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XIX WORLD WATER CONGRESS
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Kingdom of Morocco
Ministry of Equipment and Water

Soil Erosion Risk Assessment using the RUSLE Model, Remote Sensing, GIS, and Hydrological Modeling in Ksob Watershed, Tensift, Morocco

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02-12-2025

Presenting on behalf of:

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Outline

1- Introduction & Motivation
2- Research objective
3- Research approach
4- Study area presentation
5- RUSLE model
6- SWAT model
7- Conclusion and perspectives

1- Introduction & Motivation

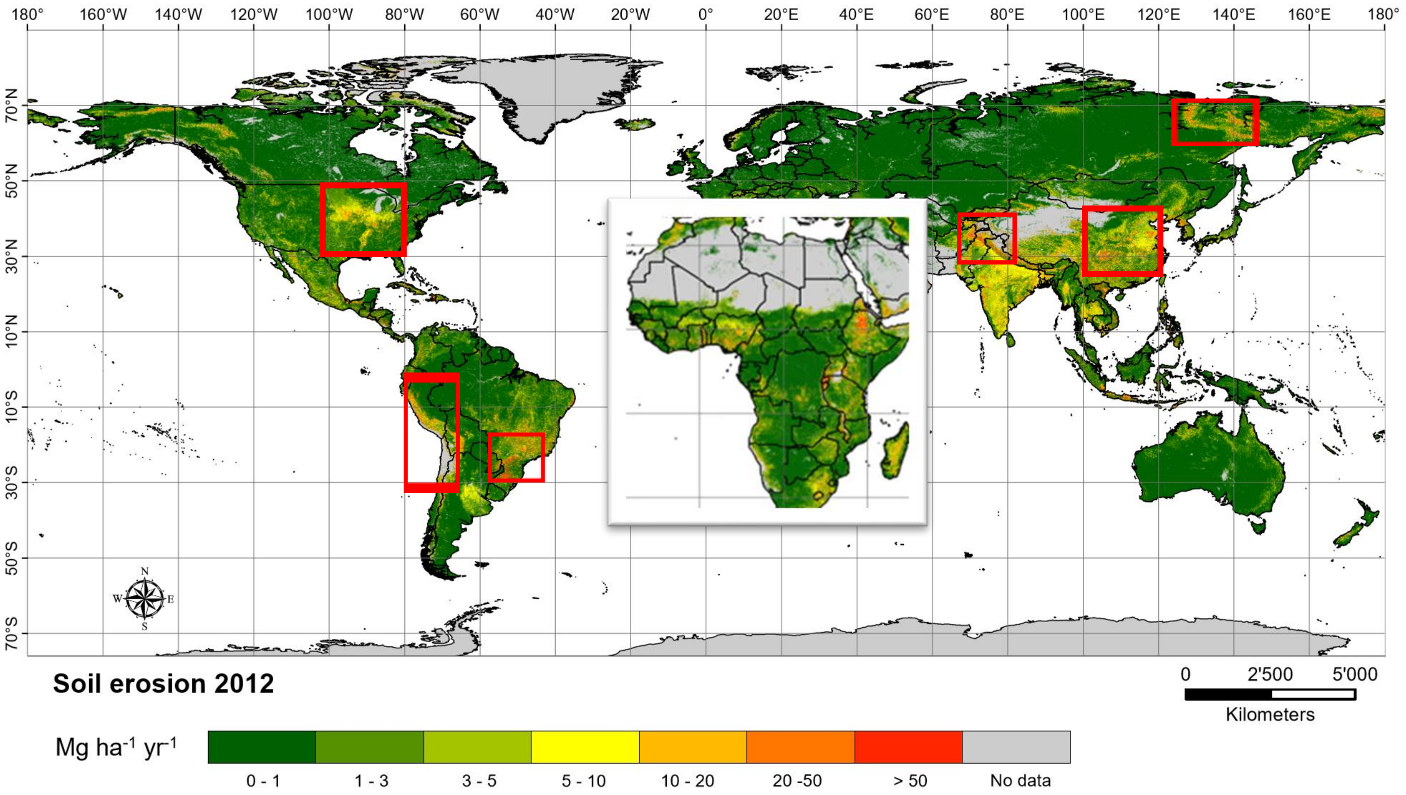


Fig. 1: Global soil erosion map (2012) produced using a RUSLE-based GIS modelling approach [1]

- The world loses ~**36 billion tonnes** of soil per year.
- Croplands produce ~**50%** of total erosion.
- Many regions exceed the tolerable threshold of **10 t/ha/yr.**
- Africa among the most affected continents by soil erosion [1].
- A **10%** increase in just 10 years (2001–2012).
- Strong impacts on agriculture, water security, hydropower & reservoir storage.
- Sedimentation increases turbidity and reduces reservoir lifespan.

1- Introduction & Motivation

Fig. 2: Soil erosion in Morocco (Illustrative examples)

- **40%** of Moroccan territory exposed to moderate–severe degradation [2].
- **2 million ha** agricultural land degraded by water erosion [3].
- Erosion rates range between **5–20 t/ha/yr**, up to **50 t/ha/yr** in northern mountains [4, 5].
- Reservoir storage loss: **75 million m³/year** (≈ one medium dam/year) [3].
- Current erosion assessment methods lack the precision and accuracy needed to identify sediment sources and capture true sediment dynamics [6, 7, 8].
- **A robust, integrated framework is urgently needed to identify erosion hotspots and support effective mitigation.**

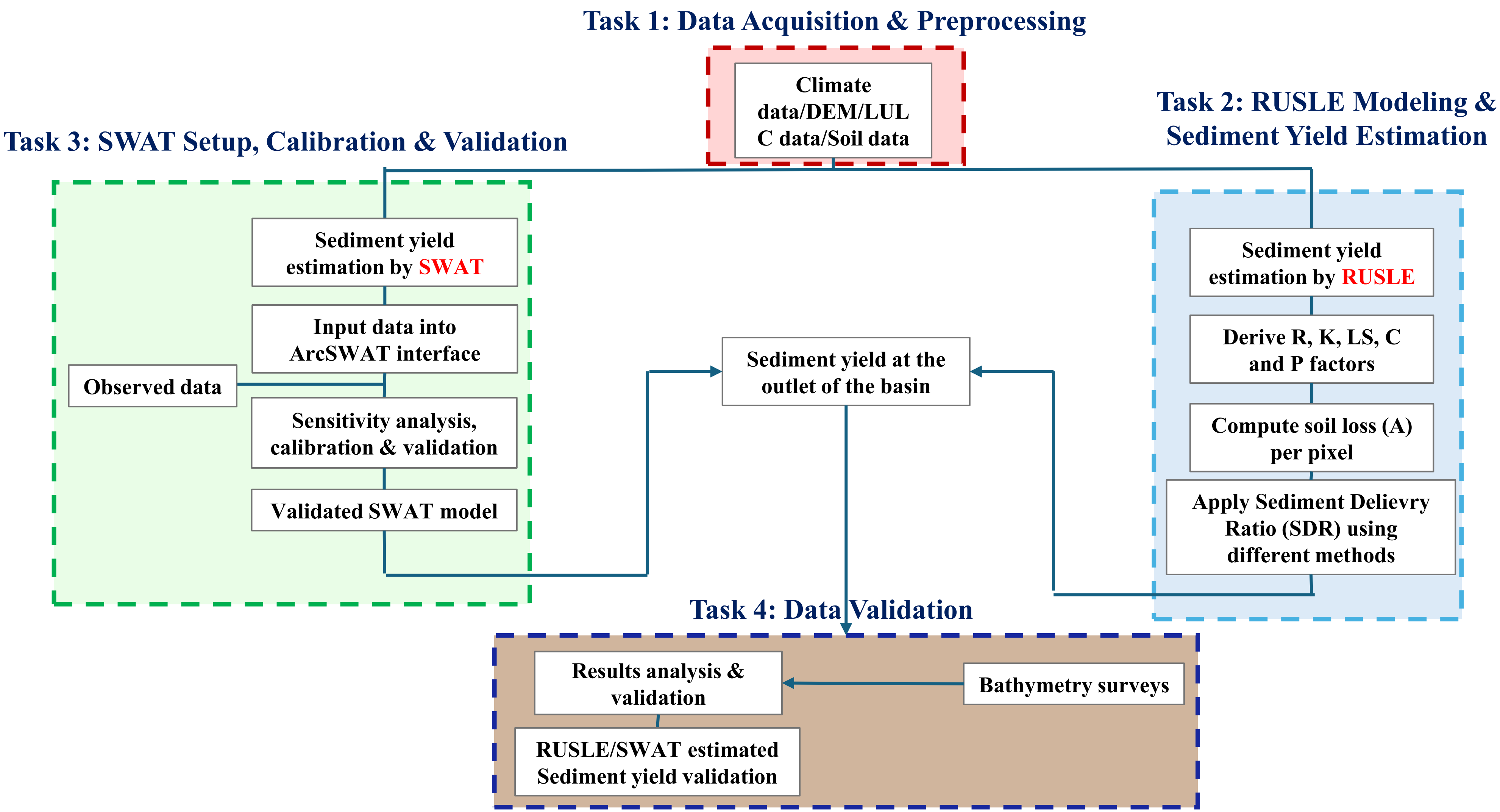
2- Research objective

This study aims to enhance soil erosion assessment in Morocco by integrating RUSLE–GIS analysis, advanced remote sensing, isotope techniques, hydrological modeling, and field measurements.

Specific objectives:

- ✓ Quantify soil erosion rates in the Ksob watershed using the RUSLE equation integrated with GIS and high-resolution remote sensing.
- ✓ Calibrate and validate SWAT hydrology and sediment outputs using field data, discharge observations, and available sediment information.
- ✓ Cross validate sediment yield using bathymetric surveys from the Moulay Abderrahman reservoir.
- ✓ Incorporate isotopic and remote sensing indicators to improve sediment source attribution.
- ✓ Develop a robust DSS tool combining modeling outputs, spatial indicators, and field evidence to guide mitigation strategies and support decision makers.

3- Research approach



4- Study area presentation

- Ksob watershed is localized on Atlantic coast of Morocco, southest of Essaouira city and extends over an area of **1245,98 Km²**

- The Ksob watershed is divided into three sub-basins: **Igrounzar**, **Zelten**, and **Adamna** in the northwest. The main river, Oued Ksob, is formed by the confluence of Oued Igrounzar and Oued Zelten, just upstream of the Moulay Abderrahman Dam

- ***Climate***: Semi-arid region with average annual rainfall below **300 mm/year** and an average temperature around **20 °C**

- Bathymetric surveys indicate a storage loss of **7.34 Mm³** between **2014 and 2022**, corresponding to an average sedimentation rate of **0.92 Mm³/yr** (Source: DRPE).

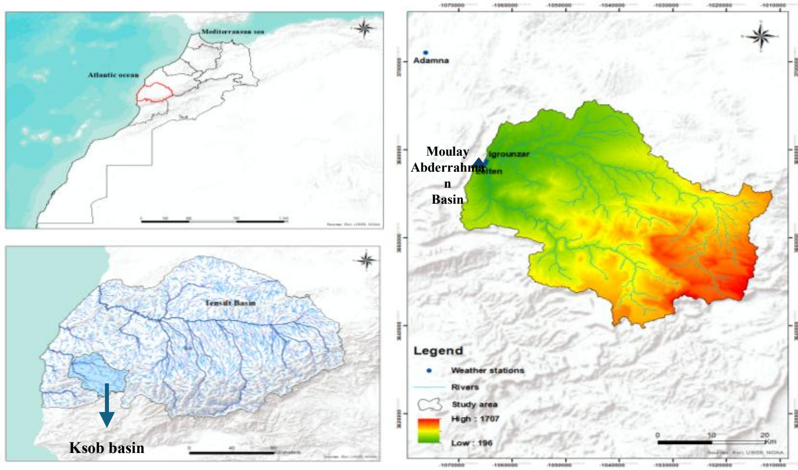


Fig. 3: Geographic location of Tte study area

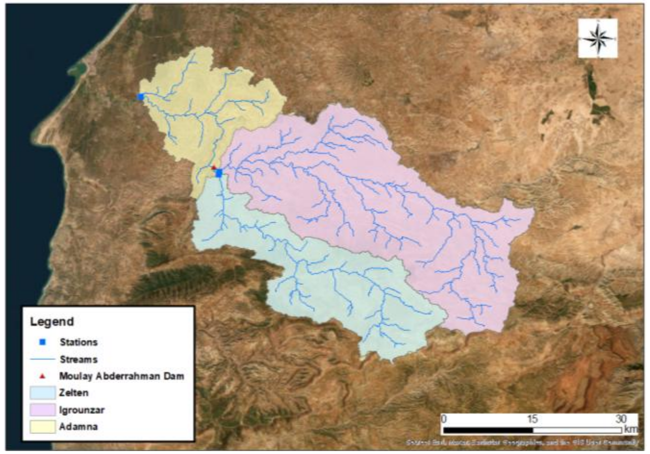


Fig. 4: Subbasins of Ksob watershed

5- RUSLE model

➢ Soil loss equation

$$A = R \times K \times LS \times C \times P$$

$$Log(R) = 1{,}74 \times \log\left(\sum \frac{p_i^2}{p}\right) + 1{,}29$$

$$LS = \left(\frac{Flowaccumulation * cellsize}{22.13}\right)^{0.4} \left(\frac{Sin\,(\theta * 0.01745)}{0.0896}\right)^{1.3}$$

P = 1

Classes	C-factor
Built-up land	0.003
Forest	0.004
Bare land	1
Water body	0
Agriculture	0.4
Uncultivated land	0.75

$$K_{usle} = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand} \times 0.1317$$

Where:

- A is the soil loss (t ha^{-1} yr^{-1})
- R is the rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1})
- K is the soil erodibility (t h MJ^{-1} mm^{-1})
- LS is the slope steepness-length factor
- C is the soil use and management factor
- P is the soil conservation practice factor
- Pi is the average monthly precipitation (mm)
- P is the average annual precipitation(mm)
- f_{csand} is a factor that lowers the K indicator in soils with high coarse sand content and increases it for soils with low sand content
- f_{cl-si} gives low erodibility factors for soils with high clay/silt ratio
- f_{orgc} reduces K values in soils with high organic carbon content
- f_{hisand} lowers the K values for soils with very high sand content
- θ is the slope angle (in degree)

5- RUSLE model

- **RUSLE inputs**

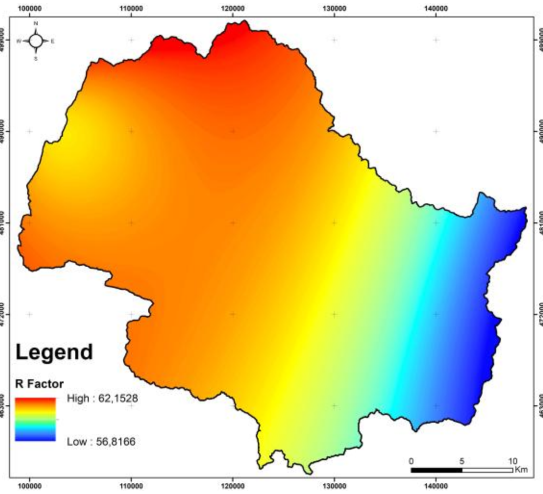


Fig. 5: Rainfall erosivity factor map using daily precipitation from Igrounzar, Iloudjane and Adamna stations (1989-2013)

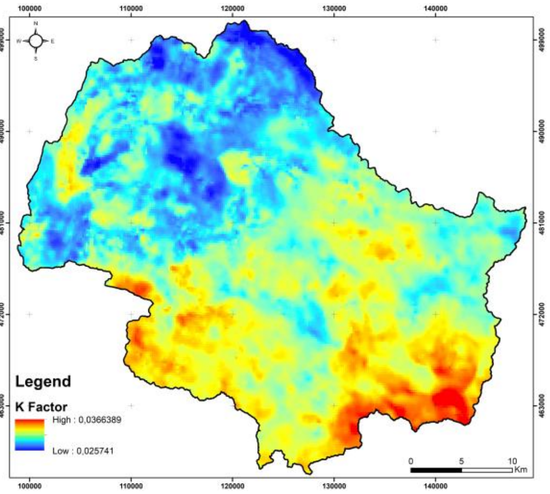


Fig. 6: Soil erodibility factor map using soil characteristics from ISRIC

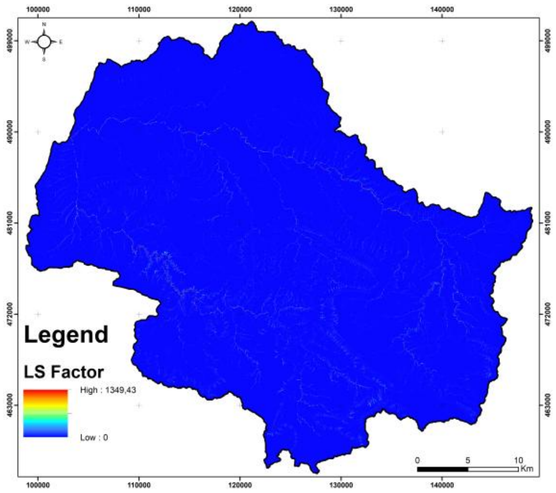


Fig. 7: Slope length and steepness factor map using DEM map based on SRTM DEM-30m

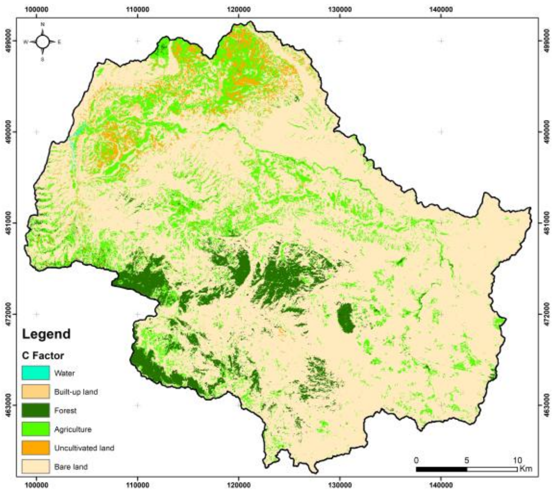


Fig. 8: Cover management factor map using Landsat images

5- RUSLE model

- RUSLE soil loss estimation

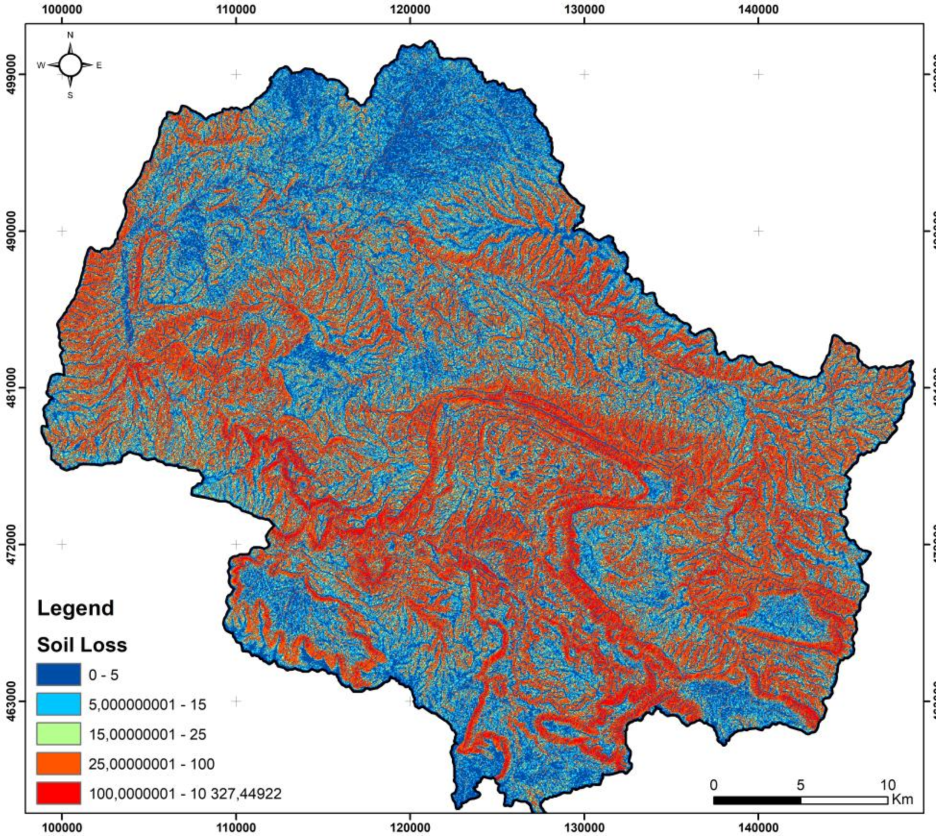


Fig. 9: Annual soil loss map (t/ha/yr)

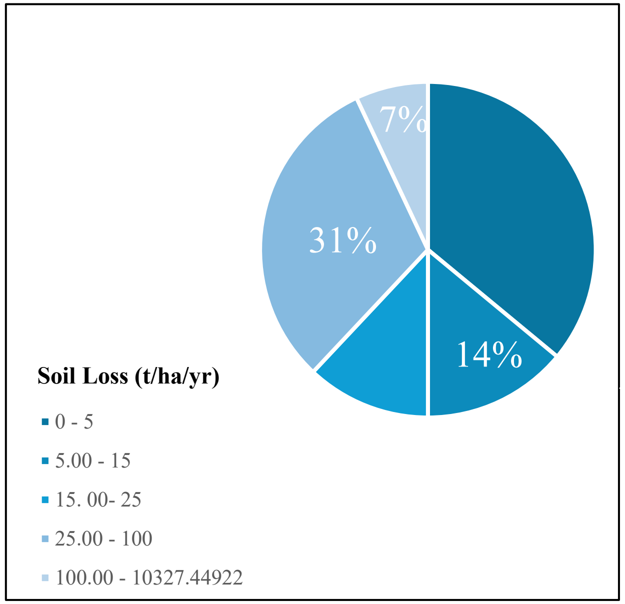


Fig. 10: Distribution of soil loss classes in the Ksob watershed

Minimum	Maximum	Mean
0	10327.45	32.83

Table 1: Minimum, maximum and mean soil loss (t/ha/yr)

5- RUSLE model (from soil loss to sediment yield at the basin outlet)

➢ Empirical SDR Methods

Row	Method	Formula	Parameters
1	Maner (1962)	Log(SDR)=1.8768−0.14191Log(25.98A)	A:Watershed area (Km^2)
2	Renfro (1975)	Log(SDR)= 2.94259+0.82362*log(R/L)	R: Maximum height of the watershed - height at the outlet (km) L: Maximum length of the watershed measured parallel to the main watercourse (km)
3	Vanoni (1975)	$SDR=0.42*2.589.A^{-0.125}$	A:Watershed area (Km^2)
4	Larence (1998)	$SDR=A^{-0.2}$	A:Watershed area (Km^2)
5	Boyce(1975)	$SDR=0.3750A^{-0.2382}$	A:Watershed area (Km^2)
6	USDA-SCS(1979)	$SDR=0.51A^{-0.11}$	A:Watershed area (Km^2)
7	USDA-SCS(1971)	$SDR=0.332A^{-0.2236}$	A:Watershed area (Km^2)
8	USDA-SCS(1983)	$SDR=0.417762A^{-0.134958}-0.127097$	A:Watershed area (Km^2)
9	USDA-SCS(1972)	$SDR=0.5656A^{-0.11}$	A:Watershed area (Km^2)

Table 2: Empirical SDR methods and their formulations

Method	SDR
Maner (1962)	0,17
Renfro (1975)	0,32
Vanoni (1975)	0,45
Larence (1998)	0,24
Boyce(1975)	0,07
USDA-SCS(1979)	0,23
USDA-SCS(1971)	0,07
USDA-SCS(1983)	0,03
USDA-SCS(1972)	0,26

Table 3: SDR values for each method

5- RUSLE model (from soil loss to sediment yield at the basin outlet)

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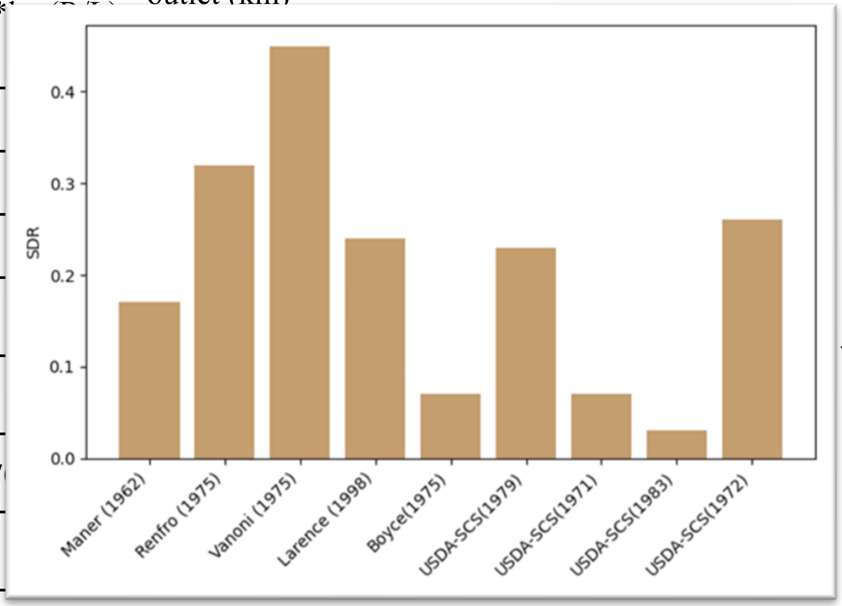

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5- RUSLE model (from soil loss to sediment yield at the basin outlet)

➢ Observed vs simulated sediment yield

$$SSY_{obs} = 100 * \frac{SV * dBD}{A * STE}$$

-**SSY $_{obs}$**: observed suspended sediment yield (t/ha/yr)
-**SV**: the measured volumetric sediment input (m3/yr)
-**dBD**: the dry sediment bulk density of the sediment (t/m3)= 1.3 t/m3 for Morocco
-**A**: the catchment area in ha
-**STE**: the sediment trap efficiency %

$$STE = 100 * (1 - \frac{1}{(1 + D * (\frac{C}{A})})$$

-**C**: the capacity of the reservoir (m3)
-**A**: the drainage basin of the watrshed (km2)
-**D**: a constant between 0.046 and 1, for the case of Morocco, a mean of 0.1 is used

⇩

SSY $_{obs}$ = 9,6 t/ha/yr (using bathymetry data from 2014 to 2022)

$$SSY_{sim} = A * SDR$$

-**SSY $_{sim}$**: simulated suspended sediment yield (t/ha/yr)
-**A**: soil loss (t/ha/yr)
-**SDR**: sediment delivery ratio

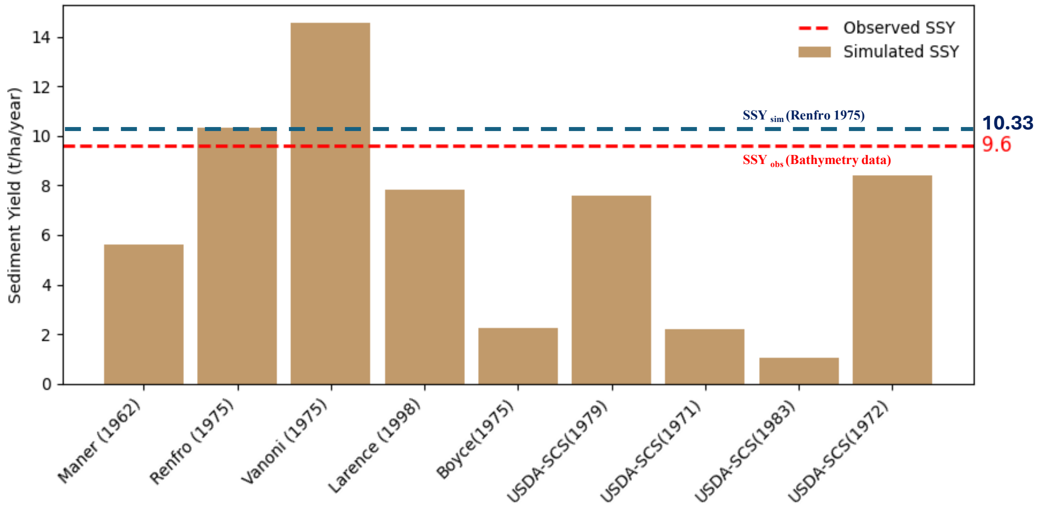

Fig. 11: Comparison of observed and modeled Sediment Yield

5- RUSLE model

➢ **Limitations of empirical SDR methods**

01 – Not physically based

02 – Developed for specific regions

03 – Ignore sediment connectivity

04 – Use a single SDR value for the whole watershed

05 – No representation of spatial and temporal variability

6- SWAT model

➢ SWAT equations

Soil & Water Assessment Tool | SWAT

Water Balance Equation

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_t - W_{seep} - Q_{gw})$$

- SW_t : Teneur en eau de su sol à l'instant t (en mm),
- SW_0 : Teneur en eau initiale du sol (en mm)
- t : Temps (en jours)
- R_{day} : Quantité de précipitations au jour i (en mm),
- Q_{surf} : Quantité de ruissellement de surface au jour i (en mm)
- E_t : Quantité d'évapotranspiration au jour i (en mm),
- W_{seep} : Quantité est la quantité d'eau pénétrant dans la zone vadose à partir du profil du sol au jour i (en mm),
- Q_{gw} : Quantité de flux de retour au jour i (en mm),

MUSLE (Modified Universal Soil Loss Equqtion

$$sed = 11.8 \cdot (Q_{surf} + q_{peak} \cdot area_{hru})^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG$$

- sed : Production de sédiments (tonnes),
- Q_{surf} : Ruissellement de surface (mm)
- q_{peak} : Débit de pointe du euissellement (m3/s)
- A_{aire} : Superficie du bassin versant ou de l'HRU (hectares),
- K_{USLE} : Facteur d'érodibilité du sol,
- C_{USLE} : Facteur de couverture végétale,
- P_{USLE} : Facteur de pratiques anti-érosives,
- LS_{USLE} : Facteur de longeur et de pente
- CRFG : Facteur de rugosité des fragments grossiers.

6- SWAT model

➢ SWAT inputs

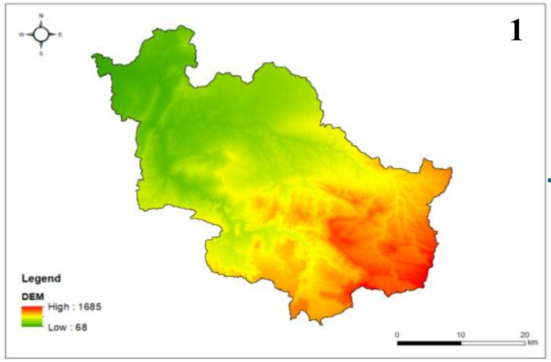

Fig. 12: DEM map

Watershed Delineation →

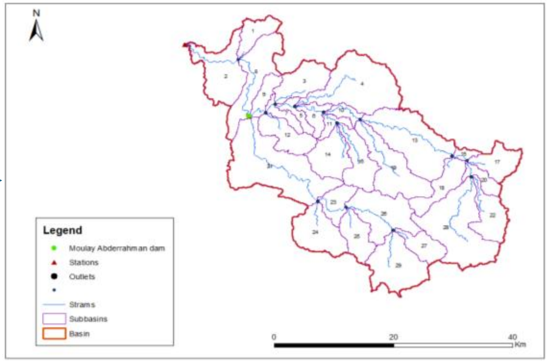

Fig. 13: Watershed delineation map

Climatic inputs: 4

- Precipitation
- Temperature

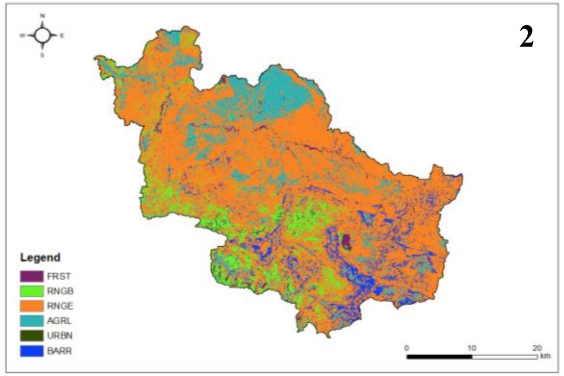

Fig. 14: LULC map

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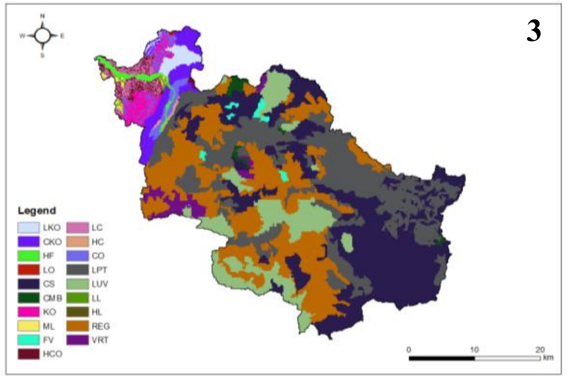

Fig. 15: Soil map

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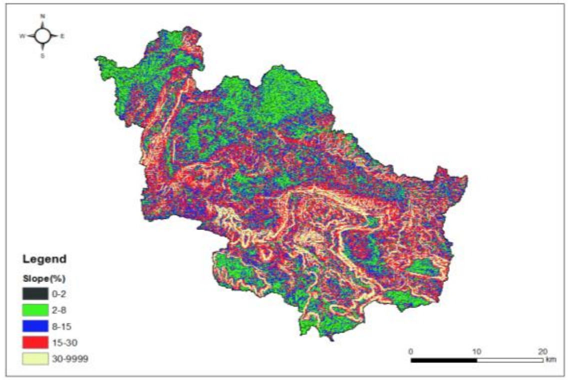

Fig. 16: Slope map

= **HRU Definition**

6- SWAT model

➢ Sensitivity analysis

- Initial parameter selection based on relevant literature, focusing on runoff processes, resulting in the choice of twenty-eight parameters,

- Application of global sensitivity analysis method to rank the sensitivity of the twenty-eight parameters, through 2,000 simulations,

- Identification of nine parameters as significantly sensitive, distinguished by large t-stat values with p-values < 0.05.

Parameter name	Description	Ranking	t-stat	p-value	minimum	maximum
SOL_AWC	Available water capacity of the soil layer	1	29.43	0.00	-1	1
TRNSRCH	Fraction of transmission losses from main channel that enter deep aquifer	2	-19.53	0.00	0	1
ALPHA_BNK	Baseflow alpha factor for bank storage	3	6.55	0.00	0	1
GW_DELAY	Groundwater delay (days)	4	6.43	0.00	0	500
SOL_K	Saturated hydraulic conductivity	5	-4.65	0.00	0	2000
CN2	SCS runoff curve number for moisture condition II	6	-3.69	0.00	-0.4	0.4
SOL_BD	Moist bulk density	7	3.10	0.00	-0.2	0.2
RCHRG_DP	Deep aquifer percolation fraction	8	-2.80	0.01	0	1
SOL_Z	Depth from soil surface to bottom of layer	9	-2.66	0.01	0	3500

Table 4: Sensitivity analysis parameters and their initial ranges

6- SWAT model

- **SWAT streamflow results before & after calibration**

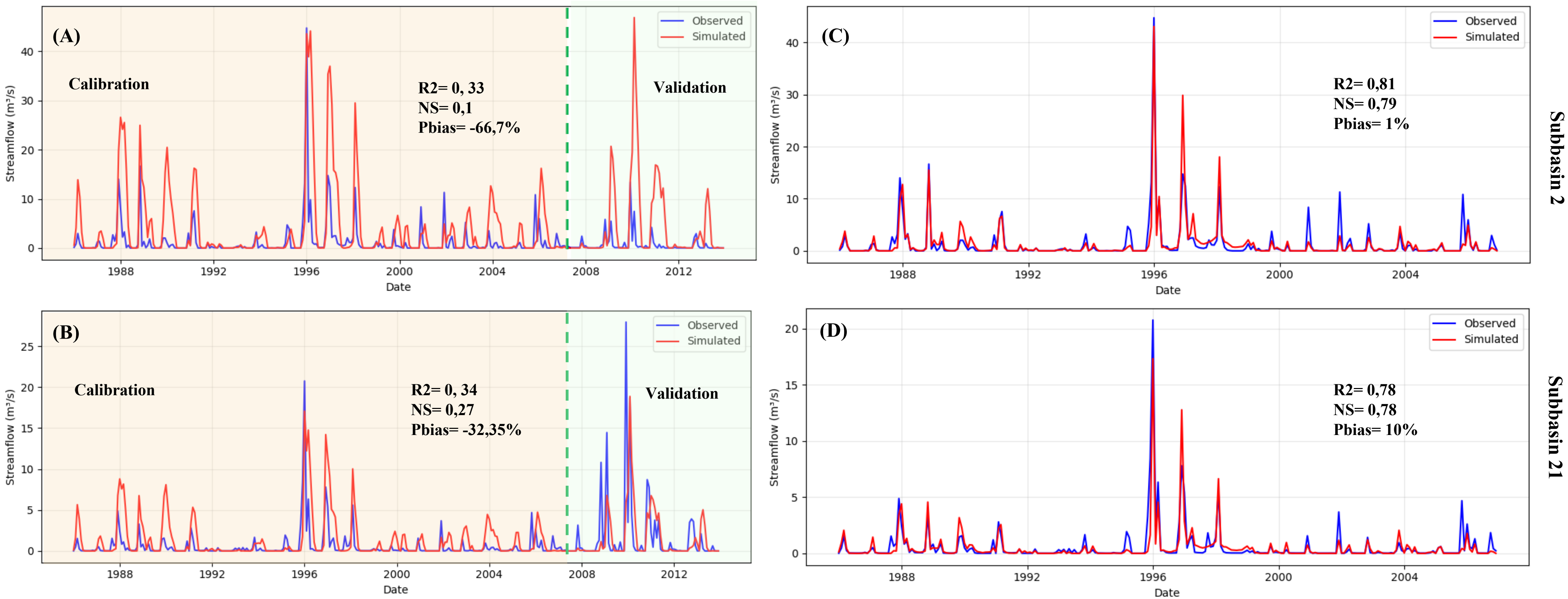

Fig. 17: (A) Streamflow results before calibration Subbasin 2 (B) Streamflow results before calibration Subbasin 21 (C) Streamflow results after calibration Subbasin 2 (D) Streamflow results after calibration Subbasin 21

➢ SWAT Sediment modeling current challenges

Sediment yield values remain very low

Deposition dominates over transport

Severe data scarcity in sediment measurements (Only 25 measurements were available at each station Igrounzar and Zelten)

MUSLE sensitivity analysis shows that USLE-K is the most influential parameter

➢ Next steps

- SWAT sediment calibration and validation
- Integration of connectivity models (IC/IC-SEDD/InVest) to better capture sediment transfer between sub-basins when using RUSLE model
- SWAT/RUSLE results comparison with bathymetry data

7- Conclusion & Perspectives

- RUSLE with different SDR functions produced large variations in sediment estimates.
- The Renfro (1975) method gave more consistent values because it includes the R and L factors.
- SWAT performed well for runoff simulation.
- More work is needed to improve soil erosion and sediment transport assessment.
- Field campaigns will be conducted to improve soil data and collect observed sediment measurements.
- High-resolution remote sensing and isotope techniques will be integrated to enhance sediment source assessment.
- A Decision Support System (DSS) tool will be developed to combine improved datasets and guide erosion-sedimentation management.
- Collaboration with African countries will be expanded to co-develop regional strategies for erosion and siltation mitigation.

References

[1] P. Borrelli *et al.*, “An assessment of the global impact of 21st century land use change on soil erosion,” *Nat. Commun.*, vol. 8, no. 1, p. 2013, 2017.
[2] S. Acharki, F. El Qorchi, Y. Arjdal, M. Amharref, A. S. Bernoussi, and H. Ben Aissa, “Soil erosion assessment in Northwestern Morocco,” Remote Sens. Appl. Soc. Environ., vol. 25, p. 100663, Jan. 2022, doi: 10.1016/j.rsase.2021.100663.
[3] A. Elmouden, N. Alahiane, M. El Faskaoui, and Z. E. A. El Morjani, “Dams Siltation and Soil Erosion in the Souss–Massa River Basin,” in *The Souss-Massa River Basin, Morocco*, vol. 53, R. Choukr-Allah, R. Ragab, L. Bouchaou, and D. Barceló, Eds., in The Handbook of Environmental Chemistry, vol. 53. , Cham: Springer International Publishing, 2016, pp. 95–120. doi: 10.1007/698_2016_70.
[4] “IAEA Highlights and Achievements in 2021 – A Year in Review | IAEA.” Accessed: Nov. 19, 2025. [Online]. Available: https://www.iaea.org/newscenter/news/iaea-highlights-and-achievements-in-2021-a-year-in-review
[5] M. Moustakim, M. Benmansour, A. Nouira, A. Benkdad, and B. Damnati, “Caesium-137 re-sampling approach and excess Lead-210 sediment dating to assess the impacts of climate change and agricultural practices on soil erosion and sedimentation in Northwest Morocco,” *Environ. Earth Sci.*, vol. 81, no. 10, p. 278, May 2022, doi: 10.1007/s12665-022-10409-6.
[6] N. Ryken *et al.*, “Soil erosion rates under different tillage practices in central Belgium: New perspectives from a combined approach of rainfall simulations and 7Be measurements,” *Soil Tillage Res.*, vol. 179, pp. 29–37, 2018.
[7] A. Alitane *et al.*, “Water erosion monitoring and prediction in response to the effects of climate change using RUSLE and SWAT equations: case of R’Dom watershed in Morocco,” *Land*, vol. 11, no. 1, p. 93, 2022.
[8] H. Briak, R. Mrabet, R. Moussadek, and K. Aboumaria, “Use of a calibrated SWAT model to evaluate the effects of agricultural BMPs on sediments of the Kalaya river basin (North of Morocco),” *Int. Soil Water Conserv. Res.*, vol. 7, no. 2, pp. 176–183, 2019.

- https://doi.org/10.1080/00207233.2017.1392771
- https://soilgrids.org/
- https://earthexplorer.usgs.gov/
- https://swat.tamu.edu/

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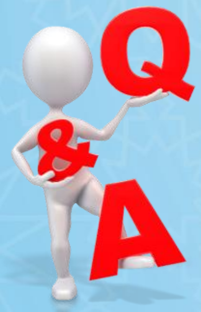

Questions and Answers Session

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