., 2013)
	Inaouene	370000	34°30′-33°50′N	3°49′-4°33′W	Idriss-I	RUSLE	37	Article	(Brahim et al., 2020)
	Khmiss	29300	35°45′-35°32′N	5°26′-5°37′W	___	USLE	36	Article	(Issa et al., 2014)
	Kalaya	3837	35°39′-35°43′N	5°37′31″-5°45′O	Atlantic Ocean	USLE	34.74	Article	(Issa et al., 2016)
	Kalaya	3838	35°39′-35°43′N	5°37′31″-5°45′O	Atlantic Ocean	SWAT	20 to 120	Article	(Briak et al., 2016)
	Loukkos	___	___	___	___	RUSLE	10	Article	(Acharki et al., 2022)
	Nakhla	10900	35°20′-35°28′N	5°20′-5°25′W	Nakhla	137Cs	Up to 50	Article	(Bouhlassa et al., 2000)
	Nakhla	10900	35°20′-35°28′N	5°20′-5°25′W	Nakhla	137Cs	12 to 29	Article	(Hassouni and Bouhlassa, 2005)
	Nakhla	10900	35°20′-35°28′N	5°20′-5°25′W	Nakhla	^{137}Cs and^{210}Pb	20 to 41	Article	(Damnati et al., 2013)
	Nakhla	11800	___	___	Nakhla	SWAT	11.25	Article	(Taleb et al., 2021)
	Nekor	78000	___	___	MBAK	RUSLE/USPED	38	Article	(Arrebei et al., 2020)
	Oued El Makhazine	241400	34°45′-35°15′N	5°14′32″-5°51′9″W	___	USLE	A max of 95	Article	(Belasri and Lakhouili, 2016)
	Oued El Malleh	3400	___	___	___	RUSLE	13.95	Article	(El Aroussi, 2013)
	Oued Haricha	22100	___	___	April 9, 1947	RUSLE/MUSLE	62.72	Article	(Tahiri et al., 2016)
	Oued Tlata	12300	___	___	___	RUSLE	Up to 50	Article	(Garouani et al., 2008)
	Oued Tlata	12300	___	___	___	USLE	61	Article	(Tribak et al., 2009)
	Ouergha	619000	34°25–35°25′N	3°45′-5°24′W	El Wahda	RUSLE	61.14 to 300	Article	(Jaouda et al., 2020)
	Ouergha	730000	34°24′-35°07′N	3°05′-5°05′W	El Wahda	SWAT/MUSLE RUSLE	27	Conference	(Tairi et al., 2021)
	Raouz	4700	___	___	Raouz	^{137}Cs and^{210}Pb	12 to 16	Article	(Damnati et al., 2013)
	Saboun	720	___	___	___	USLE	Up to 30	Thesis	(Moussadek, 1999)
	Saboun	720	___	___	___	Spectral indices	Map	Article	(Chikhaoui and Bonn, 2006)
	Tahaddart	114100	35°40′-35°20′N	5°40′-6°W	Atlantic Ocean	RUSLE/MUSLE	47.79	Article	(Tahiri et al., 2017.)
	Wadi Tarmast	6900	___	___	___	RUSLE	7 to 32	Article	(Tribak et al., 2015)
High Atlas	Aoulouz	444600	___	___	Aoulouz	GIS (Factors)	4.85	Conference	(Fox et al., 1997)
	Argana Corridor	___	___	___	Issen River	RUSLE	47.52	Article	(Bou-imajjane et al., 2020)
	Azilal (site)	10000	31°46′-31°52′N	6°45′-6°52′W	Hassan-I	Spectral indices	Map	Article	(Bannari et al., 2007)
	Azilal	7000	31°45′-31°50′N	6°45′-6°51′W	Hassan-I	Spectral indices	Map	Article	(Maimouni et al., 2012)
	Azilal (South)	5300	31°45′N-31°50′N	6°45′W-6°51′W	Hassan-I	AHP	Map	Article	(Farah et al., 2021a)
	El Ksiba (region)	6000	32°32′-32°37′N	6°–6°06′W	___	Spectral indices	Map	Article	(Bachaoui et al., 2014)
	Beni Mellal (region)	___	32°17′-32°24′N	6°14′-6°23′W	___	Spectral indices	Map	Article	(M. Bachaoui et al., 2014)
	Beni Mohand	34,894	___	___	___	RUSLE	40.38	Article	(Bou-imajjane and Belfoul, 2020)
	Lakhdar	680000	___	___	Hassan-I	Spectral indices	Map	Article	(Nouaim et al., 2019)
	Lakhdar	295000	___	___	Hassan-I	AHP	Map	Article	(Eloudi et al., 2021)
	N'fis	170400	30.5°-31.2°N	7.55°-8.40°W	Lalla Takerkoust	SWAT	131	Article	(Markhi et al., 2019)
	N'fis	170400	30.5°-31.2°N	7.55°-8.40°W	Lalla Takerkoust	RUSLE/SEDD	54	Article	(Gourfi, 2019)
	Ouarzazate	58.977	___	___	El Mansour Eddahbi	Sentinel 2 A	Map	Article	(Farah et al., 2021b)
	Oued El Abid	311900	___	___	Bin El Ouidane	IntErO/EPM	402	Conference	(El Mouatassime et al., 2019)

(*continued on next page*)

Table 2 (*continued*)

Zone	Watershed/Area	Watershed characteristics				Model	Erosion rate (t/ha/year)	Paper type	Reference
		Area (ha)	Latitude	Longitude	Dam/Outlet				
	Ourika	57600	31°–31°21′N	7°30' -7°60′W	___	RUSLE	380	Article	(Modeste et al., 2016)
	Ourika	57600	31°–31°20′N	7°30′-7°60′W	___	^{137}Cs	4.5 to 7.3	Article	(Meliho et al., 2019)
	Ourika	57300	31°–31°20′N	7°30′-7°60′W	___	SWAT	2 to 59	Conference	(Elmalki et al., 2021)
	Ourika	50300	31°–31°20′N	7°30′-7°60′W	___	InVEST-SDR	258.48	Article	(Ayt Ougougdal et al., 2020)
	Rheraya	22500	___	___	___	STREAM	4	Article	(Simonneaux et al., 2015)
	SBEI of Ain Asmama	23564	30.74°-31°N	9.03°-9.33°E	___	RUSLE	339.03	Article	(Labbaci et al., 2021)
	Tensift	2045	30°50′-32°10′N	7°12′-9°25′W	___	RUSLE	44.03	Article	(Meliho et al., 2019)
	Tessaoute upstream	141800	31°33′-31°64′N	6°48′-7°33′W	Moulay Youssef	USLE	15.44	Article	(Elaloui et al., 2017)
	Tifnout Askaoun	148800	30°35′-31°05′N	7°37′-8°11′W	Mokhtar Soussi and Aoulouz	RUSLE	14.44	Article	(Tairi et al., 2021)
	Upper Draa basin	128400	30°56′-31°23′N	7°00′-7°36′W	___	Spectral indices	Map	Article	(Ourhzif et al., 2021)
	Ziz	443500	32°05′-32°64′N	4°11′-5°46′W	Hassan Eddakhil	RUSLE	489.5	Conference	(Fenjiro et al., 2020)
Middle Atlas	High Oum Er-Rbia	153100	32°35′-33°N	5°05′-5°50′W	El Hansali	RUSLE	224	Article	(Yjjou et al., 2014)
	High Oum Er Rbia	361200	___	___	Ahmed El Hansali	CA_Marcov/RUSLE	142	Article	(Jazouli et al., 2019)
	Ikkour	5500	32°32′–32°40′N	5°50′–5°58′W	___	USLE/Spectral indices	0.68	Article	(El Jazouli et al., 2017)
	M'dez	335000	___	___	___	SWAT/RUSLE	3.95/2.94	Conference	(Boufala et al., 2020)
	Oued Beht	430.728	___	___	El Kansra	USLE	19.40	Article	(Gaatib and Larabi, 2014)
	Oued Srou	144300	32°35′-33°N	5°05′-5°50′W	___	LEAM	Map	Conference	(Elbouqdaoui et al., 2005)
	Oued Zgane	54915	33°30′-33°50′N	4°37′-5°06′W	___	PAP/RAC	Map	Article	(Ousmana et al., 2017)
	Upper Sebou	549500	33°-34°N	4°03′-5°20′W	Allal El Fassi	SWAT	6.51	Article	(Boufala et al., 2020)
Anti-Atlas	Souss	1718600	29.70°-31.11°N	7.47–9.6W	Atlantic Ocean	EPM	1.81	Article	(Ahmed et al., 2019)
	Tifnout-Askaoun	157000	___	___	Aoulouz/Mokhtar Soussi	AHP	Map	Article	(Tairi et al., 2019)
Occidental Meseta	Bouregreg	957000	34°00′-33°00′N	6°40′-5°35′W	SMBA	SWAT	___	Article	(Fadil et al., 2011)
	Bouregreg River	395600	___	___	SMBA	RUSLE	13.81	Article	(Adilmoussebbih, et al., 2019)
	Bouregreg	545	33°06′43″N	7°24′21″W	SMBA	USLE	1.1	Article	(Asserar et al., 2020)
	Bouregreg	1013000	34°00′-33°00′N	6°40′-5°35′W	SMBA	MUSLE	2.7	Article	(Ezzaouini et al., 2020)
	El Grou	350400	___	___	Ras El Fathia	SWAT	11.3	Article	(M'Barek et al., 2021)
	Harchane	___	___	___	___	137Cs/7Be	8 to 58	Conference	(Benmansour et al., 2016)
	Korifla	63600	33°00′-33°45′N	6°40′-6°52′W	SMBA	GIS	Map	Article	(Bouh, 1996)
	Korifla	63600	33°00′-33°45′N	6°40′-6°52′W	SMBA	RUSLE	0.01 to 0.14	Thesis	(El Bahi, 2006)
	Marchouch	1	33°470 N	6°420W	___	137Cs/210Pbex	12 to 14	Article	(Benmansour et al., 2013)
	Marchouch	___	___	___	___	137Cs/7Be	8 to 58	Conference	(Benmansour et al., 2016)
	Oued Aricha	13800	___	___	___	USLE	20	Article	(Anys et al., 1994)
	Oued El Maleh	0.3	33°37W	7°25N	Oued El Maleh	137Cs	82	Article	(Nouira et al., 2003)
	Oued El Maleh	257700	3290-3376N	660-750E	Oued El Maleh	USLE	8.21	Article	(Lahlaoi et al., 2015)
	Oued Mellah	___	___	___	___	137Cs/7Be	8 to 58	Conference	(Benmansour et al., 2016)
	Sbou	4000000	33°-35°N	6°35′-4°15′W	___	RUSLE	86	Article	(Chadli, 2016)
	Settat-Ben Ahmed	99932	___	___	___	SWAT	A max of 5.20	Thesis	(Bouslihim, 2020)
Oriental Meseta	Oued Isly	131200	___	___	___	RUSLE	21.78	Article	(Driss and Brahim, 2018)
	Ziz upper watershed	443.5	32°64′19″-32°05′48″N	5°46′20″-4°11′72″W	Hassan Addakhil	WaTEM/SEDEM	4.57	Article	(Mohamed et al., 2020)
Sahara	___								

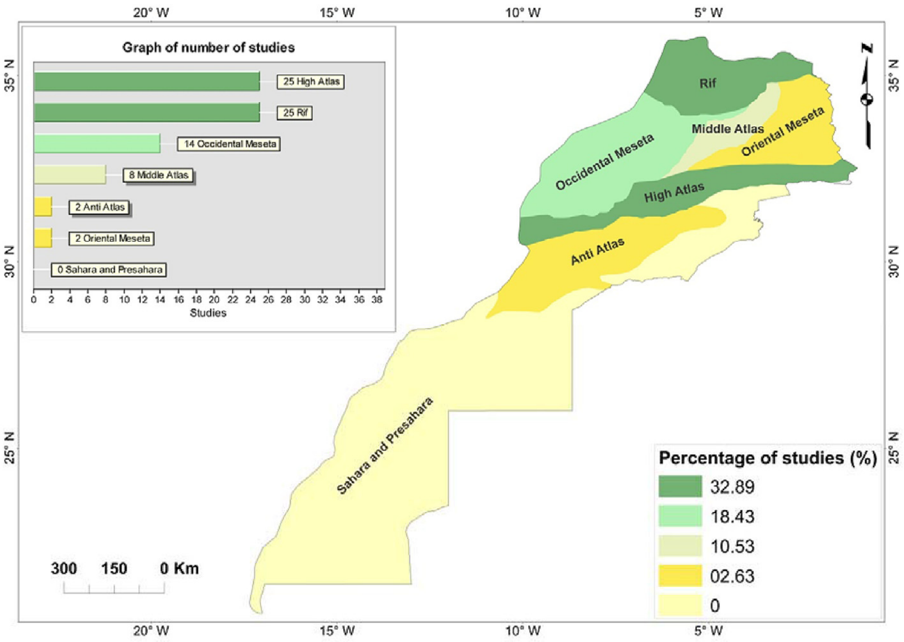

Figure 2. Geography and frequency of modeling applications.

addition, these empirical models are applied to the different structural domains (together cover approximately 51.32% of the total). Follow by SWAT (Soil and Water Assessment Tool) (Arnold et al., 2012) (n = 10; 13.16%). The other model and fingerprinting: ^{137}Cs (Caesium-137), Spectrales indices, MUSLE (Modified Universal Soil Loss Equation) (Williams and Berndt, 1977), PAP/RAC (Priority Action Program of the Regional Activity Center), ^{137}Cs and ^{210}Pb (Caesium-137 and plomb-210), EPM (Erosion Potential Model) (Gavrilovic, 1972), AHP (Analytic Hierarchy Process) (Saaty, 1977), STREAM (Cerdan et al., 2002), WaTEM/SEDEM (Water and Tillage Erosion Model and Sediment Delivery Model) (Van Oost et al., 2000), IntErO (Intensity of Erosion and Outflow) (Spalevic, 2011) and LEAM (Land Erodibility Assessment Model) (Manrique, 1988), have only about 35.52%. Spectral indices, PAP/RAC and AHP models are applied with a qualitative objective to map the erosion areas without giving the soil erosion rate.

The used models to assess soil erosion differ widely in terms of their complexity, required input variables, the processes they represent and how those processes are represented, the scale of their intended use, and the types of output information they provide (Merritt et al., 2003). Each model has a specific purpose and therefore is unable to solve the problem in all situations (Hajigholizadeh et al., 2018). For instance, RUSLE model does not consider sediment deposition or erosion from gullies and channels; it only assesses gross sheet and stream erosion (Renard et al., 1997). The northern regions of the country are characterized by a friable lithology causing massive soil erosion, in which case the RUSLE model underestimates the effective yield of suspended sediments. However, in the regions characterized by a hard lithology and steep slopes, the RUSLE model overestimates the effective yield of suspended sediments due to the absence of soil horizon (Gourfi et al., 2018). Nevertheless, by analyzing the records of previous studies, it is possible to observe the use of certain models in different regions in terms of topography, land cover and soil properties, regardless of the conditions under which the models are used. Among the relevant reports, there are two that study the Kalaya basin, the first using the USLE with an average erosion rate of 34.74 t/ha/year (Issa et al., 2016), the second using the SWAT model with an average erosion rate of 55 t/ha/year (Briak et al., 2016), both studies performed in the same year. One explanation for this contradiction could be the experimental settings involved, which emphasizes the importance of taking into account this conditions implied in interpreting the erosion rates (García-Ruiz et al., 2015).

Table 3. Lists of the most applied soil erosion prediction models.

Model	Records	%	References
RUSLE	27	35.53	(Renard et al., 1997)
USLE	12	15.79	(Wischmeier and Smith, 1978)
SWAT	10	13.16	(J. G. Arnold et al., 2012)
^{137}Cs	5	06.58	_
Spectrales indices	5	06.58	_
MUSLE	4	05.27	(Williams and Berndt, 1977)
PAP/RAC	3	03.96	_
^{137}Cs and ^{210}Pb	2	02.63	_
EPM	2	02.63	(Gavrilovic, 1972)
AHP	2	02.63	(Saaty, 1977)
STREAM	1	01.31	(Cerdan et al., 2002)
WaTEM/SEDEM	1	01.31	(Van Oost et al., 2000)
IntErO	1	01.31	(Spalevic, 2011)
LEAM	1	01.31	(Manrique, 1988)

Importantly, the (R) USLE are the commonly used models compared to other ones. However, the calibration and validation processes of these models and fingerprintings using observed datasets is necessary for practical implication in managing soil erosion at watershed scales. Yet, few studies calibrated and validated MUSLE and SWAT models in predicting soil erosion (Briak et al., 2016; EL Bilali et al., 2020; Ezzaouini et al., 2020) due to the data shortage required for the model validations. Especially, the physical parameters are the main uncertainty sources for calibrating and validating soil erosion models. However, in the recent years, machine learning (ML) models have become outstanding approach for predicting soil erosion. For instance (AlDahoul et al., 2021), evaluated ML in predicting soil erosion in Egypt and found that ML models provided high accuracy. Therefore, the ML models could be powerful tools in predicting and evaluating soil erosion in Morocco and are suggested for future works to improve the soil erosion assessment.

3.3. Distribution of the estimated soil-erosion rates

Figure 3 presents the variability of the erosion rates provided by various model and fingerprinting for different regions. From this

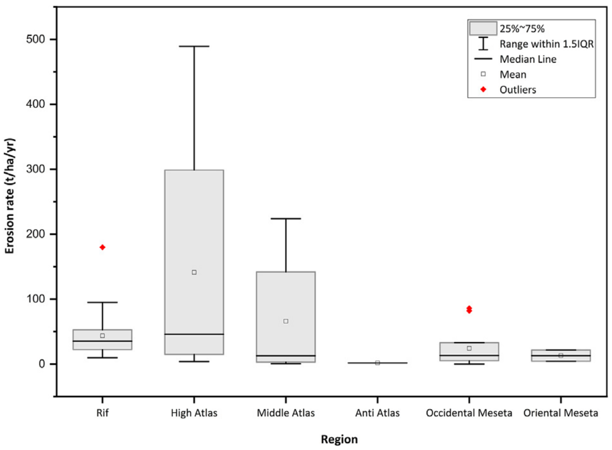

Figure 3. Box-plots of the erosion rate provided by reviewed studies in different regions.

Figure 3, it can observe that the median values are similar for all regions with some important differences, for example between the High Atlas and the two Meseta regions; this could be 5 to 10 times lower. Meanwhile, the mean value varies from one region to another. Interestingly, the Rif (when considering outlier value), High Atlas, and Middle Atlas regions presented the ranges of the erosion rate are large while the other regions presented narrow ranges. This can be explained by the number of the studies and the methods used. Indeed, using different models or fingerprintings in the same region can provide different results depending on the input variables and the uncertainties of each variable.

The results show that there was extraordinarily high variability in erosion rates. Then, the main challenge is that watersheds in different structural domains naturally have distinct erosion rates, due to geographical differences, watershed characteristics, and the type of model used. Regardless of this difficulty, we estimated the mean soil erosion and median (Figure 3). In addition, some studies on the same watershed give different results on erosion rates, even if it is in the same period; this is due to the application of different measurement methods, another reason could be that many erosion studies ignore validation or some form of evaluation of the model results. It is therefore difficult to compare average erosion rates between domains to understand the impact of the country. Based on the statistics of the articles involved, the results indicate the highest value of soil erosion rate for the areas of the Atlas Mountains and Rif (Figure 4), dominated by friable lithology, landslides, and steep slopes. These areas are the most seriously threatened and the environmental impacts of soil erosion have been observed, such as siltation of reservoir dams, decrease in water quality, and loss of soil fertility. Indeed, the extent of soil erosion is very significant in these areas which cover less than half of the national territory but produce a high quantity of sediments.

According to AEFCS (Administration of Water and Forests and Soil Conservation) Morocco in 1999, in the mountains and hills of the Rif, the average soil loss reaches 20 t/ha/year, while it is only 5 to 10 t/ha/year in the Middle and High Atlas (MAEF, 2001). Comparing these values to the data (erosion rates) in Table 2 shows that the erosion rate after this date is increasing due to climate change and anthropogenic impacts, especially in some watersheds. Indeed, the recent global assessment of soil erosion reveals values superior to 20 t/ha/year located in the High Atlas and Rif mountains (Gourfi et al., 2018; Borrelli et al., 2017). Thus, even within the same structural area, there are large differences between the erosion rate of each basin or sub-basin, even if they are adjacent and have almost the same environmental factors; this could be linked, at least partially, to experimental conditions, development within the study area, agricultural or socio-economic effects. However, in the case of the same basin, for example the N'fis basin (Gourfi, 2019; Markhi et al., 2019), the difference in the erosion rate is certainly dependent on experimental conditions. Another finding of our results is that there is a negative correlation between the erosion rate and the size of the study area involved (Table 2).

3.4. Factors characterizing the various structural domains

In order to find useful relationships between the erosion rates and environmental factors, a detailed analysis has been realized. The results presented in Figure 4 revealed that the importance of the vegetation cover, topography, soil erodibility, and rainfall erosivity in assessing soil erosion differs from one region to another. These factors are gathered in the arid and semi-arid zones in the country, which remains one of the most vulnerable to the effects of climate change (Mohamed et al., 2020). It is characterized by the spatio-temporal irregularity of rainfall (Sebbar et al., 2011) and has experienced several periods of drought (Kharraz et al., 2012; Mohammed et al., 2002); the number of dry periods is greater than the number of wet periods. In effect, the degree and extent of soil loss is governed by a number of environmental factors, including topography, climate, soil and vegetation (Wischmeier and Smith, 1978; Renard et al., 1997). Based on our analysis of the data in Morocco, we note a weak of management factor, without neglecting the importance of the role of farmer in land. Regarding the other factors; vegetation cover, topography, soil erodability and rainfall erosivity, their impact varies according to the structural domain. For example, in the Atlas and Rifain domains, there is a strong topographical impact combined with rainfall erosion, especially in the High Atlas, and soil erodability. The Occidental Meseta is vulnerable to soil erosion due to its complex topography and high levels of precipitation (Asserar et al., 2020), as also shown in Figure 4. In the Oriental Meseta, erosion is marked by the low vegetation cover in combination with the topography.

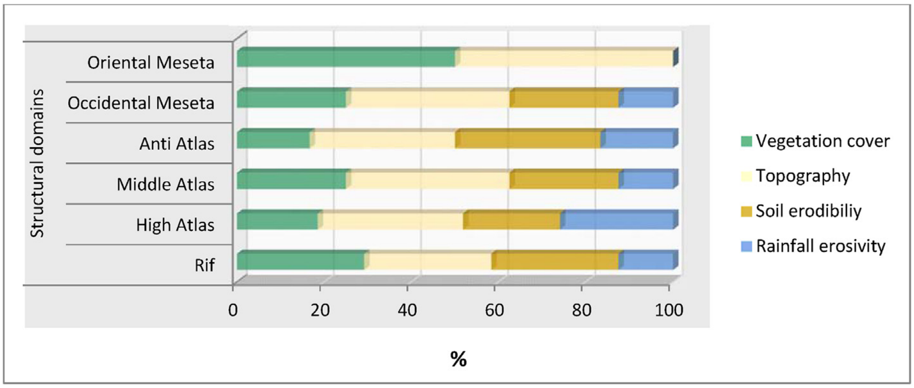

Figure 4. Percentage impact of different factor.

4. Conclusions

Statistical analysis of our systematic literature review provided the following conclusions:

(a) In spite of the seriousness of the threat of soil erosion, only a limited number of indexed studies have been conducted to characterize and evaluate soil erosion in Morocco.
(b) The distribution of studies on the modeling of water erosion reveals a focus on the north of the country, Rif, High Atlas, Middle Atlas and Occidental Meseta.
(c) The models of water erosion have been increasingly developed and linked to GIS based interfaces over the last decades.
(d) Despite geomorphological and geological diversity of Morocco (Rif, Middle and High Atlas, Mesetian and Saharan domain) several authors practice soil erosion assessment models without taking into account the unique characteristics of each study area and not adapting them to local conditions.
(e) (R) USLE models have been widely used and modified over the last two decades and remain today the most commonly used modeling tool. In fact, most of our current knowledge on the spatial distribution of soil erosion and its temporal trends is derived from (R) USLE approaches.
(f) The highest percentage of the erosion rate is concentrated in the Atlas and Rif mountains, this is due to the topography and the nature of land. Concerning Oriental Meseta, Soil erosion is aggravated by the low vegetation cover combined with the topography of the area.
(g) The evidence of a strong relationship between soil erosion rates with environmental factors, and modeling conditions. And the lack of correlation with the size of the study area and the erosion rate. Although the general results show a relatively high variance, which cannot be explained by this combination of factors, it is linked in part to the experimental conditions.

This review is presented in a clear and transparent manner that is useful to have an overview of water erosion assessment in Morocco. Furthermore, this study is more comprehensive and accurate than previous assessments, building a robust dataset for decision makers and regional policy. In addition, information on soil erosion and its effects on water quality at the watershed scale are increasingly essential for stakeholders and watershed managers. In Morocco, the climatic aggressiveness and the demographic expansion of the population, which largely exceeds the potential of the natural resources, now require an intervention that consists in emphasizing the priority of the processes of water erosion and trying to raise the problem before the irreversible occurs, and these through a rational and continuous exploitation of the environment aimed at the conservation of the capital soil-water.

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References

Acharki, S., El Qorchi, F., Arjdal, Y., Amharref, M., Bernoussi, A.S., Ben Aissa, H., 2022. Soil erosion assessment in Northwestern Morocco. Remote Sens. Appl. Soc. Environ. 25, 100663.
Adilmoussebbih et al, 2019. Modeling and mapping of the water erosion risk using gis/ rusle approach in the Bouregreg river watershed. Int. J. Mech. Prod. Eng. Res. Dev 9, 1605–1618.
Ahmed, A., Adil, D., Hasna, B., Elbachir, A., Lazaar, R., 2019. Using EPM model and GIS for estimation of soil erosion in Souss basin, Morocco. Turk. J. Agric. - Food Sci. Technol. 7, 1228.
AlDahoul, N., Essam, Y., Kumar, P., Ahmed, A.N., Sherif, M., Sefelnasr, A., Elshafie, A., 2021. Suspended sediment load prediction using long short-term memory neural network. Sci. Rep. 11, 7826.
Anys, H., Bonn, F., Merzouk, A., 1994. Remote sensing and gis based mapping and modeling of water erosion and sediment yield in a semi-arid watershed of Morocco. Geocarto Int. 9, 31–40.
Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J., Srinivasan, R., Santhi, C., Harmel, R.D., van Griensven, A., Van Liew, M.W., Kannan, N., Jha, M.K., 2012. SWAT: model use, calibration, and validation. Trans. ASABE (Am. Soc. Agric. Biol. Eng.) 55, 1491–1508.
Arrebei, N., Sabir, M., Naimi, M., Chikhaoui, M., Raclot, D., 2020. Assessment of soil erosion with RUSLE 3D and USPED in the Nekor watershed (Northern Morocco). Open J. Soil Sci. 10, 631–642.
Asserar, N., Iaaich, H., Moussadek, R., zouahri, abdelmjid, Douira, A., 2020. Estimation of soil erosion risk within the Ben Ahmed watershed, using Universal Soil Loss Equation (USLE) and geo-information technology (preprint). Preprints.
Bachaoui, B., Bachaoui, E.M., Maimouni, S., Lhissou, R., El Harti, A., El Ghmari, A., 2014. The use of spectral and geomorphometric data for water erosion mapping in El Ksiba region in the central High Atlas Mountains of Morocco. Appl. Geomat. 6, 159–169.
Ayt Ougougdal, H., Yacoubi Khebiza, M., Messouli, M., Bounoua, L., Karmaoui, A., 2020. Delineation of vulnerable areas to water erosion in a mountain region using SDR-InVEST model: a case study of the Ourika watershed, Morocco. Sci. Afr. 10 (e00646).
Bachaoui, M., Bachaoui, B., Lhissou, R., 2014. Modeling and mapping water erosion risks in the high Atlas of Morocco. The Atlas Of Beni Mellal As A Case In Point 2, 9.
Bannari, A., El-Harti, A., Haboudane, D., Bachaoui, E.M., 2007. INTÉGRATION DES VARIABLES SPECTRALES ET GÉOMORPHOMÉTRIQUES DANS UN SIG POUR LA CARTOGRAPHIE DES AIRES EXPOSÉES À L'ÉROSION. EL 16.
Belasri, A., Lakhouili, A., 2016. Estimation of soil erosion risk using the universal soil loss equation (USLE) and geo-information technology in oued El Makhazine watershed, Morocco. J. Geogr. Inf. Syst. 8, 98–107.
Benmansour, M., Mabit, L., Nouira, A., Moussadek, R., Bouksirate, H., Duchemin, M., Benkdad, A., 2013. Assessment of soil erosion and deposition rates in a Moroccan agricultural field using fallout 137Cs and 210Pbex. J. Environ. Radioact. 115, 97–106.
Benmansour, M., Mabit, L., Moussadek, R., Yassin, M., Nouira, A., Zouagui, A., Mrabet, R., Iaaich, H., Hajib, S., 2016. Effectiveness of Soil Conservation Strategies on Erosion in Morocco EPSC2016-2174.
Beroho, M., Briak, H., El Halimi, R., Ouallali, A., Boulahfa, I., Mrabet, R., Kebede, F., Aboumaria, K., 2020. Analysis and prediction of climate forecasts in Northern Morocco: application of multilevel linear mixed effects models using R software. Heliyon 6, e05094.
Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K.V., Montanarella, L., Panagos, P., 2017. An assessment of the global impact of 21st century land use change on soil erosion. Nat. Commun. 8, 2013.
Borrelli, P., Robinson, D.A., Panagos, P., Lugato, E., Yang, J.E., Alewell, C., Wuepper, D., Montanarella, L., Ballabio, C., 2020. Land use and climate change impacts on global soil erosion by water (2015-2070). Proc. Natl. Acad. Sci. USA 117, 21994–22001.
Bou-imajjane, L., Belfoul, M.A., 2020. Soil loss assessment in western high Atlas of Morocco: Beni Mohand watershed study case. Appl. Environ. Soil Sci. 2020, 1–15.
Bou-imajjane, L., Belfoul, M.A., Elkadiri, R., Stokes, M., 2020. Soil erosion assessment in a semi-arid environment: a case study from the Argana Corridor, Morocco. Environ. Earth Sci. 79, 409.
Boufala, M., El Hmaidf, A., Chadli, K., Essahlaoui, A., El Ouali, A., Lahjouj, A., 2020. Assessment of the risk of soil erosion using RUSLE method and SWAT model at the M'dez Watershed, Middle Atlas, Morocco. E3S Web Conf 150, 03014.
Bouh, S., 1996. Approche Methodologique de cartographie de L'erosion dans le bassin versant de oued korifla. Ann. Rech. For. Maroc 18.
Bouhlassa, S., Moukhchane, M., Aiachi, A., 2000. Estimates of soil erosion and deposition of cultivated soil of Nakhla watershed, Morocco, using 137Cs technique and calibration models. Acta Geol. Hisp. 35 (3).
Bouslihim, Y., 2020. Hydrological and Soil Erosion Modeling Using SWAT Model and Pedotransfert Functions: a Case Study of Settat-Ben Ahmed Watersheds, Morocco.

Brahim, B., Meshram, S.G., Abdallah, D., Larbi, B., Drisss, S., Khalid, M., Khedher, K.M., 2020. Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). Arabian J. Geosci. 13, 1153.

Briak, H., Moussadek, R., Aboumaria, K., Mrabet, R., 2016. Assessing sediment yield in Kalaya gauged watershed (Northern Morocco) using GIS and SWAT model. Int. Soil Water Conserv. Res. 4, 177–185.

Cerdan, O., Souchère, V., Lecomte, V., Couturier, A., Le Bissonnais, Y., 2002. Incorporating soil surface crusting processes in an expert-based runoff model: sealing and transfer by runoff and erosion related to agricultural management. Catena 46, 189–205.

Chadli, K., 2016. Estimation of soil loss using RUSLE model for Sebou watershed (Morocco). Model. Earth Syst. Environ. 2, 51.

Chikhaoui, M., Bonn, F., 2006. Comparaison des capteurs ASTER et ETM+ pour la cartographie de la dégradation des sols à l'aide de l'indice LDI. Can. J. Rem. Sens. 11.

Damnati, B., Ibrahimi, S., Radakovitch, O., 2013. Quantifying erosion using 137Cs and 210Pb in cultivated soils in three mediterranean watershed: synthesis study from El Hachef, Raouz and Nakhla (North West Morocco). J. Afr. Earth Sci. 79, 50–57.

Driss, E.H., Brahim, A., 2018. Quantification de L'erosion hydrique en utilisant le modèle rusle et déposition intégrée dans un sig. Cas du bassin versant de L'oued isly (Maroc oriental). Eur. Sci. J. ESJ 14, 373.

El Aroussi, O., 2013. Modelling and mapping of soil erosion on the oued EL malleh catchment using remote sensing and GIS. J. Urban Environ. Eng. 302–307.

El Bahi, 2006. Thèse quantification et modélisation de l'érosion hydrique dans le bassin versant de KORIFLA Plateau des ZAER-Maroc Central.

EL Bilali, A., Taleb, A., EL Idrissi, B., Brouziyne, Y., Mazigh, N., 2020. Comparison of a data-based model and a soil erosion model coupled with multiple linear regression for the prediction of reservoir sedimentation in a semi-arid environment. Euro-Mediterr. J. Environ. Integr. 5, 1–13.

El Jazouli, A., Barakat, A., Ghafiri, A., El Moutaki, S., Ettaqy, A., Khellouk, R., 2017. Soil erosion modeled with USLE, GIS, and remote sensing: a case study of Ikkour watershed in Middle Atlas (Morocco). Geosci. Lett. 4, 25.

El Mouatassime, S., Boukdir, A., Karaoui, I., Skataric, G., Nacka, M., Khaledi Darvishan, A., Sestras, P., Spalevic, V., 2019. Modelling of soil erosion processes and runoff for sustainable watershed management: case study oued EL abid watershed, Morocco. J. Agric. For. 65.

Elaloui, A., Marrakchi, C., Fekri, A., Maimouni, S., Aradi, M., 2017. USLE-based assessment of soil erosion by water in the watershed upstream Tessaoute (Central High Atlas, Morocco). Model. Earth Syst. Environ. 3, 873–885.

Elbouqdaoui, K., Ezzine, H., Badrahoui, M., Rouchdi, M., Zahraoui, M., Ozer, A., 2005. Approche méthodologique par télédétection et SIG de l'évaluation du risque potentiel d'érosion hydrique dans le bassin versant de l'Oued Srou (Moyen Atlas, Maroc) 12.

Elmalki, M., Mounir, F., Ichen, A., Qaini, T., Khai, T., Aarab, M., 2021. Measuring land losses caused by water erosion using the SWAT model in the Ourika watershed in the High Atlas of Morocco. E3S Web Conf 234, 00083.

Eloudi, H., Reddad, H., Hssaisoune, M., Estrany, J., Krimissa, S., Elaloui, A., Namous, M., Ouatiki, H., Aboutaib, F., Ouayah, M., Jadoud, M., Edahbi, M., Bouchaou, L., 2021. Impact of Climate Change on Soil Sensitivity Erosion in a Semi-arid Context: Insights from Lakhdar Watershed, Central High-Atlas Morocco. SSRN Electron.

Ezzaouini, M., Mahé, G., Kacimi, I., Zerouali, A., 2020. Comparison of the MUSLE model and two years of solid transport measurement, in the Bouregreg basin, and impact on the sedimentation in the sidi Mohamed ben Abdellah reservoir, Morocco. Water 12, 1882.

Ezzaouini, M., Mahe, G., Kacimi, I., el Bilali, A., Zerouali, A., Nafii, A., 2022. Predicting daily suspended sediment load using machine learning and NARX hydro-climatic inputs in semi-arid environment. Water 14, 862.

Fadil, A., Rhinane, H., Kaoukaya, A., Kharchaf, Y., Bachir, O.A., 2011. Hydrologic modeling of the Bouregreg watershed (Morocco) using GIS and SWAT model. J. Geogr. Inf. Syst. 3, 279–289.

Farah, A., Algouti, Ahmed, Algouti, Abdellah, Ifkirne, M., 2021a. Application of the hierarchical multicriteria analysis method to the study of water erosion (south of Azilal, Morocco). J. Environ. Agric. Stud. 2, 12–22.

Farah, A., Algouti, Ahmed, Algouti, Abdellah, Ifkirne, M., Ezziyani, A., 2021b. Mapping of soil degradation in semi-arid environments in the ouarzazate basin in the south of the central High Atlas, Morocco, using sentinel 2A data. Remote Sens. Appl. Soc. Environ. 23, 100548.

Fenjiro, I., Zouagui, A., Manaouch, M., 2020. Assessment of soil erosion by RUSLE model using remote sensing and GIS - a case study of ziz upper basin southeast Morocco. Forum Geogr XIX, 131–142.

Fox, H.R., Moore, H.M., Price, J.P.N., 1997. Soil Erosion and Reservoir Sedimentation in the High Atlas Mountains, Southern Morocco 8.

Gaatib, R.E., Larabi, A., 2014. Integrated evaluation of soil erosion hazard and risk management in the oued beht watershed using remote sensing and GIS techniques: impacts on El kansra dam siltation (Morocco). J. Geogr. Inf. Syst. 6, 677–689.

Ganasri, B.P., Ramesh, H., 2016. Assessment of soil erosion by RUSLE model using remote sensing and GIS - a case study of Nethravathi Basin. Geosci. Front. 7, 953–961.

García-Ruiz, J.M., Beguería, S., Nadal-Romero, E., González-Hidalgo, J.C., Lana-Renault, N., Sanjuán, Y., 2015. A meta-analysis of soil erosion rates across the world. Geomorphology 239, 160–173.

Garouani, A.E., Chen, H., Lewis, L., Tribak, A., Abahrour, 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 12.

Gavrilovic, S., 1972. Inzenjering o bujic nimtokovima i eroziji. Izgradnja (special issue). PPT, Beograd. Serbia.

Gourfi, A., 2019. Effects of land use changes on soil erosion and sedimentation of dams in semi-arid regions: example of N'fis watershed in western high Atlas. Morocco 10, 13.

Gourfi, A., Daoudi, L., Shi, Z., 2018. The assessment of soil erosion risk, sediment yield and their controlling factors on a large scale: example of Morocco. J. Afr. Earth Sci. 147, 281–299.

Gourfi, A., Daoudi, L., de Vente, J., 2020. A new simple approach to assess sediment yield at a large scale with high landscape diversity: an example of Morocco. J. Afr. Earth Sci. 168, 103871.

Gourfi, A., Daoudi, L., El fels, A.E.A., Rafik, A., Adamou, S.N., Lazaar, A., 2021. The use of Artificial neural network and advanced statistics to model sediment yield on a large scale: example of Morocco. J. Environ. Agric. Stud. 2, 103–117.

Hajigholizadeh, M., Melesse, A., Fuentes, H., 2018. Erosion and sediment transport modelling in shallow waters: a review on approaches, models and applications. Int. J. Environ. Res. Publ. Health 15, 518.

Han, F., Ren, L., Zhang, X., Li, Z., 2016. The WEPP model application in a small watershed in the loess plateau. PLoS One 11, e0148445.

Hassouni, K., Bouhlassa, S., 2005. Estimate of soil erosion on cultivated soils using 137Cs measurements and calibration models: a case study from Nakhla watershed, Morocco 12.

Hessel, R., Daroussin, J., Verzandvoort, S., Walvoort, D., 2014. Evaluation of two different soil databases to assess soil erosion sensitivity with MESALES for three areas in Europe and Morocco. Catena 118, 234–247.

Heusch, B., 1970. L'érosion du pré-rif : une étude quantitative de l'érosion hydraulique dans les collines marneuses du pré-rif Occidental 178.

Issa, L., Raissouni, A., Moussadek, R., El Arrim, A., 2014. Mapping and assessment of water erosion in the khmiss watershed (north western Rif, Morocco). Curr. Adv. Environ. Sci. 2, 119–130.

Issa, L.K., Lech-Hab, K.B.H., Raissouni, A., Arrim, A.E., 2016. Cartographie Quantitative du Risque d'Erosion des Sols par Approche SIG/USLE au Niveau du Bassin Versant Kalaya (Maroc Nord Occidental) 18.

Jaouda, I., Akhssas, A., Ouadif, L., Bahi, L., Elkasri, J., Souidi, H., Soussi, H., 2020. Study of soil erosion risks using remote sensing in Ouergha River watershed (Morocco). E3S Web Conf. 150, 03012.

Jazouli, A.E., Barakat, A., Khellouk, R., Rais, J., Baghdadi, M.E., 2019. Remote sensing and GIS techniques for prediction of land use land cover change effects on soil erosion in the high basin of the Oum Er Rbia River (Morocco). Remote Sens. Appl. Soc. Environ. 13, 361–374.

Kharraz, J.E., El-Sadek, A., Ghaffour, N., Mino, E., 2012. Water scarcity and drought in WANA countries. Procedia Eng., SWEE'11 33, 14–29.

Labbaci, A., Moukrim, S., Lahssini, S., Laaribya, S., Alaoui, H.M., Hallam, J., 2021. Estimation of land degradation loss by water erosion: case of the site of biological and ecological interest of ain Asmama (western high Atlas, Morocco). Adv. Sci. Technol. Eng. Syst. J. 6, 241–247.

Lahlaoi, H., Rhinane, H., Hilali, A., Lahssini, S., Khalile, L., 2015. Potential erosion risk calculation using remote sensing and GIS in oued El Maleh watershed, Morocco. J. Geogr. Inf. Syst. 7, 128–139.

Li, H., Guan, Q., Sun, Y., Wang, Q., Liang, L., Ma, Y., Du, Q., 2022. Spatiotemporal analysis of the quantitative attribution of soil water erosion in the upper reaches of the Yellow River Basin based on the RUSLE-TLSD model. Catena 212, 106081.

MAEF, 2001. Ministère de l'agriculture, du développement rural et des eaux et forêts) Programme d'action national de lutte contre la désertification. Roy. Maroc Rabat 93.

Maimouni, S., El-Harti, A., Bannari, A., Bachaoui, E.-M., 2012. Water erosion risk mapping using derived parameters from digital elevation model and remotely sensed data. Geo Spatial Inf. Sci. 15, 157–169.

Manrique, L.A., 1988. Land Erodibility Assessment Methodology (LEAM): Using Soil Survey Data Based on Soil Taxonomy. Editorial and Publication Shop, Honolulu, Hawaii, USA.

Markhi, A., Laftouhi, N., Grusson, Y., Soulaimani, A., 2019. Assessment of potential soil erosion and sediment yield in the semi-arid N'fis basin (High Atlas, Morocco) using the SWAT model. Acta Geophys. 67, 263–272.

Meliho, M., Nouira, A., Benmansour, M., Boulmane, M., Khattabi, A., Mhammdi, N., Benkdad, A., 2019. Assessment of soil erosion rates in a Mediterranean cultivated and uncultivated soils using fallout 137Cs. J. Environ. Radioact. 208–209, 106021.

Merritt, W.S., Letcher, R.A., Jakeman, A.J., 2003. A review of erosion and sediment transport models. Environ. Model. Software 18, 761–799.

Michard, A., Frizon de Lamotte, D., Saddiqi, O., Chalouan, A., 2008. An outline of the geology of Morocco. In: Michard, André, Saddiqi, Omar, Chalouan, Ahmed, Lamotte, D.F. de (Eds.), Continental Evolution: the Geology of Morocco, Lecture Notes in Earth Sciences. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 1–31. https://doi.org/10.1007/978-3-540-77076-3_1.

Modeste, M., Abdellatif, K., Nadia, M., Zhang, H., 2016. Impact of land use and vegetation cover on risks of erosion in the Ourika watershed (Morocco). Am. J. Eng. Res. 8.

Mohamed, M., Anis, Z., Imade, F., 2020. Regional-scale modeling of water erosion and sediment yield in a semi-arid context: case study of ziz upper watershed in south-Eastern Morocco, in: Proceedings of the 4th Edition of International Conference on Geo-IT and Water Resources 2020, Geo-IT and Water Resources 2020. Presented at the GEOIT4W-2020: 4th Edition of International Conference on Geo-IT and Water Resources 2020, Geo-IT and Water Resources 2020, ACM, Al-Hoceima Morocco, pp. 1–5.

Mohammed, B., Mennani, A., Jalal, M., Fakir, Y., 2002. Impact de la sécheresse sur les potentialités hydriques de la nappe alimentant en eau potable la ville d'Essaouira (Mogador, Maroc). Secheresse (Montrouge) 13.

Moussadek, R., 1999. Caractérisation hydrodynamique des sols et modélisation de l'érosion dans un bassin versant Tangérois (Saboun). 99p. Mémoire de 3ème cycle, IAV Hassan II-Rabat, Maroc.

M'Barek, S.A., Rochdi, A., Bouslihim, Y., Miftah, A., 2021. Multi-site calibration and validation of SWAT model for hydrologic modeling and soil erosion estimation: a case study in El Grou watershed, Morocco. Ecol. Eng. 8.

Nguyen, P., Shearer, E.J., Tran, H., Ombadi, M., Hayatbini, N., Palacios, T., Huynh, P., Braithwaite, D., Updegraff, G., Hsu, K., Kuligowski, B., Logan, W.S., Sorooshian, S., 2019. The CHRS Data Portal, an easily accessible public repository for PERSIANN global satellite precipitation data. Sci. Data 6, 1–10.

Nouaim, W., Chakiri, S., Rambourg, D., Karaoui, I., Ettaqy, A., Chao, J., Allouza, M., Razoki, B., Yazidi, M., El Hmidi, F., 2019. Mapping the water erosion risk in the Lakhdar river basin (central High Atlas, Morocco). Geol. Ecol. Landsc. 3, 22–28.

Nouira, A., Sayouty, E.H., Benmansour, M., 2003. Use of 137Cs technique for soil erosion study in the agricultural region of Casablanca in Morocco. J. Environ. Radioact. 68, 11–26.

Ouallali, A., Moukhchane, M., Aassoumi, H., Berrad, F., Dakir, I., 2016a. The Mapping of the Soils' Degradation State by Adaptation the PAP/RAC Guidelines in the Watershed of Wadi Arbaa Ayacha, Western Rif, Morocco 12.

Ouallali, A., Moukhchane, M., Aassoumi, H., Berrad, F., Dakir, I., 2016b. Evaluation et cartographie des taux d'érosion hydrique dans le bassin versant de l'Oued Arbaa Ayacha (Rif Occidental, Nord Maroc) 16.

Ouraich, I., Tyner, W.E., 2018. Moroccan agriculture, climate change, and the Moroccan Green Plan. A CGE analysis 13, 24.

Ourhzif, Z., Algouti, Ahmed, Algouti, Abdellah, Mlouk, M.A., Aydda, A., 2021. Soil Erosion Susceptibility Mapping Using Support Vector Machine and Remote Sensing Data in Semi-arid Environment: South High Atlas of Marrakech (Morocco) 18.

Ousmana, H., Hmaidi, A.E., Essahlaoui, A., Bekri, H., Ouali, A.E., 2017. Modélisation et cartographie du risque de l'érosion hydrique par l'application des SIG et des directives PAP/CAR. Cas du bassin versant de l'Oued Zgane (Moyen Atlas tabulaire, Maroc) 17.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Pol. 54, 438–447.

Piqué, A., Knidiri, M., 1994. Géologie du Maroc les domaines régionaux et leur évolution structurale. PUMAG, Marrakech.

Renard, K.G., USA, USA, 1997. Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE), Agriculture Handbook. Washington, D. C.

Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. J. Math. Psychol. 15, 234–281.

Sadiki, A., Bouhlassa, S., Auajjar, J., Faleh, A., Macaire, J.-J., 2014. Utilisation d'un SIG pour l'évaluation et la cartographie des risques d'érosion par l'Equation universelle des pertes en sol dans le Rif oriental (Maroc) : cas du bassin versant de l'oued Boussouab 12.

Sebbar, A., Badri, W., Fougrach, H., Hsaine, M., Saloui, A., 2011. E tude de la variabilit e du r egime pluviom etrique au Maroc septentrional (1935-2004). Secheresse 22, 11.

Shougang, Z., Ruishe, 2014. The application and study of GIS in soil Erosion model. Adv. Sci. Eng. 62.

Shrestha, D.P., Jetten, V.G., 2018. Modelling erosion on a daily basis, an adaptation of the MMF approach. Int. J. Appl. Earth Obs. Geoinformation 64, 117–131.

Simonneaux, V., Cheggour, A., Deschamps, C., Mouillot, F., Cerdan, O., Le Bissonnais, Y., 2015. Land use and climate change effects on soil erosion in a semi-arid mountainous watershed (High Atlas, Morocco). J. Arid Environ. 122, 64–75.

Smith, H.J., 1999. Application of empirical soil loss models in southern Africa: a review. S. Afr. J. Plant Soil 16, 158–163.

Spalevic, V., 2011. Impact of Land Use on Runoff and Soil Erosion in Polimlje (PhD Thesis). Doctoral thesis, Faculty of Agriculture of the University of Belgrade, Serbia.

Tahiri, M., Tabyaoui, H., Tahiri, A., Hadi, H.E., Hammichi, F.E., Achab, M., 2016. Modelling soil erosion and sedimentation in the oued haricha sub-basin (Tahaddart watershed, western Rif, Morocco): risk assessment. J. Geosci. Environ. Protect. 4, 107–119.

Tahiri, M., Tabyaoui, H., Hammichi, F.E., Achab, M., Tahiri, A., Hadi, H.E., 2017. Quantification de l'érosion hydrique et de la sédimentation à partir de modèles empiriques dans le bassin versant de Tahaddart (Rif nord Occidental, Maroc) 16.

Tahouri, J., Sadiki, A., Karrat, L. 'houcine, Johnson, V.C., Chan, N. weng, Fei, Z., Kung, H.T., 2021. Using a modified PAP/RAC model and GIS-for mapping water erosion and causal risk factors: case study of the Asfalou watershed, Morocco. Int. Soil Water Conserv. Res, S2095633921000721.

Tairi, A., Elmouden, A., Aboulouafa, M., 2019. Soil erosion risk mapping using the analytical Hierarchy process (AHP) and geographic information system in the Tifnout-Askaoun watershed, southern Morocco. Eur. Sci. J. ESJ 15.

Tairi, A., Elmouden, A., Bouchaou, L., Aboulouafa, M., 2021. Mapping soil erosion–prone sites through GIS and remote sensing for the Tifnout Askaoun watershed, southern Morocco. Arabian J. Geosci. 14, 811.

Taleb, R.B., Naimi, M., Chikhaoui, M., Sabir, M., 2021. Utilisation de SWAT pour la modélisation hydrologique et l'évaluation du rendement des sédiments dans le bassin versant de Nakhla, Mar 14.

Tribak, A., Arar, K., Abahrour, M., El Garouani, A., Amhani, Z., 2015. Quantitative assessment of the hydric erosion and the deposition in a marly catchment of the eastern Rif (case of wadi Tarmast – Morocco). Ann. Valahia Univ. Targoviste. Geographical Series Tome 101–111.

Tribak, A., El Garouani, A., Abahrour, M., 2009. Évaluation quantitative de l'érosion hydrique sur les terrains marneux du PréRif oriental (Maroc) : cas du sous-bassin de l'oued Tlata. Secheresse (Montrouge) 20, 333–337.

Van Oost, K., Govers, G., Desmet, P., 2000. [No title found]. Landsc. Ecol. 15, 577–589.

Verner, D., Treguer, D., Redwood, J., Christensen, J., McDonnell, R., Elbert, C., Konishi, Y., 2018. Climate Variability, Drought, and Drought Management in Tunisia's Agricultural Sector. World Bank, Washington, DC.

Williams, J.R., Berndt, H.D., 1977. Sediment yield prediction based on watershed hydrology. Trans. ASAE (Am. Soc. Agric. Eng.) 20, 1100–1104.

Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Department of Agriculture, Science and Education Administration.

Yjjou, M., Bouabid, R., Hmaidi, A.E., Essahlaoui, A., Abassi, M.E., 2014. Modélisation de l'érosion hydrique via les SIG et l'équation universelle des pertes en sol au niveau du bassin versant de l'Oum Er-Rbia 9.