ISSN: 2977-0041

Review Article

Journal of Material Sciences and Engineering Technology

SWAT Modele Applications in Morocco: A Review

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Received: December 18, 2025; **Accepted:** December 24, 2025; **Published:** January 02, 2026

ABSTRACT
This work attempt to identify conducted Swat studies in Morocco and determine main gaps and challenges of these studies. Search was done on « Science Direct », « Research Gate » and the SWAT webset database. A total of 38 articles and research reports were identified and reviewed over a period of 15 years (2008-2023). 41% of these studies were carried out during the last three years which demonstrates the growing interest in the Swat tool. Surface area of the studied watersheds varies between 38 and 39000 km2. Major topographic and climatic regions of Morocco are represented including mountains, hills and floodplains under humid, sud-humid and semi-arid climate. These studies are categorized into four areas: water ressources management, erosion and sediment yield, landuse management and climate change scenarios. Analysis of all this data made it possible to give a feel of how the Swat model is used in Moroccan context.

Keywords: Model, SWAT, Hydrology, Morocco, Semi-Arid

Introduction

The Soil and Water Assessment Tool (SWAT) have gained international acceptance as a robust interdisciplinary watershed modeling tool, distinguished for its ability to simulate complex land-use, soil, and water management interactions [1]. Consequently, it is widely recognized as one of the top hydrological models applied globally to address critical hydrologic, environmental, and water quality issues [2]. In the Mediterranean region, characterized by climatic variability, water scarcity, and anthropogenic pressures, robust modeling frameworks are essential for sustainable water resource management. SWAT has proven to be adaptive and flexible enough to successfully simulate diverse Mediterranean watersheds, demonstrating its utility in capturing the unique hydrological dynamics of this climatic zone [3]. In Morocco, a North African nation facing significant water stress, the application of such a powerful model is of paramount importance. This article provides a comprehensive review of the current status of SWAT applications across Moroccan territories. It examines the model's deployment in addressing local challenges such as rainfall-runoff modeling, soil erosion assessment, land-use change impact, and climate change scenarios. By synthesizing existing research, this review aims to highlight key achievements, identify research gaps, and discuss future directions for leveraging the SWAT model to support informed and sustainable water resource planning and policy-making in Morocco.

Inventory of Hydrologic SWAT Applications in Morocco

The application of the SWAT model in Morocco encompasses the majority of the nation's principal watersheds, with the notable exception of the eastern Moulouya basin, as indicated in Figure 1. This body of work spans diverse physiographic and climatic domains, from mountainous terrains and alluvial plains to humid and hyper-arid zones. A geographical analysis reveals a concentration of studies, with 59% of documented applications focused on northern Morocco, particularly the North West region and the Sebou basin (Figure 1). The Oum Er Rbiaa and Tensift basins each account for 10% of applications, while the remaining 21% are distributed across the Atlantic coastal basins, Souss, and Daraa. It is pertinent to note that the total number of SWAT applications (n=39) exceeds the count of distinct watersheds studied (n=28), indicating that several basins have been the subject of multiple, potentially complementary, investigations (Table 1). The scale of analysis

Citation: Mohamed Yacoubi. Impact of the COVID-19 Pandemic on Public Procurement and Market Prices. J Mat Sci Eng Technol. 2026. 4(1): 1-5.
DOI: doi.org/10.61440/JMSET.2026.v4.91

varies significantly, with studied catchment areas ranging from 18 km² to 40,000 km². The majority of applications (57%) have been conducted on medium-sized watersheds with areas between 1,000 and 10,000 km². Comprehensive modeling efforts have been directed at Morocco's two largest river systems, the Sebou and Oum Er Rbiaa basins, employing both full-basin and nested sub-basin approaches.

Table 1: SWAT applications in Morocco

Application N°	watershed	author	Year of publication
1	Rhiraya	Chaponnière et al.[4]	2008
2	Sebou	Terink et al. [5]	2011
3	Bouregreg	Fadil et al. [6]	2011
4	Oum Erbiaa	Kharchaf et al. [7]	2013
5	Bab Merzouka	Bouslihim et al. [8]	2016
6	Kalaya	Briak et al. [9]	2016
7	Mikkés	Chadli[10]	2017
8	Rdom	Brouzyine et al. [11]	2017
9	Laou	Semlali et al. [12]	2017
10	R'dom	Brouzyine et al. [13]	2018
11	Beht	Mimich et al. [14]	2018
12	Tleta	Choukri et al. [15]	2019
13	Kalaya	Briak et al. [16]	2019
14	Laou	Aqnouy et al. [17]	2019
15	N'fis	Markhi et al. [18]	2019
16	Allal_El_ Fassi	Boufala et al. [19]	2019
17	Tamedroust	Bouslihim et al. [20]	2019
18	Arbaa Ayacha	Ouallali et al. [21]	2020
19	Oum Er Rbia	Meliewski et al. [22]	2020
20	Innaouene	Moumen et al. [23]	2020
21	Mazer	Bouslihim et al. [24]	2020
22	Tleta	Choukri et al. [25]	2020
23	Bouregreg	Brouzyine et al. [26]	2020
24	Ourika	Elmalki et al. [27]	2021
25	Ouergha	Taia et al. [28]	2021
26	Mdez	Boufala et al. [29]	2021
27	Tleta	El Harche et al. [30]	2021
28	Nakhla	Boukhari Taleb et al. [31]	2021
29	Bin El Ouidane	El Harraki et al. [32]	2021
30	Grou	Ait M'Barek et al. [33]	2021
31	Ouergha	Erraioui et al. [34]	2022
32	Rdom	Alitane et al. [35]	2022
33	Tata	Echogdali et al. [36]	2022
34	Rdom	Alitane et al. [37]	2022
35	Souss	Kusi et al. [38]	2023
36	El Abid	Taia et al. [39]	2023
37	Loukkos	Acharki et al. [40]	2023
38	Ouergha	Erraioui et al. [41]	2023
39	N'fis	Joumar et al. [42]	2023

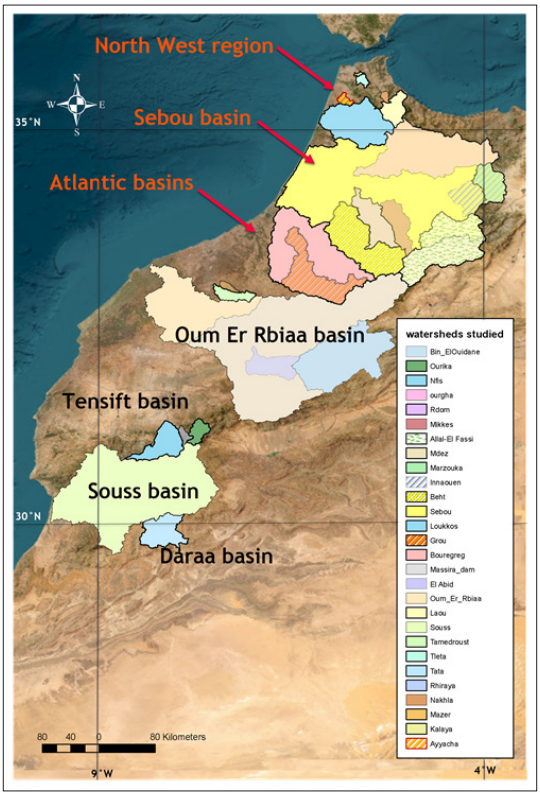

Figure 1: Geographical Distribution of SWAT Application Watersheds in Morocco

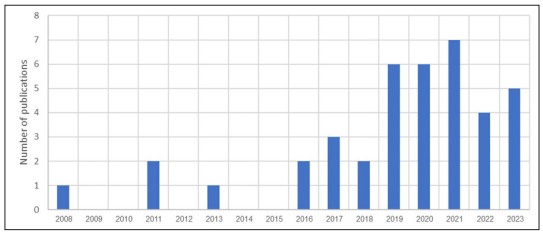

Figure 2: Trend of the SWAT published papers since 2008

Categorization

Water Resources Studies

The Soil and Water Assessment Tool (SWAT) have been extensively utilized in Moroccan hydrologic research to address diverse water resource management challenges. Its application

spectrum includes the quantification of mountainous water resources, the estimation of reservoir inflows, and the replication of hydrological processes across varied catchment typologies, from pilot-scale watersheds to larger basins [4,6-8,11]. Furthermore, SWAT has demonstrated robust performance in environmentally sensitive and complex terrains. It has been validated in erosion-prone landscapes, applied for monthly flow assessment supporting reservoir operations, and implemented in distinctive karstic systems [12,17,14,23].

Recent applications reflect methodological advancements and refined research questions. Studies have investigated the sensitivity of model outputs to input data resolution, such as soil characteristics and land-use maps [20,32]. The adoption of the updated SWAT+ framework has enabled enhanced quantification of water balance components [35]. SWAT has also been leveraged to model cryospheric processes, including snow cover dynamics in High Atlas watersheds, and to conduct integrated analyses of major dam catchments [39,41]. Finally, successful calibration and validation in challenging mountainous environments further attest to the model's adaptability [42].

Soil Erosion and Sedimentation Studies

The severity of soil erosion in Morocco, particularly within the Rif Mountain region, is substantiated by a substantial body of research employing the Soil and Water Assessment Tool (SWAT) model. This concentration of studies demonstrates the model's robust applicability across varied Moroccan watersheds for quantifying sediment dynamics. Research has systematically applied SWAT to key objectives: predicting suspended sediment yield (e.g., Kalaya watershed), generating spatial sediment yield maps (e.g., Mikkes and Nakhla Dam watersheds), and simulating integrated hydro-sedimentary processes (e.g., Tleta watershed) [9,10,31,15]. Model applications have proven critical for assessing reservoir siltation impacts, with validated studies on the Lalla Takerkoust and Allal El Fassi reservoirs, the latter corroborated by bathymetric data [18,19]. SWAT has also been deployed to estimate specific soil loss rates, yielding averages from 9.18 to 28 tons ha^{-1} yr^{-1} in watersheds such as Ourika, El Grou, and Ayyacha [27,33,21]. Furthermore, methodologies have been developed to extrapolate calibrated parameters to ungauged basins, and the model has been utilized for predictive siltation assessment in planned dam reservoirs within arid contexts [24,36]. Collectively, these applications validate SWAT as an effective tool for diagnosing erosion severity and informing soil conservation strategies in Morocco.

Climate Change Impact

Climate change presents a critical threat to global and regional hydrological systems, driving a focused research agenda to quantify its impacts, develop adaptive management strategies, and promote sustainable freshwater use to bolster ecosystem and societal resilience. The Soil and Water Assessment Tool (SWAT) have been widely applied in Morocco to project climate change effects on water resources. Studies consistently project declines in key hydrological components. For instance, in the Souss watershed, SWAT simulations indicate reduced groundwater recharge (-17.6%) and surface runoff (-13.8%) [22]. Research on the Nakhla dam highlights compounded pressures, showing that coupled climate and land-use change scenarios could reduce annual dam inflow by 9.9–33.3% and sediment yield by 28.7–45.8% [25]. Vulnerability assessments for the Bouregreg watershed project severe water deficits (-46% to -96%) by the end of the century, with an increased frequency of dry years [26]. Analyses of dam inflows further reveal not only volumetric declines but also hydrological regime shifts, such as a delayed peak inflow from December to January for the Ouergha dam [34]. Projections for other basins, including the Souss [38] and Loukkos, underscore this trend, with the latter showing potential streamflow reductions of up to -96.3% by 2071–2100 under severe scenarios [40]. This collective evidence underscores the urgent need for robust water resource planning and adaptation in the face of a changing climate.

Best Management Practices

Best Management Practices (BMPs) are structured strategies implemented at the watershed scale to mitigate anthropogenic impacts on water resources, with the dual objectives of preserving water quality and quantity and controlling processes such as water erosion. The Soil and Water Assessment Tool (SWAT) have been instrumental in evaluating the efficacy of specific BMPs across Moroccan watersheds. A foundational application by [5] in the Sebou basin simulated three soil conservation measures—stone lines, bench terraces, and contour tillage—demonstrating their potential to reduce reservoir sediment inflow while simultaneously enhancing groundwater recharge. Subsequent research has quantified these sediment reduction benefits. In the Kalaya watershed, found that terracing and strip-cropping decreased sediment yield by 28% and 9%, respectively, whereas contouring alone increased yield by 31% [16]. Similarly, in the Mdez watershed, a study modeled the impact of BMPs on the projected siltation rate of a proposed dam, reporting a 2.5% reduction with contour tillage and a more substantial 57.5% reduction when combined with afforestation [29]. These studies collectively validate the utility of SWAT for simulating and optimizing BMP scenarios to achieve targeted sediment control and water conservation outcomes.

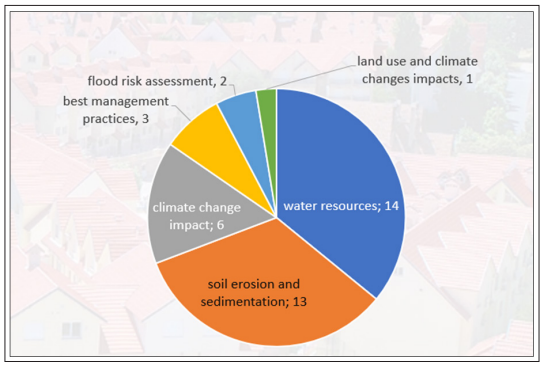

Figure 3: Number of SWAT applications per category

Conclusion

This review synthesizes 15 years of SWAT model applications across diverse Moroccan watersheds, revealing its established utility as a robust hydrological tool for addressing critical water resource challenges. The analysis of 39 studies demonstrates that SWAT has been successfully employed in four primary domains: water resources assessment, soil erosion and sediment yield quantification, evaluation of best management practices (BMPs), and climate change impact projections. The model has proven adaptable to Morocco's varied physiographic and

climatic contexts, from humid northern mountains to semi-arid and arid regions, effectively simulating processes from snowmelt dynamics to reservoir siltation.

Notably, applications are geographically concentrated in northern basins (59%), highlighting a research gap in eastern and southern regions. Key findings underscore severe projected climate change impacts, including significant reductions in streamflow, groundwater recharge, and dam inflows, coupled with shifts in hydrological regimes. Furthermore, SWAT-based evaluations confirm the efficacy of soil conservation BMPs, such as terracing and contour tillage, in mitigating sediment yield and enhancing water conservation.

Despite its widespread adoption, challenges remain, including reliance on limited local data and the need for more integrated assessments combining land-use and climate scenarios. Future research should prioritize expanding geographical coverage, enhancing model calibration with localized data, and employing SWAT to foster integrated water resource management strategies. This will be crucial for informing sustainable policy and adaptation planning in Morocco's water-stressed environments.

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