

Original Research

Received 18 June 2026

Revised 19 July 2026

Accepted 02 Aug 2026

Natural Resources for Human
Health 2026, Vol. 6 (16s): 443–467

KEYWORDS:

Flash floods; debris flow; sediment
yield; soil erodibility; RUSLE;
index of connectivity; WMS; Wadi
Mikeimin.

Spatially Explicit Debris Flow Assessment in Flash Flood-Prone Wadi Mikeimin, Egypt: A Remote Sensing and GIS Approach

Mohamed Hassan¹, Hany G.I. Ahmed¹, Ahmed M. Metwally¹,
M. Abo-Taha²

¹Irrigation and Hydraulics Engineering Division, Civil Engineering Department, Faculty
of Engineering, Al -Azhar University, Cairo, Egypt

²Civil Engineering Department, Al -Safwa Higher Institute of Engineering, Al Qalyubia
Egypt

ABSTRACT: Flash floods in Egypt's arid wadis are brief, high-energy events that mobilise large volumes of sediment and debris. This debris flow amplifies their destructive power and loads dams, barrages and water-diversion works with sediment, eroding storage capacity and structural integrity while endangering downstream settlements and roads. Earlier studies have modelled sedimentation largely in isolation. This study maps sediment generation, transfer and delivery together with the flash-flood hydrology of the same design event in Wadi Mikeimin (11.53 km²), a sub-basin of Wadi Watir in South Sinai draining toward Nuweiba City. Five techniques are combined in one spatially explicit framework: the Revised Universal Soil Loss Equation (RUSLE), converted to sediment yield through a sediment delivery ratio (SDR) based on the Index of Connectivity (IC); Geographic Information Systems (ArcGIS Pro); remote sensing (Sentinel-2 land cover); analysis of a 12.5 m Digital Elevation Model; and event-based hydrological modelling (curve-number losses and unit-hydrograph routing in WMS 9.1) of the 100-year design storm. Field visits supplied ground data.

For the 100-year event, peak discharge was 8.02 m³ s⁻¹ with a runoff volume of 107,505 m³. Maximum gross soil loss reached 6.25 t ha⁻¹ h⁻¹ and maximum sediment yield 5.99 t ha⁻¹ h⁻¹ (SDR up to 0.968), concentrated along the main channel network draining toward Nuweiba City rather than spread across the catchment. The WMS workflow was benchmarked against a published flood-hazard study of a 70.44 km² basin, reproducing its curve number, time to peak and discharge volume within 1.4%, 2.8% and 4.8% and its peak discharge within 10%, and the RUSLE-GIS approach has been corroborated against surveyed check-dam sediment volumes elsewhere in Wadi Watir (within 2.5% and 7.4%). Because no discharge or sediment record exists for Wadi Mikeimin itself, the results are best read as relative, spatially distributed indicators of erosion hazard rather than absolute values. They allow check dams, sediment traps and channel protection to be targeted at a small part of the catchment, giving designers of mega hydraulic structures a quantified, spatially explicit basis. The workflow relies on openly available data and is recommended for comparable watersheds.

1. INTRODUCTION

Sedimentation is a critical process inherently associated with flash-flood events in arid and semi-arid environments, where the mobilisation of debris and sediment poses a persistent and escalating threat to mega hydraulic structures. Sediment deposited in dams, barrages and diversion works reduces their operational efficiency and accelerates their functional deterioration, a

challenge of acute significance in data-scarce arid regions such as the Egyptian Eastern Desert and the Sinai Peninsula (Awadallah et al., 2015; Dawoud, 2020; Masoud, 2009; Metwally, 2024).

The quantification of soil erosion and sediment yield has advanced considerably through the Revised Universal Soil Loss Equation (RUSLE), originally developed by Wischmeier and Smith (1978) and subsequently refined by Renard et al. (1997). RUSLE has been widely applied across diverse arid and semi-arid watersheds, where it estimates soil detachment as a function of rainfall erosivity, soil erodibility, slope characteristics, land cover and conservation practices (Benavidez et al., 2018; Suhara et al., 2023). Integrated with Geographic Information Systems (GIS) and remote sensing, RUSLE enables spatially distributed erosion-risk mapping at watershed scale, an approach successfully applied in comparable arid environments in Syria (Abdo, 2021; Al-hasn et al., 2024), Algeria (Benchettouh et al., 2017; Djoukbal et al., 2022) and China (Tang et al., 2014). The slope length and steepness factor (LS), a critical RUSLE component in steep arid terrain, was examined by Moore and Wilson (1992), whose formulations underpin spatially explicit LS estimation in GIS. Sediment connectivity, the degree to which eroded material is transferred through the landscape to downstream structures, has been identified as a key determinant of debris-flow hazard (Borselli et al., 2008; Li et al., 2022) yet remains insufficiently characterised in Egyptian wadi systems.

Despite these advances, earlier investigations have predominantly addressed sedimentation modelling in isolation, without capturing the spatial distribution of sediment yield or integrating geomorphological and hydrological dimensions in a unified framework (Mashal et al., 2017). This gap, particularly the limited application of spatially explicit, multi-technique frameworks to Egyptian arid watersheds, motivated the present investigation. The research was accordingly designed to develop a comprehensive, spatially informed assessment of sedimentation in Wadi Mikeimin and the Watir Valley, using RUSLE, ArcGIS Pro, remote sensing and hydrological modelling to quantify and visualise sediment yield and debris-flow dynamics. The findings are intended as a practical foundation for designers of mega hydraulic structures in Egypt, and the methodology is recommended for analogous watersheds under similar physiographic conditions.

1.1 Novelty and Scientific Contribution

This study addresses three specific gaps in the literature on sedimentation in Egyptian arid catchments. First, whereas most previous RUSLE-based studies in Egypt and neighbouring arid regions report only gross soil loss (the A term), the present work couples RUSLE with an Index-of-Connectivity (IC) sediment-delivery model (Borselli et al., 2008; Li et al., 2022) to translate gross erosion into spatially distributed sediment yield, explicitly identifying which parts of the catchment both produce and deliver sediment to the outlet rather than merely eroding in place. Second, the analysis is performed jointly for Wadi Mikeimin and the wider Watir Valley, so that sediment-transport patterns in a small, data-scarce tributary catchment can be interpreted within the morphological context of a larger, better-documented regional system, a cross-scale framing not previously applied to this catchment. Third, the RUSLE/SDR erosion-and-delivery outputs are coupled with an independent event-based hydrological simulation (curve-number losses and unit-hydrograph routing in WMS) for the same 100-year design storm, so that sediment-yield estimates are presented alongside a physically consistent peak discharge and runoff volume rather than as a standalone erosion map. The hydrological component is further benchmarked against a published flood-hazard study (Section 3.5).

Collectively, these elements provide a spatially explicit, multi-technique sedimentation assessment for a flash-flood-prone Sinai wadi that is intended to generalise to other Egyptian arid catchments upstream of hydraulic structures, where comparable sediment-connectivity assessments are, to the authors' knowledge, not yet available.

2. MATERIALS AND METHODS

2.1 Study Area and Field Investigation

Several site visits to the study area were carried out. Photographs were captured, measurements were taken and native residents were interviewed; published studies were also reviewed for additional data. All assembled data were analysed to build a complete picture of the study area.

Wadi Mikeimin lies in the south of the Sinai Peninsula, between approximately 29°02' and 29°05' N and 34°30' and 34°34' E, and covers an area of 11.5267 km². It forms part of Wadi Watir, the most important wadi in South Sinai, and conveys its water toward Nuweiba City (Fig. 1).



Fig. 1. Location and extent of the study area (Wadi Mikeimin) as a tributary sub-basin of Wadi Watir, South Sinai, Egypt; inset shows the regional context relative to the Gulf of Aqaba.

2.2 Implemented Techniques and Workflow

Investigation of Wadi Mikeimin combined five complementary techniques: the Revised Universal Soil Loss Equation (RUSLE), the Spatially Variable Universal Soil Loss Equation (SVUSLE), remote sensing, hydrological modelling, and GIS analysis built on a Digital Elevation Model (DEM). The overall workflow, from input datasets through GIS processing to the R, K, LS, C and P factor rasters and the final soil-erosion maps, is shown in Fig. 2.

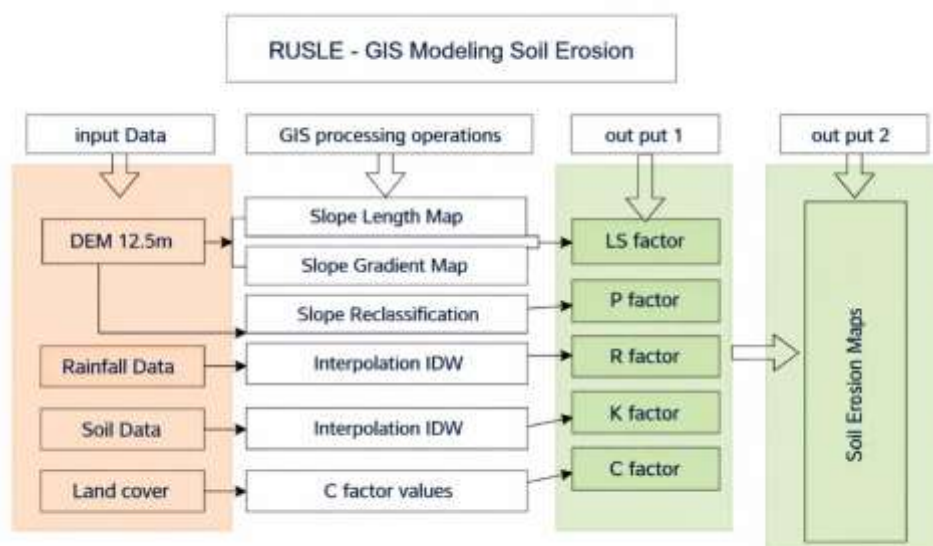


Fig. 2. Schematic workflow of the RUSLE-GIS soil-erosion model, showing the input datasets (DEM, rainfall, soil and land-cover data), the associated GIS processing operations, and the resulting R, K, LS, C and P factor rasters that are combined into the final soil-erosion maps.

2.3 Digital Elevation Model

A DEM with 12.5 m resolution, obtained from the Alaska Satellite Facility (ASF) Vertex portal of NASA, was used for basin delineation and terrain analysis (Fig. 3). To ensure the accuracy of the stream alignment over the surface topography, the streams

were displayed in Google Earth and adjusted so that the simulation is processed along its correct route. Contour lines at 100 m interval classes are shown in Fig. 4.

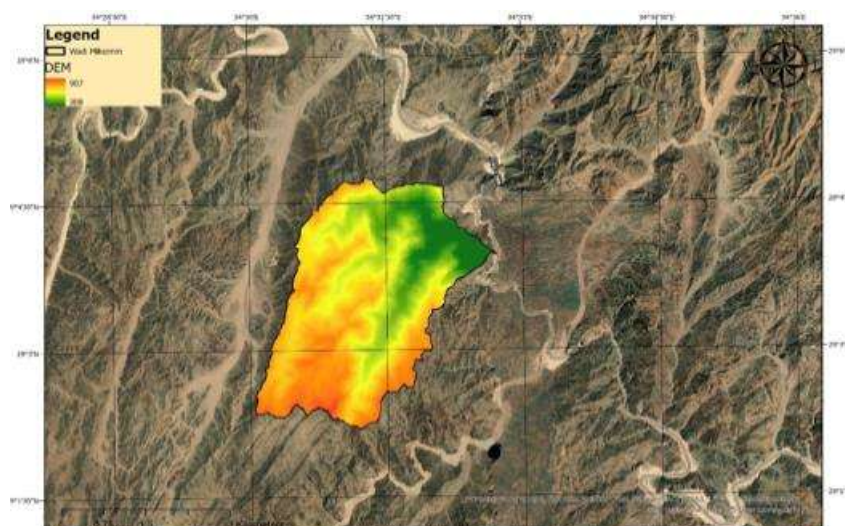


Fig. 3. Digital Elevation Model (12.5 m resolution) of Wadi Mikeimin derived from ASF/NASA data, illustrating the elevation gradient from the low-relief outlet near the coast to the higher-relief headwater areas that generate the steepest RUSLE LS-factor values.

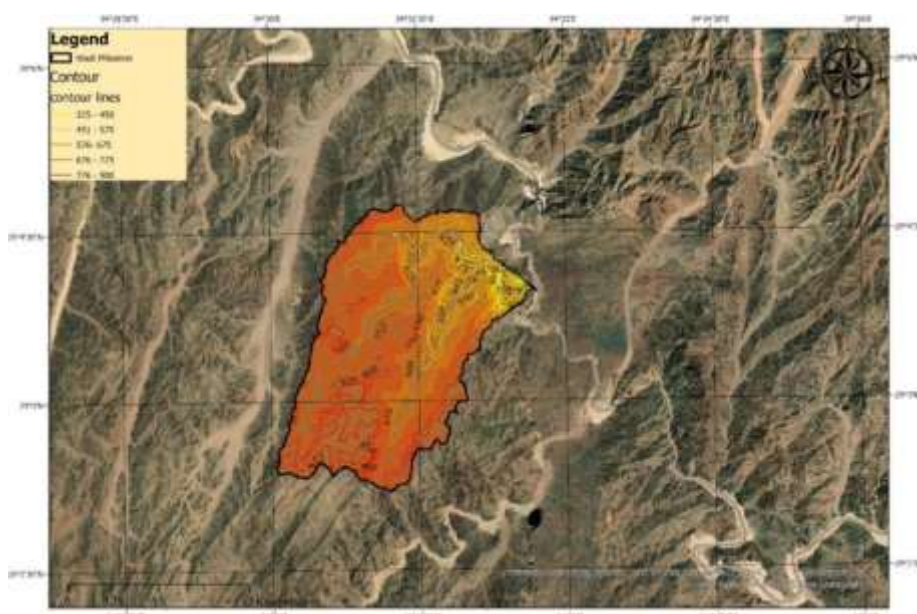


Fig. 4. Contour lines (100 m interval classes) in Wadi Mikeimin, showing the concentration of steep terrain in the upper and central portions of the catchment.

2.4 Rainfall Data and Design Storm

Rainfall data were acquired for the Nuweiba, Ain Om Ahamed and Ras Ghazala stations (Table 1). The three gauges record values relatively similar to those of the study area, over different periods within 1989–2023, and they were used to represent the flash-flood event. Detailed rainfall measurements would be needed to represent the sediment-transport event itself, because the flood record of 25/10/2015 could not be used directly; only daily rain depths at different return periods (Table 2) and event data from the Water Resources Research Institute (WRRI) were available. The 100-year rainfall depths (Ras Ghazala 42.17 mm, Ain Om Ahamed 16.23 mm and Nuweiba 22.76 mm per day) were adopted as the design event.

Table 1. Rain gauge station coordinates

Station name	Longitude (x), easting	Latitude (y), northing
Ras Ghazala station	34°27.7333' E	28°52.3000' N
Ain Om Ahamed station	34°24.3500' E	29°3.3000' N
Nuweiba station	34°40.9333' E	[to be verified]

Table 2. Rain depth (mm day⁻¹) at different return periods

Return period (years)	25	50	100
Ras Ghazala station	26.57	34.37	42.17
Ain Om Ahamed station	10.29	13.26	16.23
Nuweiba station	16.08	19.42	22.76

2.5 Soil, Land Cover and Hydrological Modelling

Event-based rainfall–runoff simulation was carried out in the Watershed Modeling System (WMS), version 9.1. The basin was delineated from the 12.5 m DEM and the stream alignment was checked against Google Earth, giving an 11.5267 km² catchment that drains through three main streams to the Wadi Watir main channel, with a single outlet near Nuweiba City. Remote-sensing layers were divided into several bands according to their wavelength, and the land-use and geological maps of the area are shown in Fig. 5 and Fig. 6.

Because the study area lies inside Wadi Watir, soil type was obtained from the Digital Soil Map of the World (DSMW) (Table 3). The catchment encompasses bare rock areas whose hydrologic soil group is C; the sand, clay and silt percentages were taken from the FAO soil texture triangle (FAO, 1995), classifying the soil as medium–coarse granular. Rainfall losses were computed with the SCS Curve Number (CN) method. Published CN values for the wider Watir watershed reflect urban development and range from 83 (Masoud, 2009) and 84.9 (Gheith and Sultan, 2002) to 76–78 (Awadallah et al., 2015), but the bare-rock, group C, sandy clay loam conditions of Wadi Mikeimin led to a single CN of 97. This corresponds to a potential maximum retention $S = 7.86$ mm and, with the standard initial-abstraction ratio of 0.2, an initial abstraction $I_a = 1.57$ mm. The lag time was 0.648 h and the time of concentration 6.33 h.

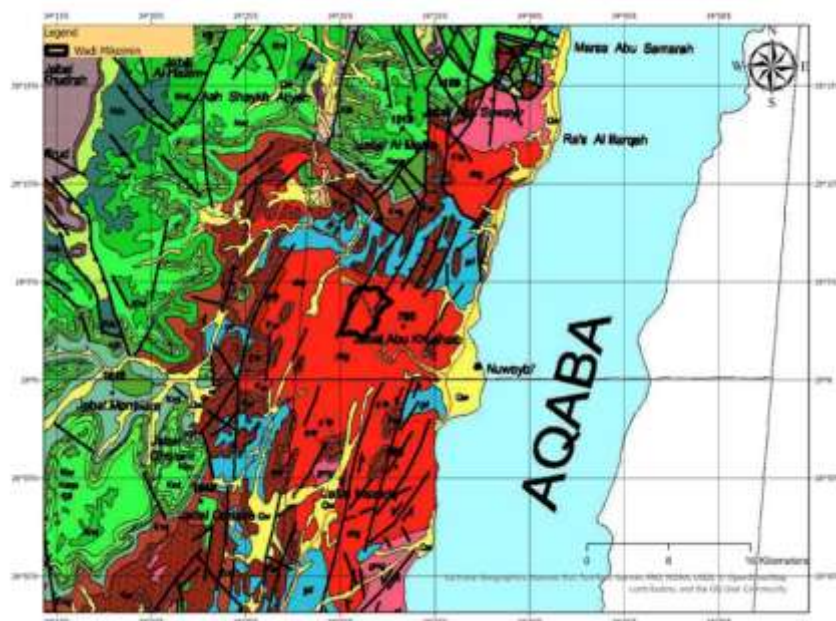


Fig. 5. Land-cover classification of the wider study area (bare area, built area, flooded vegetation, range land and water bodies), used to assign RUSLE C-factor and CN-loss values within the Wadi Mikeimin boundary.

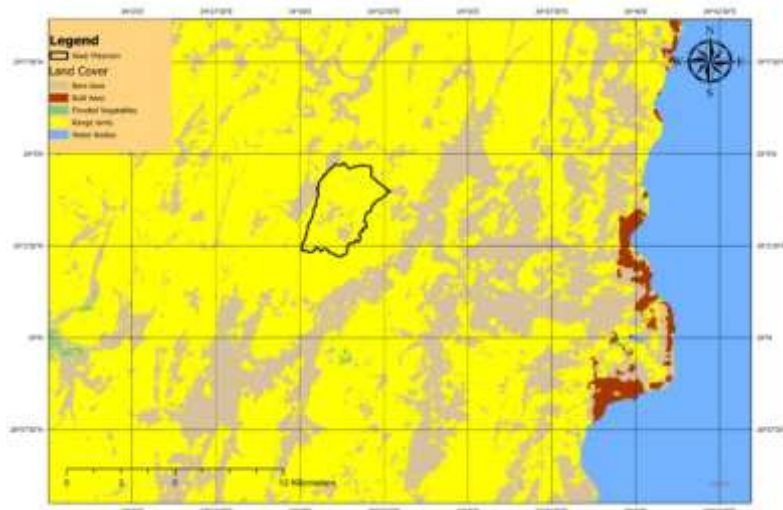


Fig. 6. Regional geological map of the Wadi Mikeimin/Watir area, showing the lithological units that control soil erodibility and infiltration characteristics across the catchment.

Table 3. Soil percentages from the DSMW in Wadi Mikeimin

Soil unit	Sand (%)	Clay (%)	Silt (%)	Organic carbon (%)
I	58.9	24.9	16.2	0.97

2.6 Remote Sensing and GIS

Remote-sensing features were integrated with the GIS to characterise land cover and surface conditions. Satellite imagery was analysed in ArcGIS Pro to identify the flood path and sediment sources, and the resulting raster values were used to evaluate

sediment yield through cell-based calculations. Land-use/land-cover (LULC) data came from the ESRI Sentinel-2 product at 10 m resolution.

2.7 RUSLE, SVUSLE and Sediment-Delivery Modelling

SVUSLE is an updated version of RUSLE. It rests on a similar conceptual framework and also estimates soil loss by water, but it places emphasis on parameters that can be obtained from remote-sensing information, giving a better representation of surface-cover conditions. RUSLE is the modified version of the USLE, with refined parameters supported by updated datasets and equations (Benavidez et al., 2018; Darwish et al., 2016; Foster and Renard, 1983; Moore and Wilson, 1992; Oliveira et al., 2024; Suhara et al., 2023; USDA NRCS, 2002). SVUSLE is used to designate soil loss and, since its main concept is soil loss, it can also be used to estimate sediment yield. RUSLE estimates gross erosion, the total amount of soil transported by water during flash-flood events; however, not all eroded soil is transported within the stream. Equations (1) to (6) were therefore implemented to compute soil loss, sediment yield, the Sediment Delivery Ratio (SDR) and the Index of Connectivity (IC) (Borselli et al., 2008; Li et al., 2022), and GIS was used throughout, as shown in Fig. 2.

$$A = R \times K \times LS \times C \times P \quad (1)$$

$$SY = A \times SDR \quad (2)$$

$$SDR = \frac{1}{1 + \left(\frac{IC}{C_{SDR}}\right)} \quad (3)$$

$$IC = [D_{up} - D_{dn}] \quad (4)$$

$$D_{up} = \ln(\text{flow accumulation} \times \text{slope}) \quad (5)$$

$$D_{dn} = \ln\left(\frac{1}{(C \times \text{slope}) + 1}\right) \quad (6)$$

where A is the soil loss ($\text{t ha}^{-1} \text{ h}^{-1}$); R the rainfall-erosivity factor (mm h^{-1}); K the soil-erodibility factor ($\text{t h MJ}^{-1} \text{ mm}^{-1}$); LS the slope-length and steepness factor (dimensionless); C the cover-management factor (dimensionless); P the support-practice factor (dimensionless); SY the sediment yield ($\text{t ha}^{-1} \text{ h}^{-1}$); SDR the sediment delivery ratio (0–1); C_{SDR} a calibration constant (0.5–2); D_{up} the upslope component; and D_{dn} the downslope component, calculated from both land cover and slope.

2.8 Derivation of the RUSLE Factors

2.8.1 Rainfall erosivity (R)

The R factor is the rainfall and runoff erosivity factor of RUSLE (Chae et al., 2005). It accounts for the influence of rainfall kinetic energy and generated runoff on erosion, which depends on the spatial-temporal distribution, intensity, momentum, kinetic energy and drop size of rainfall (Djoukbal et al., 2022; Tang et al., 2014). R is normally computed as the average sum of the erosivity of individual storms (Wischmeier and Smith, 1978). For the simulated sediment-flow event, the average rainfall intensity i_{av} was used instead (Equation 7).

$$R = \alpha \times i_{av} \quad (7)$$

where R is the rainfall and runoff erosivity factor (mm h^{-1}); i_{av} the average rainfall intensity throughout the simulation period (mm h^{-1}); and α a dimensionless conversion coefficient needed to obtain the full RUSLE EI_{30} value. Detailed sub-hourly data are not available for single events in arid and semi-arid areas, so α was taken within the range 0.1–0.25. Several publications (Abdo, 2021; Al-hasn et al., 2024; Benchettouh et al., 2017) assume the conversion to be 20% of i_{av} , i.e. $R = 0.2 i_{av}$, and this study followed the same assumption. The event rainfall data were provided by the Water Resources Research Institute (WRRI) (Mashal et al., 2017), and the gauge values were interpolated with Inverse Distance Weighting (IDW) in ArcGIS Pro (Mashal et al., 2017; Suhara et al., 2023).

2.8.2 Soil erodibility (K)

The K factor expresses the susceptibility of soil particles to detachment at a given discharge in a given rainfall event; it ranges between 0 and 1, where 0 indicates the lowest and 1 the highest susceptibility to erosion. K can be calculated from soil properties

or measured directly. Based on the soil characteristics of Wadi Mikeimin (58.9% sand, 16.2% silt, 24.9% clay and 0.97% organic carbon; Table 3), K was calculated with the Williams formulation used in RUSLE (Mashal et al., 2017; Suhara et al., 2023) by incorporating Equations (8) to (12) in ArcGIS Pro.

$$K = f_{csand} \times f_{cl-si} \times f_{orgC} \times f_{hisand} \quad (8)$$

$$f_{csand} = 0.2 + 0.3 \exp \left[-0.256 M_s \left(1 - \frac{M_{silt}}{100} \right) \right] \quad (9)$$

$$f_{cl-si} = \left(\frac{M_{silt}}{M_c + M_{silt}} \right)^{0.3} \quad (10)$$

$$f_{orgC} = 1 - \frac{0.25 \text{ orgC}}{\text{orgC} + \exp(3.72 - 2.95 \text{ orgC})} \quad (11)$$

$$f_{hisand} = 1 - \frac{0.25 \left(1 - \frac{M_s}{100} \right)}{\left(1 - \frac{M_s}{100} \right) + \exp \left[-5.51 + 22.9 \left(1 - \frac{M_s}{100} \right) \right]} \quad (12)$$

where K is the soil-erodibility factor ($t \text{ h MJ}^{-1} \text{ mm}^{-1}$); M_s , M_{silt} and M_c the percentages of sand, silt and clay; orgC the soil organic-carbon content (%); f_{csand} a factor that lowers K in soils with high coarse-sand content and raises it for soils with little sand; f_{cl-si} a factor giving low erodibility for soils with high clay-to-silt ratios; f_{orgC} a factor that reduces K in soils with high organic carbon; and f_{hisand} a factor that lowers K in soils with extremely high sand content.

2.8.3 Slope length and steepness (LS)

The LS factor represents the topographic influence on soil erosion: as slope length increases, cumulative runoff and its rate increase, and steeper slopes make runoff move faster and erode more severely (Moore and Wilson, 1992; Desai et al., 2022). LS was estimated from the DEM in GIS using flow accumulation, DEM cell size ($12.5 \text{ m} \times 12.5 \text{ m}$) and the slope raster derived from the DEM (Equations 13 to 15).

$$LS = \left(\text{FlowAcc} \times \frac{\text{cell size}}{22.13} \right)^m \times \left(\frac{\sin(\text{slope})}{0.0896} \right)^n \quad (13)$$

$$L = \left(\text{FlowAcc} \times \frac{\text{cell size}}{22.13} \right)^m \quad (14)$$

$$S = \left(\frac{\sin \beta}{0.0896} \right)^n \quad (15)$$

where FlowAcc is the raster of flow accumulated into each cell; cell size the raster pixel dimension (12.5 m); slope the slope raster extracted from the DEM; β the slope angle (%); m the slope-length exponent, ranging between 0.2 and 0.6; and n the slope-steepness exponent. A trial-and-error approach showed that m grows with slope, being about 0.15 on very gentle slopes and 0.3–0.5 on moderate slopes. In GIS, the slope grid was reclassified into ranges, each with a fixed exponent: $m = 0.5$, 0.4 and 0.3 for slopes above 4.5%, 3–4.5% and 1–3%, respectively, and $m = 0.2$ for slopes below 1%; n was assumed to be 1. A conditional evaluation of the flow-direction grid separated orthogonal and diagonal flow-direction pixels. The L factor was computed with the raster calculator and multiplied by the S factor to obtain the LS raster.

2.8.4 Cover management (C)

The C factor designates the relative effectiveness of soil and crop management in preventing soil loss; values close to 0 indicate well-covered, protected surfaces and values close to 1 bare, unprotected ones. C was estimated from the 10 m Sentinel-2 LULC raster by attaching a C value to each land-use class in the attribute table in ArcGIS Pro (Table 4), using values from Benavidez et al. (2018) and Renard et al. (1997).

Table 4. C-factor values assigned to the land-use/land-cover (LULC) classes

LULC code	Class name	C value
1	Water	0
2	Trees	0.025
3	Grass	0.02
4	Flooded vegetation	1
5	Crops	0.05
6	Shrubs	0.4
7	Built area	1
8	Bare ground	1
9	Snow/ice	0
10	Clouds	0

2.8.5 Support practice (P)

The support-practice factor P reflects practices that reduce the amount and rate of surface runoff, and hence erosion, by adjusting flow pattern, grade or direction; it is the ratio of soil loss with a specific support practice (e.g. contouring) to the corresponding loss with up-and-down-slope tillage (Foster and Renard, 1983). P was assigned according to the slope percentage of the study area and the supporting practice, following Shin (1999) (Table 5).

Table 5. Support-practice (P) factor values (Shin, 1999)

Slope (%)	Contouring	Strip cropping	Terracing
0–7	0.55	0.27	0.10
7–11.3	0.60	0.30	0.12
11.3–17.6	0.80	0.40	0.16
17.6–26.8	0.90	0.45	0.18
>26.8	1.00	0.50	0.20

2.8.6 Soil loss, connectivity and sediment yield

The soil loss A was obtained by multiplying the five RUSLE factor rasters in the ArcGIS Pro raster calculator. The total soil loss was then used as a weight in the GIS flow-accumulation function, accumulating the soil loss of all upslope pixels along the flow-direction routes. The upslope and downslope components of the IC (Equations 5 and 6) were computed following Borselli et al. (2008), the calibration constant C_{SDR} was set to 0.56, and the SDR and sediment yield were derived by raster calculation (Equations 2 to 4). Soil loss was classified into five erosion levels (Table 6).

Table 6. Soil-loss level classification ($\text{t ha}^{-1} \text{h}^{-1}$)

Level	Soil loss
Very low erosion	0–1
Low erosion	1–5
Medium erosion	5–10
High erosion	10–50
Extreme erosion	>50

2.9 Validation Approach

No continuous discharge, reservoir-sedimentation or dated sediment-deposit record exists for Wadi Mikeimin, so a formal validation against site data was not possible. Validation therefore relied on two external checks and on indirect evidence. First, the WMS hydrological workflow was benchmarked against the published GIS-MCDA flood-hazard study of Abo-Taha et al. (2022), which modelled a 70.44 km² basin with the HEC-1 model. A validation trial was made using the same sources of data: the 12.5 m ASF/NASA DEM, the same stream-rectification method, and a rainfall analysis giving a 100-year depth of 44.1 mm. Curve number, basin area, peak discharge, time to peak and discharge volume were compared. Second, the RUSLE-GIS cell-based approach was compared with the field-validated SVUSLE application of Mashal et al. (2017), who compared modelled sediment accumulation against surveyed check-dam sediment volumes elsewhere in Wadi Watir. Third, the spatial coherence and magnitudes of the results were checked against regional literature (3.5).

3. RESULTS AND DISCUSSION

3.1 Terrain and Drainage Network

The DEM and contour analyses (Fig. 3 and Fig. 4) show steep terrain concentrated in the upper and central portions of the catchment, with a low-relief outlet near the coast. The drainage network delineated from the DEM at a 200 m² flow-accumulation threshold has a dendritic pattern that concentrates flow toward the single outlet near Nuweiba City (Fig. 7), and the Strahler stream-order classification identifies the higher-order trunk channels, where flow and hence sediment-transport capacity are greatest (Fig. 8).



Fig. 7. Drainage network of Wadi Mikeimin delineated from the DEM at a 200 m² flow-accumulation threshold, showing the dendritic pattern that concentrates flow toward the single outlet near Nuweiba City.



Fig. 8. Strahler stream-order classification in Wadi Mikeimin; higher-order channels (orange) mark the main trunk streams where flow, and hence sediment-transport capacity, is greatest.

3.2 Rainfall Losses and Surface Runoff

Rainfall losses and soil type were derived from the land-use, geological and soil data (Fig. 5, Fig. 6 and Table 3) with the curve-number method. With a CN of 97 for bare rock of hydrologic soil group C and the 100-year rainfall at the three gauges, the WMS 9.1 simulation produced the hydrograph in Fig. 9: a peak discharge of $8.02 \text{ m}^3 \text{ s}^{-1}$ at 810 min, and a total runoff volume of $107,504.55 \text{ m}^3$.

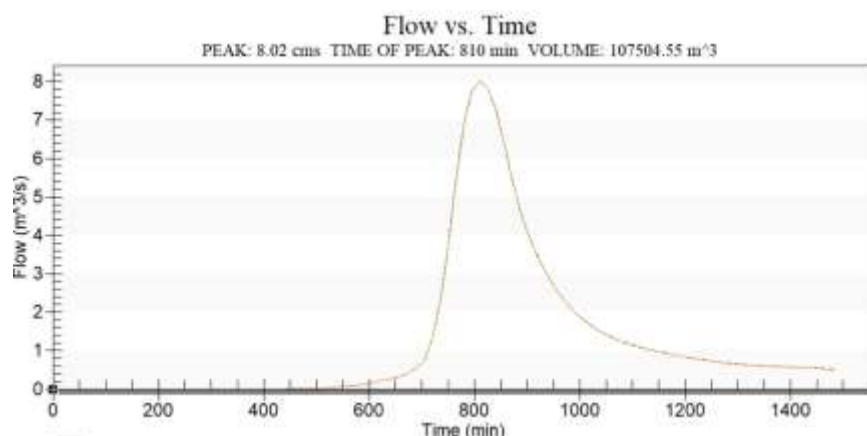


Fig. 9. Hydrograph of the 100-year design storm simulated by WMS 9.1 for Wadi Mikeimin (peak $8.02 \text{ m}^3 \text{ s}^{-1}$ at 810 min; volume $107,504.55 \text{ m}^3$).

3.3 RUSLE Factor Maps

Rainfall erosivity (R). The event-based R values at the three gauges are listed in Table 7. After IDW interpolation, R across the catchment ranges from about 4.94 to 5.93 mm h^{-1} (Fig. 10).

Table 7. Values of rainfall erosivity in Wadi Mikeimin

Rain gauge	Precipitation (mm)	i_{av} (mm h ⁻¹)	R (mm h ⁻¹)
Ras Ghazala	7.5	11.6	2.32
Nuweiba	12.6	38.1	7.62
Ain Om Ahamed	2.2	3.72	0.744

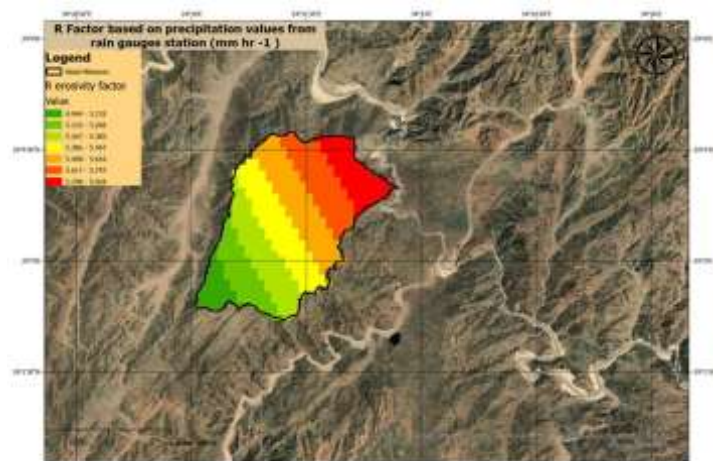


Fig. 10. R-factor (rainfall-erosivity) surface for Wadi Mikeimin, interpolated by Inverse Distance Weighting (IDW) from the three rain-gauge values in Table 7.

Soil erodibility (K). Because the DSMW classifies the entire catchment as a single soil unit, the K factor computed from Equations (8) to (12) is spatially uniform, at 0.138 t h MJ⁻¹ mm⁻¹ (Fig. 11).

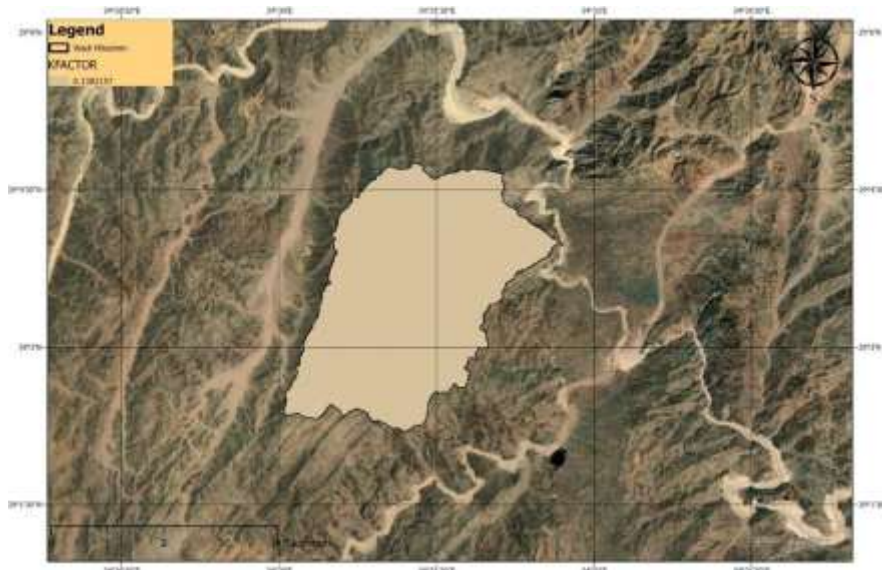


Fig. 11. Spatial distribution of the RUSLE K-factor (soil erodibility) across Wadi Mikeimin, computed from the Williams formula using the DSMW soil-texture and organic-carbon data.

Slope length and steepness (LS). Flow accumulation derived from the DEM (Fig. 12) and the slope-dependent exponent m (Fig. 13) gave the L factor (Fig. 14); multiplied by the S factor this yields the LS raster, which ranges up to 7.09 and is highest along the steep upper-catchment channel heads (Fig. 15).



Fig. 12. Flow accumulation rates from the DEM, computed in ArcGIS Pro.



Fig. 13. Spatial distribution of the LS-factor exponent m in Wadi Mikeimin, reclassified from the DEM-derived slope grid into the ranges $m = 0.2\text{--}0.6$.



Fig. 14. L-factor (slope-length) raster for Wadi Mikeimin, computed from flow accumulation and cell size via Equation (14).



Fig. 15. Combined LS-factor raster for Wadi Mikeimin (range 0–7.09), showing the highest topographic erosion potential concentrated along the steep upper-catchment channel heads.

Cover management (C). The C factor was close to 1 across nearly the entire catchment, because it is surrounded by and consists of bare ground, which offers essentially no vegetative protection against erosion (Fig. 16).



Fig. 16. C-factor (cover-management) raster for Wadi Mikeimin; the near-uniform value of 1 reflects the catchment's near-complete bare-ground land cover.

Support practice (P). Since the catchment is entirely unmanaged bare terrain, the P values derived from the slope classes of Table 5 are close to the upper bound, i.e. no conservation practice is in effect (Fig. 17).

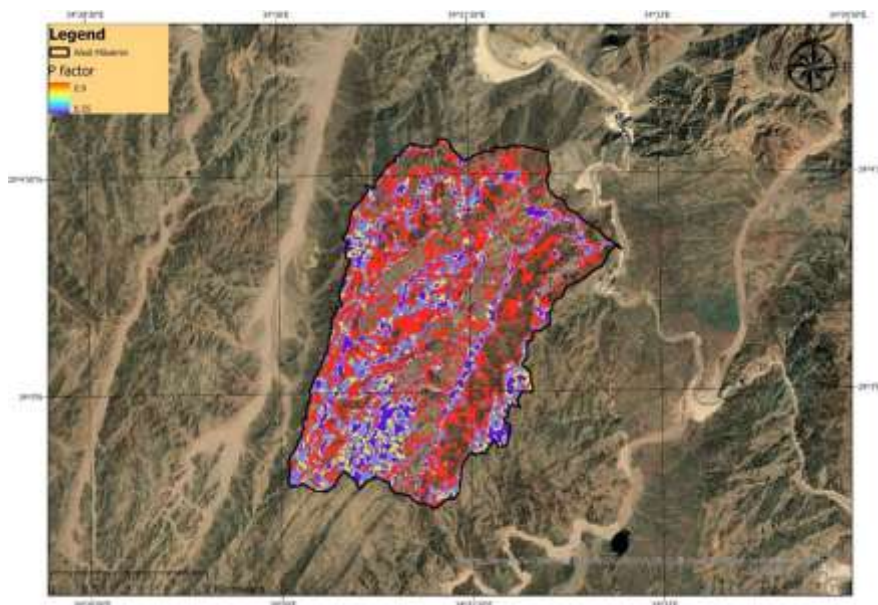


Fig. 17. P-factor (support-practice) raster for Wadi Mikeimin, derived from the slope-percentage classification in Table 5; because the catchment is entirely unmanaged bare terrain, values are close to the upper bound.

3.4 Soil Loss, Connectivity and Sediment Yield

Combining the five factors (Equation 1) gives the composite soil-erosion map of Fig. 18 and the gross soil-loss raster of Fig. 19, in which the maximum value is $6.25 \text{ t ha}^{-1} \text{ h}^{-1}$ and the highest values are concentrated along the steep catchment margins. According to the classification of Table 6, the most erosion-prone cells fall in the medium class ($5\text{--}10 \text{ t ha}^{-1} \text{ h}^{-1}$), whereas most of the catchment falls within the very-low-to-low classes (Fig. 20).



Fig. 18. Composite RUSLE soil-erosion map for Wadi Mikeimin, combining the R, K, LS, C and P rasters (Equation 1); the highest soil-loss values are concentrated along the steep catchment margins.



Fig. 19. Gross soil-loss (A) raster for Wadi Mikeimin ($\text{t ha}^{-1} \text{h}^{-1}$, maximum 6.25), overlaid on the catchment boundary.



Fig. 20. Soil-loss severity classification (Table 6) mapped across Wadi Mikeimin; the catchment falls predominantly within the very-low-to-low erosion classes, with isolated higher-severity cells along steep channel margins.

The upslope and downslope connectivity components are shown in Fig. 21 and Fig. 22. Combined (Equation 4), they give an Index of Connectivity with a maximum of 17.20 (Fig. 23); higher IC values indicate a stronger hydrological connection between hillslopes and the channel network. With $C_{\text{SDR}} = 0.56$ the sediment delivery ratio reaches a maximum of 0.968 along the well-connected main-channel corridor (Fig. 24). Applying Equation (2) to the soil-loss and SDR rasters, the maximum sediment yield for the 100-year design event is $5.9883 \text{ t ha}^{-1} \text{h}^{-1}$ (Fig. 25). The pattern closely follows the main drainage network, consistent with debris-flow observations reported for comparable South Sinai wadis.

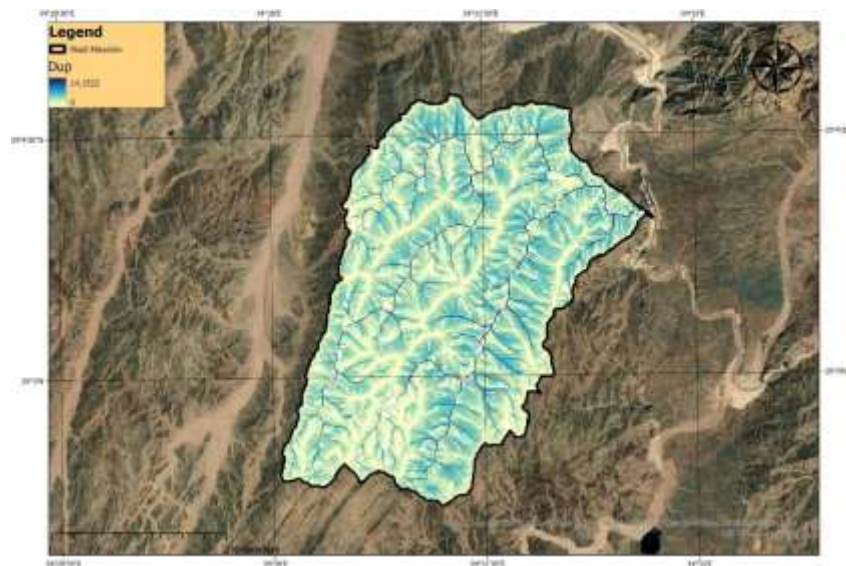


Fig. 21. Upslope (D_{up}) connectivity component for Wadi Mikeimin (Equation 5), highest along the steep, high-flow-accumulation upper-catchment channels.

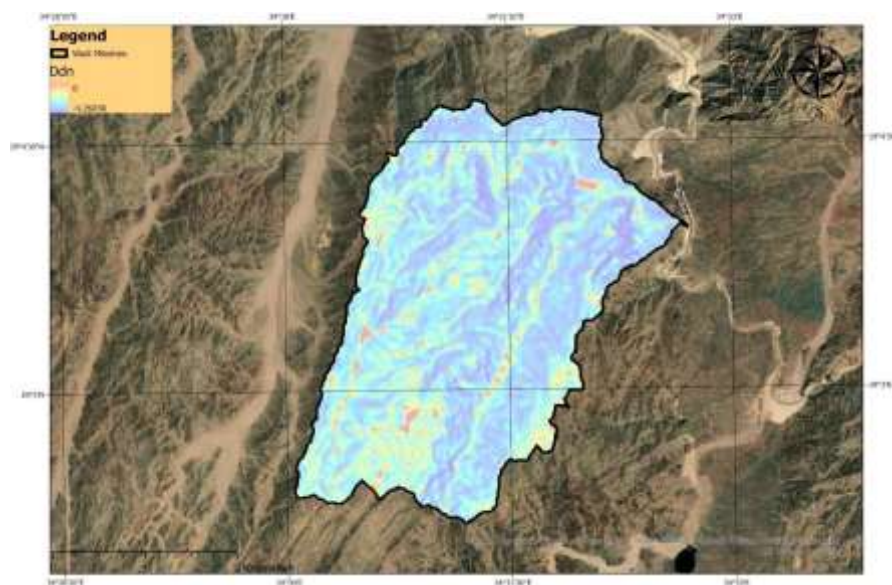


Fig. 22. Downslope (D_{dn}) connectivity component for Wadi Mikeimin (Equation 6), reflecting the combined influence of land cover and slope on sediment transfer toward the outlet.



Fig. 23. Index of Connectivity (IC) raster for Wadi Mikeimin (Equation 4, maximum 17.20), combining the upslope and downslope components in Fig. 21 and Fig. 22; higher IC values indicate stronger hydrological connection between hillslopes and the channel network.

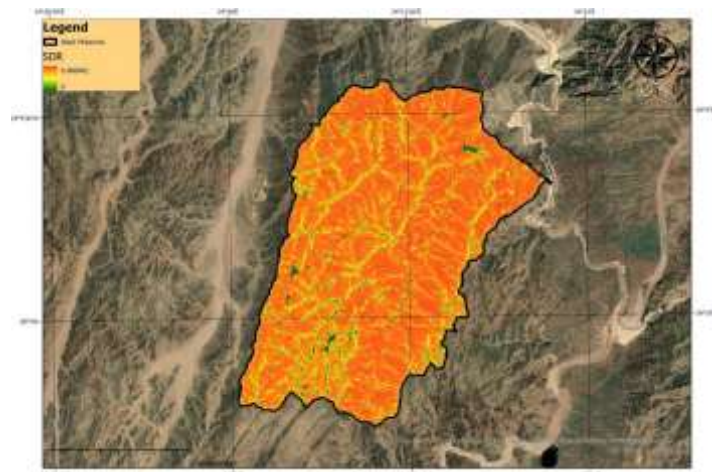


Fig. 24. Sediment Delivery Ratio (SDR) raster for Wadi Mikeimin (Equation 3, $C_{SDR} = 0.56$, maximum 0.968), showing near-complete sediment delivery along the well-connected main-channel corridor.



Fig. 25. Final sediment-yield (SY) raster for Wadi Mikeimin (Equation 2, maximum $5.99 \text{ t ha}^{-1} \text{ h}^{-1}$ for the 100-year design event), obtained by combining the RUSLE soil-loss map with the Sediment Delivery Ratio; the pattern closely follows the main drainage network.

3.5 Validation of Results

3.5.1 Benchmark of the WMS hydrological simulation

The simulation was benchmarked against the GIS-MCDA flood-hazard study of Abo-Taha et al. (2022), which analysed a 70.44 km² basin in the Hegaza Village area of Qena Governorate, Upper Egypt. To make the trial comparable, the same sources of data were used: the 12.5 m DEM from the ASF/NASA Vertex portal, the same stream-rectification method, and a rainfall analysis giving a 100-year depth of 44.1 mm. The basin was delineated in WMS 9.1 (Fig. 26) and its weighted curve number was computed from the land-use and hydrologic-soil-group report (Table 8). Table 9 compares the results with the published values, and Fig. 27 shows the simulated hydrograph.

Table 8. Runoff curve-number computation for the benchmark basin (WMS report)

HSG	Land-use description	CN	Area (km ²)	CN × area
A	Artificial surfaces and associated areas	81	59.481	4817.956
D	Artificial surfaces and associated areas	93	5.940	552.439
D	Sparse (<15%) vegetation	94	4.915	462.022
D	Bare areas	98	0.105	10.303
	Weighted CN = $\Sigma(\text{CN} \times \text{area}) / \Sigma \text{area}$	82.944	70.441	5842.720



Fig. 26. Delineation of the 70.44 km² benchmark basin in WMS 9.1 (weighted CN = 82.9).

Table 9. Comparison of the WMS 9.1 simulation with the published GIS-MCDA study (Abo-Taha et al., 2022)

Parameter	Published study	This simulation	Difference (%)
Curve number	84.132	82.944	-1.4
Area of the watershed (km ²)	70.44	70.44	0.0
Peak discharge (m ³ s ⁻¹)	27.14	24.44	-9.9
Time to peak (min)	1065	1095	+2.8
Volume of discharge (m ³)	975,292.2	928,637.5	-4.8

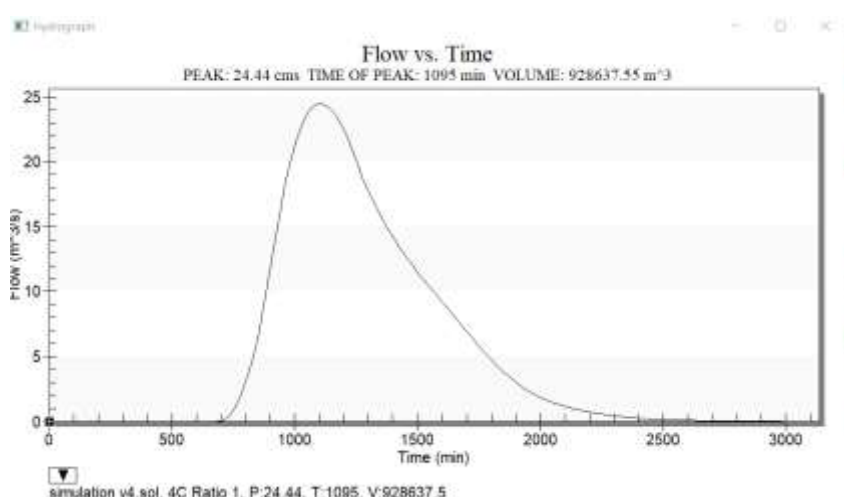


Fig. 27. Hydrograph simulated in WMS 9.1 for the benchmark basin (peak 24.44 m³ s⁻¹ at 1095 min; volume 928,637.55 m³).

The simulation reproduced the basin area exactly and the weighted curve number, time to peak and discharge volume to within 1.4%, 2.8% and 4.8%, respectively. The peak discharge was about 10% lower (24.44 against 27.14 m³ s⁻¹). The lower peak and volume are consistent in sign with the slightly lower weighted CN, which reduces runoff, and part of the difference may also arise from differences between the rainfall–runoff routing of the published (HEC-1) and present (WMS) models. The trial demonstrates that the data sources, stream-rectification method and WMS workflow used for Wadi Mikeimin reproduce the basin characteristics and discharge of an independently published study. It is a check of the modelling workflow on an external basin and does not by itself validate the Wadi Mikeimin discharge, which has no observed record.

3.5.2 Regional corroboration of the *RUSLE-GIS* sediment model

While no field-measured sediment or discharge record exists for Wadi Mikeimin itself (Section 3.6), the *RUSLE*-based cell-by-cell modelling framework applied here has been field-validated elsewhere within the same Wadi Watir system. Mashal et al. (2017) applied an equivalent cell-based *RUSLE*/GIS sediment model (SVUSLE), using the same rainfall-erosivity formulation ($R = \alpha \cdot i_{av}$, $\alpha = 0.2$) and, for the Ras Ghazala and Nuweiba gauges, the same underlying *WRI* rainfall data used in the present study (Table 7), to two check-dam catchments elsewhere in Wadi Watir. They compared modelled sediment accumulation against dam-sediment volumes surveyed before and after the 25/10/2015 storm. Their model reproduced the measured trapped volumes to within 2.5% (7,627.5 m³ modelled against 7,440 m³ measured) and 7.4% (7,853.8 m³ against 8,478 m³) at the two sites. This provides regional, methodology-level corroboration that the *RUSLE*-GIS cell-based approach, the $\alpha = 0.2$ rainfall-erosivity convention and the *WRI* rainfall dataset yield sediment estimates consistent with field measurement elsewhere in the same catchment system. It does not constitute a direct validation of the Wadi Mikeimin sediment-yield or discharge results, since the field sites of Mashal et al. lie outside the Mikeimin sub-basin, their event was an observed storm rather than the 100-

year design event modelled here, and their study included no discharge or hydrological simulation. The absence of site-specific sediment and discharge validation therefore remains a limitation of the present study (Section 3.8).

3.5.3 Indirect corroboration

Three further lines of indirect evidence support the plausibility of the results. First, internal consistency: the spatial pattern of high modelled soil loss, high connectivity (IC) and high sediment-delivery ratio (SDR) converges, as expected physically, along the main channel network draining toward Nuweiba City (Fig. 19, Fig. 23, Fig. 24 and Fig. 25), rather than being randomly distributed, which is consistent with the debris-flow and sediment-accumulation pathways documented qualitatively during the field visits and interviews with local residents (Section 2.1). Second, magnitude plausibility: the peak simulated discharge ($8.02 \text{ m}^3 \text{ s}^{-1}$) and the maximum sediment yield ($5.99 \text{ t ha}^{-1} \text{ h}^{-1}$) fall within the ranges reported for similarly sized ungauged Sinai and Eastern Desert wadi catchments under comparable curve-number and rainfall-erosivity assumptions (Awadallah et al., 2015; Gheith and Sultan, 2002; Masoud, 2009). Third, methodological consistency: the R-factor conversion coefficient ($\alpha = 0.2$) and the RUSLE parameterisation follow values previously applied and evaluated in analogous arid catchments in Syria and Algeria (Abdo, 2021; Al-hasn et al., 2024; Benchettouh et al., 2017), which increases confidence that the erosion-factor magnitudes are of the correct order even though they cannot be checked against site-specific ground truth.

This corroboration is necessarily indirect and does not substitute for direct validation. The installation of stage/discharge gauges and periodic post-event sediment surveys in Wadi Mikeimin, together with retrospective comparison of the modelled sediment-yield pattern against reservoir bathymetric surveys or downstream deposit thickness where available, is identified as a priority for future work (Section 4). Accordingly, the results should be interpreted as relative, spatially distributed indicators of erosion and sediment-delivery hazard rather than as absolute, field-verified values.

3.6 Uncertainty Analysis

Several sources of uncertainty propagate through the modelling chain and should be considered when interpreting the reported soil-loss, sediment-yield and discharge values.

Rainfall interpolation and the R factor. R was derived from only three rain gauges, none located within the catchment, and interpolated by IDW. Because R enters Equation (1) as a linear multiplier, a $\pm 25\%$ change in the α coefficient (from the low to the high end of the 0.1–0.25 literature range) would translate directly into an approximately proportional change in mapped soil loss and sediment yield. IDW interpolation over sparse, external gauges also smooths true spatial rainfall variability, likely underestimating the localised convective-storm intensities characteristic of Sinai flash floods.

DEM resolution. The 12.5 m DEM is adequate for watershed-scale delineation but generalises fine-scale features (micro-channels, terracing, rock outcrops) that influence local flow concentration and the LS factor. Coarser DEMs are known to underestimate LS-factor peaks systematically relative to higher-resolution (e.g. 1–5 m) DEMs, so the mapped LS maxima (Fig. 15) should be regarded as conservative.

Soil-map resolution (K factor). The DSMW classifies the entire catchment as a single soil unit (Table 3), producing a spatially uniform K-factor field (Fig. 11) that cannot capture the sub-kilometre heterogeneity in texture and organic-carbon content typical of arid wadi substrates. This is likely to smooth, and potentially underestimate, local peaks in soil-loss susceptibility.

Land-cover classification (C factor). The 10 m Sentinel-2 land-cover product used to assign C values may misclassify sparse desert vegetation or rock-shadow effects as bare ground, or vice versa.

3.7 Discussion

The integrated RUSLE–SDR–hydrological modelling framework applied to Wadi Mikeimin reproduces the general pattern reported by RUSLE/GIS studies in other arid and semi-arid catchments: erosion hazard is concentrated on steep, sparsely vegetated slopes and channel heads, and is strongly modulated by the LS and C factors rather than by K, which is comparatively uniform across the near-bare-rock terrain (Section 3.6). This pattern is qualitatively consistent with RUSLE-based assessments of the Al-Sanaoubar and Wadi Qandeel basins in coastal Syria (Abdo, 2021; Al-hasn et al., 2024) and the Wadi Mina basin in north-western Algeria (Benchettouh et al., 2017), all of which report bare, steep terrain as the dominant control on modelled soil loss in the absence of significant vegetative cover or conservation practice.

The maximum sediment yield obtained here ($5.99 \text{ t ha}^{-1} \text{ h}^{-1}$ for the 100-year design event) falls within the medium erosion class of Table 6 and is broadly comparable in order of magnitude to estimates reported for other small, steep, ungauged wadi catchments in the Eastern Desert and Sinai under similarly arid climatic and curve-number conditions (Awadallah et al., 2015; Gheith and Sultan, 2002; Masoud, 2009). This consistency across independently parameterised studies, together with the hydrological benchmark and the regional corroboration of Section 3.5, lends support to the plausibility of the present estimates, notwithstanding the absence of direct site validation.

Compared with earlier sedimentation studies in the region, which have generally reported only a gross soil-loss (A) map without an explicit sediment-delivery step (Mashal et al., 2017), the coupling of RUSLE with the Index-of-Connectivity SDR model (Borselli et al., 2008; Li et al., 2022) provides an additional and arguably more design-relevant layer of information. It distinguishes catchment areas that erode but do not efficiently deliver sediment downstream from areas where high erosion coincides with high connectivity and therefore poses the greatest practical risk to downstream hydraulic structures (Fig. 19, Fig. 23 and Fig. 25). This distinction is directly analogous to the connectivity-based debris-flow susceptibility mapping applied after the 2017 Jiuzhaigou earthquake in China (Li et al., 2022), and its transfer to an Egyptian arid-wadi context, where sediment connectivity has previously been noted as insufficiently characterised, represents the principal contribution of the study relative to the existing regional literature.

The results also carry a practical implication for the design and protection of mega hydraulic structures downstream of Wadi Mikeimin and comparable Sinai wadis. Because sediment hazard is concentrated along a small fraction of the catchment corresponding to the main channel network (Fig. 25) rather than distributed uniformly, sediment-control measures (check dams, sediment traps or vegetated buffers) are likely to be most cost-effective when targeted at these high-connectivity reaches rather than applied catchment-wide. This targeting logic mirrors recommendations from RUSLE–connectivity studies elsewhere (Li et al., 2022; Tang et al., 2014) and reinforces the practical value of the spatially explicit approach relative to a single catchment-average erosion figure.

3.8 Limitations

Several limitations inherent to the study must be acknowledged to contextualise its findings and guide future research. (i) **Rainfall data scarcity and spatial sparsity:** the R factor was derived from only three rain-gauge stations (Ras Ghazala, Ain Om Ahamed and Nuweiba), none situated within Wadi Mikeimin, and IDW interpolation introduces spatial uncertainty (Section 3.6). (ii) **DEM resolution:** the 12.5 m DEM (ASF/NASA) imposes topographic generalisation that may obscure fine-scale morphological features governing localised erosion. (iii) **Soil-data resolution:** the DSMW classifies the whole study area as a single soil unit (Unit I), which does not capture the heterogeneity in texture, organic carbon and structure that commonly exists across arid wadi catchments at sub-kilometre scale. (iv) **Absence of field validation:** no observed discharge or sediment-deposit record was available to validate the modelled hydrograph or sediment-yield map, so the results rely on the external hydrological benchmark and on indirect, regional corroboration (Section 3.5) rather than direct site-specific verification. (v) **Fixed SDR calibration constant:** C_{SDR} was adopted from the literature (Borselli et al., 2008) rather than calibrated locally, contributing to the sediment-yield uncertainty discussed above.

4. CONCLUSION

This study developed a spatially explicit, multi-technique assessment of flash-flood-driven sedimentation and debris-flow hazard in Wadi Mikeimin, South Sinai, Egypt, by coupling RUSLE-based soil-loss estimation, an Index-of-Connectivity sediment-delivery model, GIS raster analysis, remote sensing and event-based hydrological modelling. The principal quantitative findings are as follows.

For the 100-year design storm, the simulated peak discharge at the catchment outlet was $8.02 \text{ m}^3 \text{ s}^{-1}$, with a time to peak of 810 min and a total event runoff volume of $107,504.55 \text{ m}^3$, generated under a curve number of 97 reflecting near-complete bare-rock cover. Rainfall erosivity (R), derived from three regional gauges and interpolated by IDW, ranged from 0.744 mm h^{-1} (Ain Om Ahamed) to 7.62 mm h^{-1} (Nuweiba) at the gauges, with a mapped catchment range of approximately $4.94\text{--}5.93 \text{ mm h}^{-1}$. The soil-erodibility (K) factor was uniform at $0.138 \text{ t h MJ}^{-1} \text{ mm}^{-1}$, reflecting the single-soil-unit classification of the DSMW; the LS factor ranged up to 7.09, with the highest values on steep upper-catchment channel heads; and the C factor was close to 1 across nearly the entire catchment.

Gross soil loss (A) reached a maximum of $6.25 \text{ t ha}^{-1} \text{ h}^{-1}$, placing the most erosion-prone cells in the medium class of the erosion classification, while the majority of the catchment fell within the very-low-to-low classes. The Index of Connectivity reached a maximum of 17.20 and the Sediment Delivery Ratio ($C_{\text{SDR}} = 0.56$) a maximum of 0.968 along the main channel network, yielding a maximum sediment yield of $5.9883 \text{ t ha}^{-1} \text{ h}^{-1}$ for the design event, concentrated almost entirely along the drainage network rather than distributed across the catchment.

The WMS workflow reproduced the basin area, curve number, time to peak and discharge volume of a published 70.44 km^2 benchmark basin to within 5% and its peak discharge to within 10%, and a RUSLE-GIS model of the same type has been shown to reproduce surveyed check-dam sediment volumes within 2.5% and 7.4% elsewhere in Wadi Watir. Because the Wadi Mikeimin estimates have not been validated against independent discharge or sediment-deposit records and are subject to the parameter and data-resolution uncertainties discussed above, the absolute magnitudes should be treated as first-order, design-screening estimates rather than field-verified values. The spatial pattern of relative hazard, concentrated along the main channel network, is the more robust and directly transferable finding. Interpreted within the broader morphological framework of the Watir Valley, the results offer a substantive, transferable contribution to understanding erosion processes and sedimentation risk in arid, flash-flood-prone environments, with clear relevance for the design and protection of mega hydraulic structures across Egypt.

Recommendations for future research. (i) Extend the investigation to flash-flood events over longer time horizons, as flood recurrence is expected to alter vegetation cover and urban development patterns progressively, and with them erosion rates and sediment yield. (ii) Accumulate additional field measurements, including post-event sediment-deposit surveys and, where feasible, reservoir or check-dam bathymetric surveys, to refine spatial accuracy and enable direct validation of the sediment-yield and discharge estimates. (iii) Incorporate these measurements into the modelling framework, including local calibration of the curve number, the R-factor conversion coefficient (α) and the SDR calibration constant (C_{SDR}). (iv) Investigate higher-resolution DEM and soil datasets, where available, to test the sensitivity of the LS- and K-factor maps to the generalisation identified above.

Recommendations for engineering practice. The methodology is recommended for adoption in other arid watersheds with comparable physiographic and hydrological characteristics, and the quantitative results for direct use by hydraulic engineers and infrastructure planners engaged in the design and protection of mega hydraulic structures across Egypt, where flash-flood-driven sedimentation is an ongoing operational threat. The installation of efficient rainfall-gauging networks within the study area is strongly advocated as a prerequisite for improved hydrological modelling and reliable long-term sedimentation monitoring.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Alaska Satellite Facility (ASF) for providing access to the 12.5 m Digital Elevation Model (DEM) data. The authors also acknowledge the Water Resources Research Institute (WRRI) for providing rainfall data for the Ras Ghazala, Ain Om Ahamed, and Nuweiba stations. The authors further acknowledge the data providers of the Sentinel-2 land-cover data and the Digital Soil Map of the World used in this study. Finally, the authors sincerely thank the residents of the Nuweiba area for sharing their local knowledge of historical flash floods and sediment deposition during the field visits.

AUTHOR CONTRIBUTIONS

- Mohamed Hassan: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Visualization, Writing – Original Draft.
- M. Abo-Taha: Data Curation, – Review & Editing.
- Hany G.I. Ahmed, Ahmed M. Metwally: Supervision, Project Administration, Resources, Writing – Review & Editing.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

FUNDING

This research received no external funding.

ETHICS STATEMENT

Ethics approval and consent to participate are not applicable.

DATA AVAILABILITY STATEMENT

All data and materials used in this study are available upon reasonable request from the corresponding author.

REFERENCES

- [1] Abdo, H.G., 2021. Estimating water erosion using RUSLE, GIS and remote sensing in Wadi-Qandeel river basin, Lattakia, Syria. *Proceedings of the Indian National Science Academy* 87(3), 514–523. <https://doi.org/10.1007/s43538-021-00047-0>
- [2] Abo-Taha, M.L., Ahmed, H., El-Molla, A., 2022. Mapping flood hazards by multi-criteria decision analysis technique in geographic information system (GIS-MCDA). *Journal of Al-Azhar University Engineering Sector* 17(62), 26–38. https://journals.ekb.eg/article_216573.html
- [3] Al-hasn, R., Alghamaz, F., Dikkeh, M., Idriss, Y., 2024. Water soil erosion modeling with RUSLE, GIS & remote sensing: a case study of the Al-Sanaoubar River basin (Syria). *Journal of the Saudi Society of Agricultural Sciences* 23(7), 474–484. <https://doi.org/10.1016/j.jssas.2024.05.004>
- [4] Awadallah, A.G., Saad, H., El Moustafa, A., Hassan, A., 2015. Reliability assessment of water structures subject to data scarcity using the SCS-CN model. *Hydrological Sciences Journal*. <https://doi.org/10.1080/02626667.2015.1027709>
- [5] Benavidez, R., Jackson, B., Maxwell, D., Norton, K., 2018. A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences* 22, 6059–6086. <https://doi.org/10.5194/hess-22-6059-2018>
- [6] Benchettouh, A., Kouri, L., Jebari, S., 2017. Spatial estimation of soil erosion risk using RUSLE/GIS techniques and practices conservation suggested for reducing soil erosion in Wadi Mina watershed (northwest, Algeria). *Arabian Journal of Geosciences*. <https://doi.org/10.1007/s12517-017-2875-6>
- [7] Borselli, L., Cassi, P., Torri, D., 2008. Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. *Catena* 75, 268–277. <https://doi.org/10.1016/j.catena.2008.07.006>
- [8] Chae, H.-S., Lee, G.-S., Kim, T.-J., Koh, D., 2005. Application of remotely sensed data and geographic information system in watershed management planning in Imha, Korea. <https://www.researchgate.net/publication/228727087>
- [9] Darwish, K.M., Abdel Kawy, W.A.M., Afifi, A.A., Zölitz, R., 2016. Estimating the rainfall erosivity for management planning in the Eastern Desert, Egypt. *Geocarto International*. <https://doi.org/10.1080/10106049.2015.1120352>
- [10] Dawoud, M.A., 2020. Strategic water reserve using aquifer recharge with desalinated water in Abu Dhabi Emirate. *Desalination and Water Treatment*. <https://doi.org/10.5004/dwt.2020.25505>
- [11] Desai, A.R., Patel, V.M., Trambadia, N.K., 2022. A review of the application of the Revised Universal Soil Loss Equation for estimation of annual soil loss using conventional methods and GIS. 1440–1450. <https://www.academia.edu/3570874>
- [12] Djoukbala, O., Hasbaia, M., Benselama, O., Hamouda, B., Djerbouai, S., Ferhati, A., 2022. Water erosion and sediment transport in an ungauged semiarid area: the case of Hodna Basin in Algeria. Springer Singapore. <https://doi.org/10.1007/978-981-16-2904-4>
- [13] FAO, 1995. The State of Food and Agriculture 1995. <https://openknowledge.fao.org/items/de761960-5d4c-4d23-b715-252be2b58ca2>
- [14] Foster, G.R., Renard, K.G., 1983. Soil conservation: principle of erosion by water. <https://www.sciencedirect.com/book/9780123485208/fundamentals-of-soil-physics>
- [15] Gheith, H., Sultan, M., 2002. Construction of a hydrologic model for estimating wadi runoff and groundwater recharge in the Eastern Desert, Egypt. *Journal of Hydrology* 263, 36–55. [https://doi.org/10.1016/S0022-1694\(02\)00027-6](https://doi.org/10.1016/S0022-1694(02)00027-6)
- [16] Li, Y., Hu, K., Zhang, X., Hu, X., Ning, L., Li, H., 2022. Assessment of debris flow activity in response to an earthquake using the sediment connectivity index. *Frontiers in Earth Science* 10, 1–14. <https://doi.org/10.3389/feart.2022.921706>
- [17] Mashal, M., Attia, K., Gad, M.A., 2017. A GIS-based model for estimating runoff sedimentation in semi-arid wadies. <https://www.researchgate.net/publication/339326734>

- [18] Masoud, A.A., 2009. Runoff modeling of the wadi systems for estimating flash flood and groundwater recharge potential in Southern Sinai, Egypt. *Arabian Journal of Geosciences*, 785–801. <https://doi.org/10.1007/s12517-009-0090-9>
- [19] Metwally, A.M., 2024. Developing design curves to determine recharge wells influence zones under various soil characteristics. *Journal of Al-Azhar University Engineering Sector* 19(72), 70–85. <https://doi.org/10.21608/aej.2024.256875.1542>
- [20] Moore, I.D., Wilson, J.P., 1992. Length-slope factors for the Revised Universal Soil Loss Equation: simplified method of estimation. *Journal of Soil and Water Conservation* 47(5), 423–428. <https://doi.org/10.1080/00224561.1992.12456740>
- [21] Oliveira, A.X. de, Almeida, F.T. de, Souza, A.P. de, Paulista, R.S.D., Zolin, C.A., Hoshide, A.K., 2024. Determination of soil erodibility by different methodologies in the Renato and Caiabi River sub-basins in Brazil. *Land* 13(9), 1442. <https://doi.org/10.3390/land13091442>
- [22] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp. https://archive.org/details/isbn_9780160489389
- [23] Shin, G., 1999. The analysis of soil erosion in watershed using GIS. <https://library.gwnu.ac.kr/>
- [24] Suhara, K.K.S., Varughese, A.N.U., Sunny, A.C., 2023. Erosivity factor of the Revised Universal Soil Loss Equation (RUSLE) – a systematized review. *Current World Environment* 18. <https://doi.org/10.12944/CWE.18.2.02>
- [25] Tang, Q., Xu, Y., Bennett, S.J., 2014. Assessment of soil erosion using RUSLE and GIS: a case study of the Yangou watershed in the Loess Plateau, China. *Environmental Earth Sciences*. <https://doi.org/10.1007/s12665-014-3523-z>
- [26] USDA NRCS, 2002. Universal Soil Erosion Prediction (USLE) used for HEL, NRI, and other designated programs. In: USDA–NRCS National Soil Survey Handbook / National Agronomy Manual, pp. 1–36. https://efotg.sc.egov.usda.gov/references/Agency/OH/Section_I_-_USLE_Soil_Loss_Prediction.pdf
- [27] Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses. U.S. Department of Agriculture, Agriculture Handbook No. 537. <https://naldc.nal.usda.gov/catalog/CAT79706928>