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

Houda Lamane, Rachid Moussadek, Bouamar Baghdad, Latifa Mouhir, Hamza Briak, Meriem Laghlimi, Abdelmjid Zouahri

Laboratory of Process Engineering and Environment, University of Hassan II, Mohammedia, Morocco
Research Unit on Environment and Conservation of Natural Resources, National Institute for Agricultural Research, Rabat, Morocco
International Center for Agricultural Research in the Dry Areas (ICARDA)
Georesources and Environment Laboratory, Department of Natural Resources and Environment, Hassan II Agronomy and Veterinary Institute, Rabat, Morocco
Center of Excellence for Soil and Fertilizer Research in Africa (CESFRA), AgroBioSciences (AgBS), Mohammed VI Polytechnic University (UM6P), 43150 Ben Guerir, Morocco

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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. 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 applications. 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 is 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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commonly suffered from land degradation and mismanagement (Jazouli et al., 2019). Over the past decades, Morocco has implemented a strategy of the most powerful countries in the field 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., 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 m³ to supply water demand about 11 billion m³. 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 hm³/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 km², 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 different 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 flyshfield 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...
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 (Heausch, 1970) when the first studies of soil erosion started till date 2021 (Elmaldi et al., 2021; Farah et al., 2021b; 2021a; Labbaci et al., 2021; M'Barek et al., 2021; Taouiri et al., 2021; Taiuri et al., 2021; Talbe et al., 2021; Elouidi 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.

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 | Area (ha) | Latitude | Longitude | Dam/Outlet | Model | Erosion rate (t/ha/year) | Paper type | Reference                  |
|-------|----------------|---------------------------|-----------|----------|-----------|------------|-------|--------------------------|------------|---------------------------|
| **Rif** |                |                            |    |         |           |            |       |                          |            |                           |
| Arbaa Ayacha | 19900  | 31°31'21"N | 7°30'7"60"O  | ___           | RUSLE     | 25.77      | Article (Oualalli et al., 2016a) |
| Arbaa Ayacha | 19900  | 31°31'21"N | 7°30'7"60"O  | ___           | PAP/RAC   | Map        | Article (Oualalli et al., 2016b) |
| Asfalou | 81023  | ___           | ___           | Asfalou     | PAP/RAC   | Map        | Article (Tahouri et al., 2021) |
| Bousouab | 25220  | 34°30'34°35"N | 3°35'3°40"W  | ___           | USLE      | 55.35      | Article (Sadiki et al., 2014) |
| El Hachef | 23000  | 34°30'33°50"N | 3°49'4°33"W  | El Hachef    | ___       | 137Cs and 210Po | 20 to 32 Article (Dannati et al., 2013) |
| Inaouene | 370000 | 34°30'33°50"N | 3°49'4°33"W  | Idriss-I     | RUSLE     | 37         | Article (Brighim et al., 2020) |
| Rhmiss | 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 (Brak et al., 2016) |
| Loukos | 78000  | ___           | ___           | ___          | RUSLE     | 10         | Article (Acharki et al., 2022) |
| Nakhlala | 10900  | 35°20'35°28"N | 5°20'5°25"W  | Nakhlala     | 137Cs     | Up to 50   | Article (Bouhlaissa et al., 2000) |
| Nakhlala | 10900  | 35°20'35°28"N | 5°20'5°25"W  | Nakhlala     | 137Cs     | 12 to 29   | Article (Hassouni and Bouhlaissa, 2005) |
| Nakhlala | 11800  | ___           | ___           | Nakhlala     | SWAT      | 11.25      | Article (Taleb et al., 2021) |
| Nekor | 78000  | ___           | ___           | MBAK         | RUSLE/USPED | 38         | Article (Arrebey et al., 2020) |
| Oued El Makhazine | 241400 | 3445°35°15"N | 51°43°5°51"W  | ___           | USLE      | A max of 95 | Article (Bensari and Lakhroui, 2016) |
| Oued El Malleh | 3400   | ___           | ___           | ___          | RUSLE     | 13.95      | Article (El Aroussi, 2013) |
| Oued Haricha | 22100  | ___           | ___           | ___          | USLE      | 62.72      | Article (Tahiri et al., 2016) |
| Oued Tleta | 12300  | ___           | ___           | ___          | RUSLE     | Up to 50    | Article (Garouni et al., 2008) |
| Oued Tleta | 12300  | ___           | ___           | ___          | USLE      | 61         | Article (Trihak et al., 2009) |
| Ouergha | 619000 | 34°25'35°25"N | 3°45'5°24"W  | El Wahda     | RUSLE     | 61.14 to 300 | Article (Jasoud et al., 2020) |
| Ouergha | 730000 | 34°24'35°07"N | 3°05'5°95"W  | El Wahda     | RUSLE/MUSLE | 27         | Conference (Tairi et al., 2021) |
| Raouz | 4700   | ___           | ___           | Raouz        | 137Cs and 210Po | 12 to 16 | Article (Dannati et al., 2013) |
| Sabouin | 720    | ___           | ___           | ___          | USLE      | Up to 30    | Thesis (Moussadek, 1999) |
| Sabouin | 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., 2017a) |
| Wadi Tarmast | 6900   | ___           | ___           | ___          | RUSLE     | 7 to 32     | Article (Trihak et al., 2015) |
| Aoulouz | 444600 | ___           | ___           | Aoulouz      | GIS (Factors) | 4.85  | Conference (Fox et al., 1997) |
| Argana Corridor | ___ | Issen River   | RUSLE       | 47.52       | Article (Boi-imajane 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°45'31°50"N | 6°45'6°51"W  | Hassan-I     | AHP        | Map         | Article (Farah et al., 2021a) |
| El Kiba (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 (Boi-imajane and Belfroid, 2020) |
| Lakhdar | 680000 | ___           | ___           | Hassan-I     | Spectral indices | Map     | Article (Nouain et al., 2019) |
| Lakhdar | 295000 | ___           | ___           | Hassan-I     | AHP        | Map         | Article (Elouidi et al., 2021) |
| Nfis | 170400 | 30°5'31°2"N   | 7°55'8°40"W  | Lalla Takerkoust | SWAT      | 131        | Article (Markhi et al., 2019) |
| Nfis | 170400 | 30°5'31°2"N   | 7°55'8°40"W  | Lalla Takerkoust | RUSLE/SEDD | 54         | Article (Gourfi, 2019) |
| Ourazzarate | 58,977 | ___           | ___           | El Mansour El Kaddabi | Sentinel 2 A | Map         | Article (Farah et al., 2021b) |
| Oued El Abid | 311900 | ___           | ___           | Bin El Ouidane | InteRO/EPFM | 402       | Conference (El Mouataamine et al., 2019) |

(continued on next page)
| Zone      | Watershed/Area                        | Watershed characteristics | Model          | Erosion rate (t/ha/year) | Paper type | Reference                  |
|-----------|--------------------------------------|---------------------------|----------------|--------------------------|------------|----------------------------|
|          |                                      | Area (ha)                  | Latitude       | Longitude                |            |                            |
|          |                                      |                           |                |                          |            |                            |
|          |                                      | 57600                     | 31°31’-31°21’N | 7°30’-7°60’W             | RUSLE      | 380                        | Article (Modeste et al., 2016) |
|          |                                      | 57600                     | 31°31’-31°20’N | 7°30’-7°60’W             | RUSLE      | 380                        | Article (Modeste et al., 2016) |
|          |                                      | 57300                     | 31°31’-31°20’N | 7°30’-7°60’W             | SWAT       | 2 to 59                    | Conference (Imlalki et al., 2021) |
|          |                                      | 50300                     | 31°31’-31°20’N | 7°30’-7°60’W             | InVEST-SDR | 258.48                     | Article (Ayt Ougougda et al., 2020) |
|          |                                      | 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) |
|          |                                      | 2045                      | 30°50’-32’10’N | 7°12’-9°25’W             | RUSLE      | 44.03                      | Article (Melibo et al., 2019)   |
|          |                                      | 141800                    | 31°33’-31°64’N | 6°48’-7°33’W             | USLE       | 15.44                      | Article (Blaoua et al., 2017) |
|          |                                      | 148800                    | 30°5’-35°0’5’N | 7°37’-8°11’W             | RUSLE      | 14.44                      | Article (Tairi et al., 2021) |
|          |                                      | 128400                    | 30°56’-31°23’N | 7°00’-7°36’W             | Spectral indices | Map | Article (Ouchtaz et al., 2021) |
|          |                                      | 443500                    | 32°05’-32°64’N | 4°11’-5°46’W             | RUSLE      | 489.5                      | Conference (Fenjiri et al., 2020) |
|          |                                      | 153100                    | 32°35’-35°3’N  | 5°05’-5°50’W             | El Hansali | RUSLE                       | 224                        | Article (Yjou et al., 2014) |
|          |                                      | 361200                    | ---            | ---                      | El Hansali | CA_Marcov/RUSLE             | 142                        | Article (Jazouli et al., 2019) |
|          |                                      | 5500                      | 32°32’-32°40’N | 5°50’-5°58’W             | USLE/Spectral indices | 0.68 | Article (El Jazouli et al., 2017) |
|          |                                      | 535000                    | ---            | ---                      | ---         | 3.95/2.94                  | Conference (Bouafa et al., 2020) |
|          |                                      | 430728                    | ---            | ---                      | El Kansra  | USLE                        | 19.40                      | Article (Gastil and Larabi, 2014) |
|          |                                      | 144300                    | 32°35’-35°3’N  | 5°05’-5°50’W             | LEAM       | 1.1                        | Article (Blouqaoua et al., 2005) |
|          |                                      | 54915                     | 33°30’-50°50’N | 4°37’-5°06’W             | PAP/RAC    | Map                         | Conference (Oussama et al., 2017) |
|          |                                      | 549500                    | 33°34’-34°N    | 4°03’-5°20’W             | Allal El Fassi | SWAT                       | 6.51                      | Article (Bouafa et al., 2020) |
|          |                                      | 1718600                   | 29°70’-31°11’N | 7°47’-9.6W               | Atlantic Ocean | EPM                    | 1.81                        | Article (Ahmed et al., 2019) |
|          |                                      | 1570000                   | ---            | ---                      | Aoulouz/Mokhtar Soussi | AHP         | Map                         | Article (Tairi et al., 2019) |
|          |                                      | 957000                    | 34°00’-33°00’N | 6°40’-5°35’W             | SMBA       | SWAT                        | ---                        | Article (Fadl et al., 2011) |
|          |                                      | 395600                    | ---            | ---                      | SMBA       | ---                        | 13.81                      | Article (Adilmoussib et al., 2019) |
|          |                                      | 545                       | 33°06’43’N     | 7°24’21’W                | SMBA       | USLE                        | 1.1                        | Article (Azararf et al., 2020) |
|          |                                      | 1013000                   | 34°00’-33°00’N | 6°40’-5°35’W             | SMBA       | USLE                        | 2.7                        | Article (Ezzouine et al., 2020) |
|          |                                      | 350000                    | ---            | ---                      | Ras El Fathia | SWAT                       | 11.3                      | Article (H'Barek et al., 2021) |
|          |                                      | 63600                     | 33°00’-33°45’N | 6°40’-6°52’W             | SMBA       | 137Cs/7Be                   | 8 to 58                    | Conference (Bernansour et al., 2016) |
|          |                                      | 63600                     | 33°00’-33°45’N | 6°40’-6°52’W             | SMBA       | 137Cs/210Phex               | 12 to 14                   | Article (Bernansour et al., 2013) |
|          |                                      | 1                         | 33°470 N       | 6°420W                   | ---         | 137Cs/7Be                   | 8 to 58                    | Conference (Bernansour et al., 2016) |
|          |                                      | 13800                     | ---            | ---                      | USLE       | 20                         | Article (AOU et al., 1994) |
|          |                                      | 0.3                       | 33°37’W        | 7°25N                    | Oued El Maleh | 137Cs                       | 82                        | Article (Nouira et al., 2003) |
|          |                                      | 257700                    | 3290-3376N     | 660-756E                 | Oued El Maleh | USLE                        | 8.21                      | Article (Ihaba et al., 2015) |
|          |                                      | ---                       | ---            | ---                      | ---         | USLE                        | 8 to 58                    | Conference (Bernansour et al., 2016) |
|          |                                      | 4006000                   | 33°35’N        | 6°38°4’15’W              | RUSLE      | 86                         | Article (Chadi, 2016) |
|          |                                      | 99932                     | ---            | ---                      | SWAT        | A max of 5.20               | Thesis (Boukthir et al., 2020) |
|          |                                      | 131200                    | ---            | ---                      | RUSLE       | 21.78                      | Article (Dreiss and Ibrahim, 2018) |
|          |                                      | 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) |
|          |                                      | ---                       | ---            | ---                      | ---         |                            |                            |                            |

**Continued...**
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: 137Cs (Caesium-137), Spectrales indices, MUSLE (Modified Universal Soil Loss Equation) (Williams and Berndt, 1977), PAP/RAC (Priority Action Program of the Regional Activity Center), 137Cs and 210Pb (Caesium-137 and plomb-210), EPM (Erosion Potential Model) (Gavrilovic, 1972), AHP (Analytic Hierarchy Process) (Saaty, 1977), 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).

Importantly, the (R) USLE are the commonly used models compared to other ones. However, the calibration and validation processes of these models and fingerprints 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.

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) |
| 137Cs         | 5       | 6.58  | -                           |
| Spectrales indices | 5   | 6.58  | -                           |
| MUSLE         | 4       | 5.27  | (Williams and Berndt, 1977) |
| PAP/RAC       | 3       | 3.96  | -                           |
| 137Cs and 210Pb | 2     | 2.63  | -                           |
| EPM           | 2       | 2.63  | (Gavrilovic, 1972)          |
| AHP           | 2       | 2.63  | (Saaty, 1977)               |
| STREAM        | 1       | 0.31  | (Cerdan et al., 2002)       |
| WaTEM/SEDEM   | 1       | 0.31  | (Van Oost et al., 2000)     |
| IntErO        | 1       | 0.31  | (Spalevic, 2011)            |
| LEAM          | 1       | 0.31  | (Manrique, 1988)            |

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
soil fertility. Indeed, the extent of soil erosion is very significant, especially in some regions, such as siltation of reservoir dams, decrease in water quality, and loss of land productivity. These areas are the most seriously threatened and the environmental impacts of soil erosion have been observed, leading to landslides, and steep slopes. These areas are the most seriously threatened and the environmental impacts of soil erosion have been observed, leading to landslides, and steep slopes.

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 Nfis 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.

Additional information

No additional information is available for this paper.

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