JJEES

JJEES (2025) 16 (3): 227-236
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Sediments Transport Mitigation and Management in Wadi Shu'eib Dam

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Received on September 30, 2024, Accepted on February 16, 2025

Abstract

Accumulation of sediments in dams is a significant problem that impacts the storage function of the dam. In Jordan, over 20% of the capacities of major dams are filled with sediment. This study aims to mitigate and manage sediment yield, as well as predict it based on peak flow at the Wadi Shu'eib Dam (WSD) catchment. The WSD has a capacity of 1.4 MCM in the Wadi Shu'eib catchment area in the Al-Balqa governorate. The Watershed Modeling System (WMS) and Soil and Water Assessment Tool (SWAT) models were employed to predict the runoff flood hydrograph and sediment yield of the catchment from 1985 to 2018. The rainfall stations at Wadi Shu'eib, Salt, South Shuna, and Hummar were utilized in the hydrologic modeling. The results indicated that the dominant land use is agricultural, characterized by loamy soil and steep slopes. The average annual precipitation over Wadi Shu'eib is 325 mm, with 60% evapotranspiration and 57 mm of surface runoff. The peak flow values for design storms with return periods of 25, 50, and 100 years were 158, 213, and 277 m3/s, respectively. The average annual sediment yield at the outlet of this dam is approximately 7.6 tons/ha. Four sediment mitigation measures are proposed to decrease the sediment deposited behind the dam. The results of the SWAT model indicated that reforesting 20 ha (about 1.5% of the catchment) would reduce sediment by 21%. Similarly, installing a hydraulic slurry dredge near the dam crest will decrease sediment by 38%. Furthermore, dry excavation of sediment during dry periods will lower the sediment by 40%. Moreover, if all proposed measures are implemented together, sediment removal could increase to 53%.

Keywords: Hydrology, Sediment Mitigation, WMS, SWAT, Wadi Shu'eib

1. Introduction

Jordan is one of the most water-scarce countries in the world, with estimated renewable water resources of less than 61 m³ per capita annually, and 85% of the country receives less than 200 mm of rainfall per year (MWI, 2023). Given this acute water scarcity, artificial surface water bodies, including dams, are essential for securing residential and agricultural water supplies. Currently, Jordan operates 14 major dams with a combined capacity of approximately 280 million cubic meters (MCM) (JVA, 2021). In rural areas, where household incomes are generally lower, rainwater reservoirs have long served as a critical water supply system, supported by donor agencies and nongovernmental organizations promoting rainwater harvesting systems (FAO, 2011). This infrastructure plays a crucial role in enhancing the country's resilience to fluctuating and often limited rainfall patterns.

Among the key challenges +- Jordan's dam infrastructure faces is sedimentation, which refers to accumulating suspended particles that settle out of water due to gravity. This process, driven by erosion caused by rainfall and runoff, leads to sediment transport and deposition in dam reservoirs. The issue of sedimentation is particularly critical in Jordan, where more than 20% of the storage capacities of major dams are filled with sediments, significantly undermining their efficiency and operational longevity (Oroud, 2015; Al-Shibli et.al., 2017; MWI, 2023).

The accumulation of sediments in dam reservoirs reduces both storage capacity and operational efficiency, directly impacting water availability and management strategies. For example, the Wadi Shu'eib Dam (WSD), an earth-fill dam constructed in 1969, was initially designed with a storage capacity of 2.4 MCM. However, due to sedimentation and seepage, its current operational capacity stands at only 1.43 MCM—a reduction of over 40% (MWI, 2020). This significant loss underscores the urgency of adopting effective sedimentation management strategies, especially given the limited opportunities to construct new dams due to geographic and financial constraints.

Understanding and mitigating sedimentation in existing dams require a comprehensive examination of hydrological and sediment transport processes. Surface runoff, the primary driver of sediment yield in catchments, must be thoroughly studied to develop appropriate mitigation strategies. This entails hydrological modelling and analysing flood hydrographs for various design storms (Bani Baker et al., 2022).

Hydrological modelling tools, such as the Watershed Modelling System (WMS), have been widely used to

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simulate hydrological processes and provide essential tools for watershed delineation, calculations, and modelling (Daniel, 2011; Srinivas et al., 2018; AQUAVEO, 2021). For instance, Al-Weshah and El-Khoury (1999) applied the Hydrologic Engineering Centre (HEC-1) model to analyse and mitigate flood risks in Petra's catchment area. Their study demonstrated the effectiveness of flood mitigation measures, which reduced peak flow by up to 70% for storm events with return periods ranging from 2 to 200 years. Similarly, Aziz (2020) employed the WMS model to estimate annual runoff and peak flow at the Nazanin watershed in Iraq, achieving a mean annual runoff volume of approximately 8 MCM using the SCS method.

In addition to hydrological modelling, sedimentation studies often utilize the Soil and Water Assessment Tool (SWAT) to simulate and predict sediment yields. Developed by the USDA Agricultural Research Service and Texas A&M AgriLife Research, SWAT is a conceptual, physically-based model designed for long-term simulations of watershed processes. The model incorporates the Universal Soil Loss Equation (ULSE) to estimate soil erosion as a function of rainfall energy and other factors (Zeiger et al., 2021; Wischmeier and Smith, 1978). In Jordan, Shaheen (2017) conducted a study on sediment accumulation at King Talal Dam, using SWAT, estimating an annual sediment yield of 0.35 MCM. Similarly, Abu-Zreig and Bani Hani (2021) validated the SWAT model for simulating runoff in the arid Yarmouk River catchment.

This study aims to build upon these research findings by leveraging advanced hydrological and sediment modelling tools to address the sedimentation challenges at Wadi Shu'eib Dam. Given its strategic importance within Jordan's water management system, ensuring the dam's operational sustainability is essential for addressing the country's ongoing water resource challenges. By understanding sediment dynamics and proposing effective mitigation measures, this research seeks to enhance the dam's storage capacity, optimize its operations, and contribute to the broader goal of sustainable water resource management in Jordan.

1.1 Research Context and Objectives

The Wadi Shu'eib Dam catchment, located in the Lower Jordan River basin, encompasses approximately 176 km² in the Al-Balqa governorate, west of Amman, as shown in Figure 1. The catchment features steep slopes and predominantly agricultural land, with loamy soils contributing to sedimentation risks. Limited studies have addressed sediment yields and their management in this area.

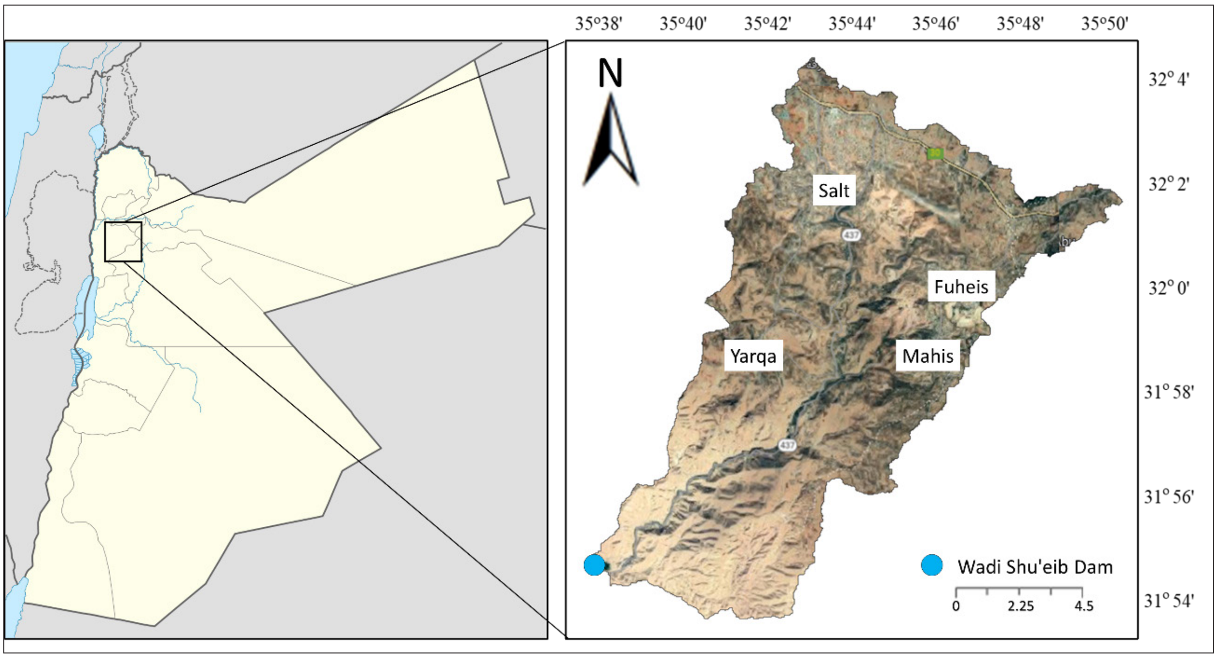

Figure 1. Wadi Shu'eib catchment area and dam location

This research aims to address the sedimentation challenges in WSD by:

- Developing a hydrological model, using WMS to estimate surface runoff and flood hydrographs for design storms with return periods of 25, 50, and 100 years.
- Predicting sediment yield inflow to the reservoir, using the SWAT model.
- Proposing effective sediment mitigation techniques to enhance dam performance.

2. Methods and Tools

The methodology employed in this research includes data collection, hydrologic modelling using the Watershed Modelling System (WMS), sediment yield analysis using the Soil and Water Assessment Tool (SWAT), and the development of mitigation strategies for sediment accumulation.

The WMS version (WMS 11.1) was chosen due to its user-friendly interface and robust hydrologic modelling capabilities, particularly its integration with various runoff estimation methods such as the Curve Number method and its ability to handle complex watershed delineation and terrain analysis. However, the specific version of WMS used in this study needs to be clarified.

The SWAT model version (ArcSWAT 2012 for ArcGIS 10.5) was selected for its comprehensive simulation of watershed processes, including surface runoff, sediment yield, and nutrient transport over long time scales. SWAT is well-known for its applicability in diverse catchments, both gauged and ungauged, and its compatibility with GIS for spatial data integration.

2.1 Data Collection

Data for the Wadi Shu'eib catchment were collected to support hydrological and sediment modeling. The data types and sources included:

- Digital Elevation Model (DEM) used for watershed delineation and slope analysis, Figure 2a.
- Land Use and Cover Maps used to classify and map the land cover categories, Figure 2.b.
- Watershed Characteristics, that is, information on the area, slope, and elevation.
- Soil Maps that Provided data on the distribution and properties of soil types, Figure 2.c.
- Rainfall Data that functioned as historical rainfall records from four stations (Salt, Wadi Shu'eib, Hummar, and South Shuna) and were collected for the period 1985 to 2018.

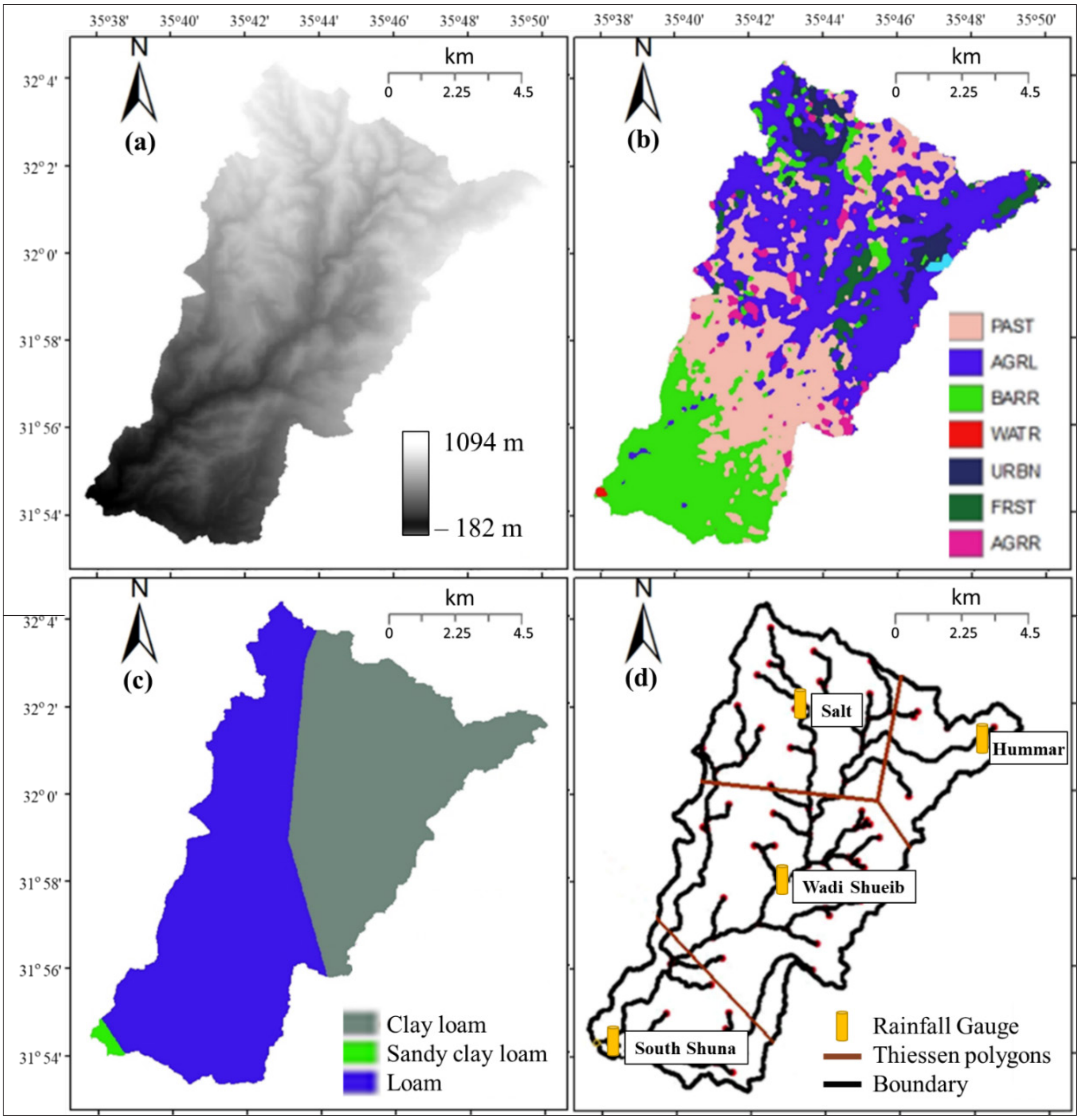

Figure 2. (a) Elevation, **(b)** Land use **(c)** Soil, and **(d)** Thiessen polygons maps of Wadi Shu'eib by WMS 11.1

3. Description of the Study Area

3.1 Location

The Wadi Shu'eib Drainage (WSD) catchment is located at the Lower Jordan River catchment within Al-Balqa Governorate, west of Amman, Jordan. It covers an area of approximately 176 km² at the outlet of WSD. Geographically, it lies between latitudes 31°50' to 32°02' N and longitudes 35°35' to 35°50' E. The catchment has a generally rectangular shape, encompassing Salt City and the towns of Fuheis, Mahis, Yarqa, and Wadi Shu'eib (MWI, 2020), as depicted in Figure 1.

The WSD catchment is characterized by steep terrain, with elevations, ranging from 376 meters below mean sea level in the southwest to 1,100 meters above mean sea level in the northeast. Based on the Digital Elevation Model (DEM), generated using the Watershed Modelling System (WMS), the average elevation is approximately 560 meters, and the average slope is 0.223 m/m. The DEM, with a resolution of 30×30 meters, is presented in Figure 2(a).

3.2.1 Land Use Distribution

A digitized land use map obtained from the Ministry of Water and Irrigation (MWI, 2020) reveals significant variations across the catchment. Figure 2(b) illustrates the land cover distribution. The most dominant land use is Agricultural Land-Generic (AGRL), occupying nearly 46% of the total area, mainly in the upper half of the wadi in the north and east. Row crop land use covers a mere 0.5%.

Pastures (PAST) and barren lands (BARR) dominate the lower section of the wadi. Pastures, the second most common land use, cover more than 30% of the area, while barren lands account for 18%. Residential areas, mixed forests, and water bodies are scattered throughout the watershed, constituting less than 6% of the total area. Each land use type varies in terms of land cover management factors, curve numbers, and Manning's values for overland flow.

3.2.2 Soil Type Distribution

Soil maps from the Ministry of Water and Irrigation (MWI) show that the WSD catchment primarily consists of three soil types: loam, clay loam, and sandy clay loam, as shown in Figure 2(c). Loam is the most prevalent soil type, covering approximately 55.8% of the total area, mainly in the western half of the wadi. Clay loam makes up around 44% and is concentrated in the eastern half. Sandy clay loam, which constitutes less than 0.2% of the area, is primarily found in the southwestern region.

3.2.3 Climate and Rainfall

The climate in the WSD catchment is a combination of Mediterranean and desert climates, characterized by low rainfall and high evaporation rates, with 92.2% of the rainfall evaporating. The average daily minimum temperature in January is around 12°C, while the average daily maximum temperature in July exceeds 40°C. Relative humidity ranges from 38% in June to 68% in January (MWI, 2020).

- Intensity-Duration-Frequency (IDF) curves were used to predict rainfall intensity for different storm durations.
- Thiessen polygon networks were generated for four rainfall stations—Salt, Wadi Shu'eib, Hummar, and South Shuna—using WMS 11.1, as shown in Table 1 and Figure 2(d). Rainfall data from 1985 to 2018 were analysed for 25-, 50-, and 100-year design storms (MWI, 2020).
- The estimation of peak discharge was conducted using the WMS software version 11.1 through the following steps (Figure 3):
- Delineating the catchment area: the catchment area was delineated and subdivided into smaller sub-catchments to enhance the accuracy of the analysis (Table 2).
- Generating synthetic hydrographs: Synthetic hydrographs for 50 and 100-year design storms, utilizing the HEC-1 model integrated within the WMS software.
- Calculating the peak flow rates: The peak flow rates associated with these synthetic hydrographs were calculated to determine the maximum discharge for each return period.

Table 1. Rainfall stations coordination and Thiessen polygons areas with 100-year design storm precipitation

Rainfall station	JTM - N	JTM - E	Elv. (m) (Z)	% of the total area	Design storm precipitation (mm)		
					25 yr	50 yr	100 yr
Wadi Shu'eib	31° 58'	35° 43'	317	42%	87	104	122
Salt	32° 2'	35° 44'	784	28%	112	123	133
South Shuna	31° 54'	35° 38'	-169	17%	35	39	43
Hummar	32° 1'	35° 49'	923	13%	102	113	123
Average precipitation (mm)					87	99	112

Table 2. Sub-catchments characteristics

Sub-catchment	Mean Elevation (m)	Longest path (m)	Area (ha)	No. of HRUs
1	962	5921	867	9
2	949	4909	449	13
3	853	5608	1036	8
4	909	9886	1157	3
5	699	3318	268	8
6	840	6378	590	6
7	749	6741	1185	14
8	591	4330	287	6
9	678	5760	594	8
10	679	5224	728	4
11	571	5323	446	13
12	409	1036	37	7
13	595	4808	449	13
14	415	2311	195	14
15	366	4113	343	8
16	557	7043	987	10
17	592	16035	2252	7
18	275	6784	902	7
19	-109	2234	56	12
20	116	10352	1170	7
21	172	3978	391	4
22	309	10120	1052	6
23	43	8684	1101	4

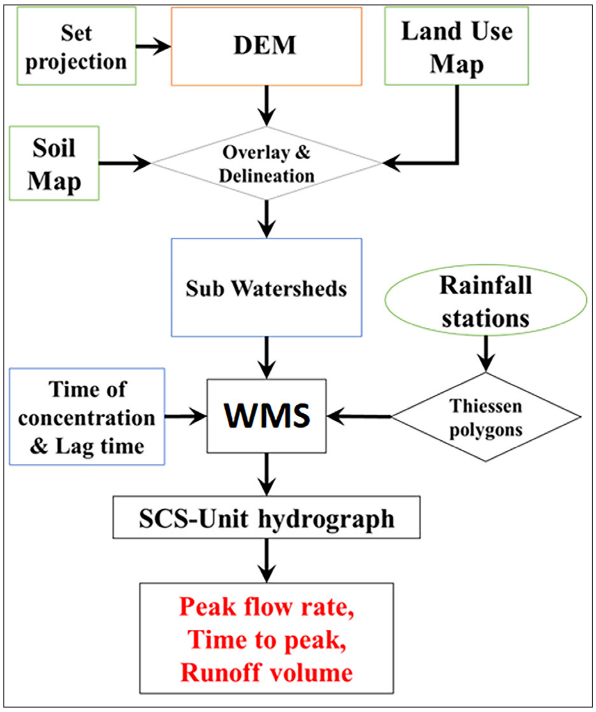

Figure 3. WMS model flowchart

3.4 Estimation of the transported sediments

The sediment yield analysis, using the SWAT model, as summarized in Figure 4, was carried out through the following steps:

1. Watershed Delineation: A DEM grid of the WSD watershed was loaded into the model to define the stream network, flow direction, and accumulation areas. Since the objective of this research is to estimate sediment yield, WSD was selected as the outlet of the catchment. The delineation process involved the following steps:

    a. The projection system used was Jordan Transverse Mercator (JTM), which is commonly applied to geographic maps in Jordan.

    b. The study area boundaries were defined using a catchment shapefile. Flow direction and accumulation areas were then identified to assist the model in creating stream networks and outlets.

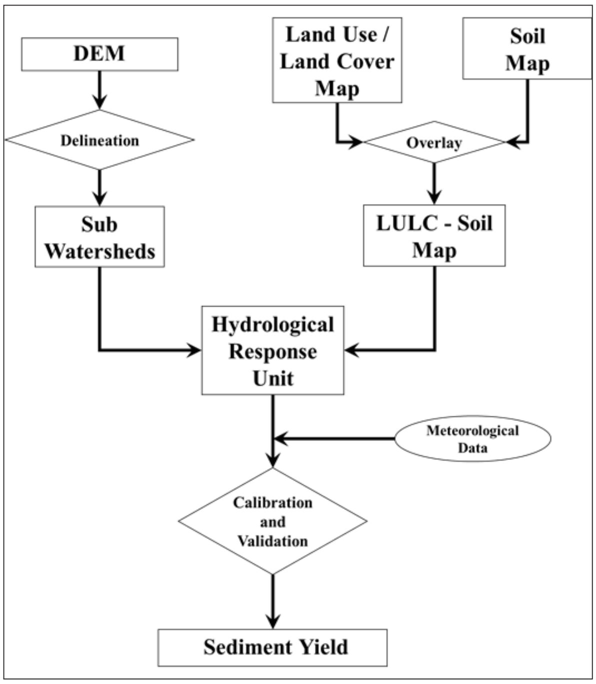

Figure 4. SWAT model flowchart

c. The WSD was identified as the outlet of the catchment, determining the effective sub-catchments, contributing to sediment formation. Parameters such as sub-catchment area, average slope, and stream lengths were generated. The sub-catchment distribution layout is displayed in Figure 5.

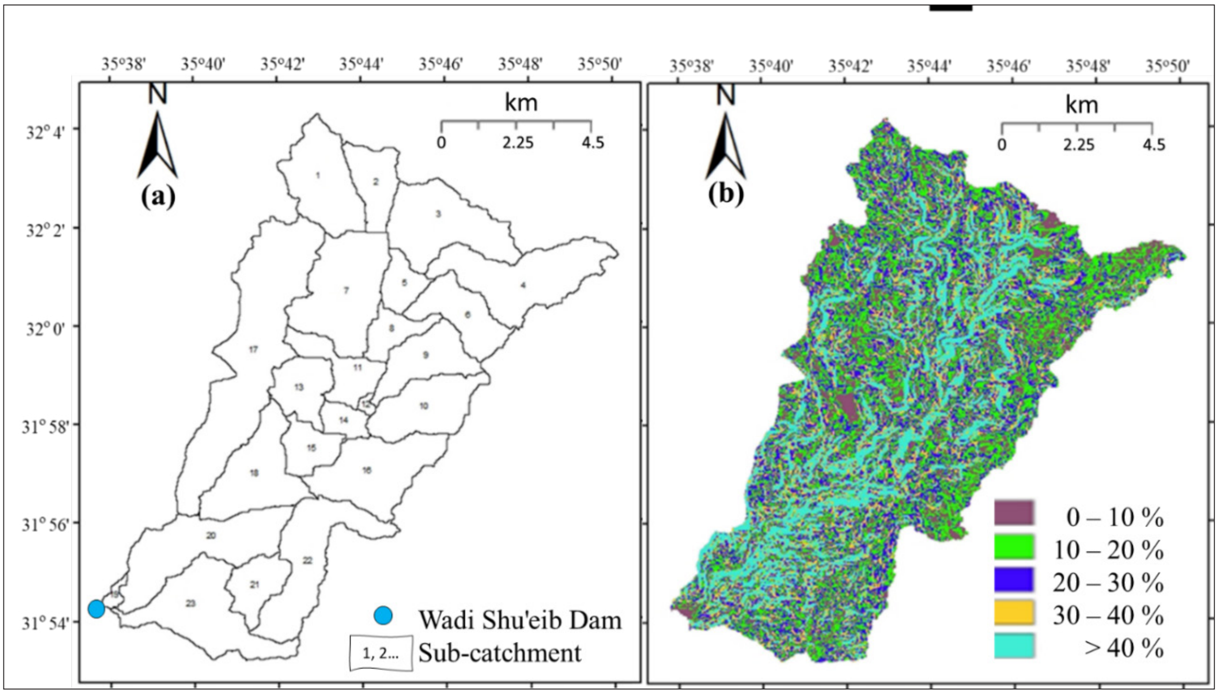

Figure 5. SWAT model **(a)** Sub-catchments and **(b)** Slopes maps of WSD

3. Hydrological Response Units (HRUs) are distinct areas within the sub-catchment that possess unique combinations of land cover, soil types, and slopes (Neitsch et al., 2009). The HRUs for the watershed were defined as follows:
   a. The land use raster map was loaded, and the land use data were reclassified using a text file that specified the properties of the land use categories.
   b. The soil raster map was imported, and a soil text file was inserted to link the map's soil types with those in the SWAT model.
   c. Slopes were categorized into five distinct classes, representing various slope ranges, as illustrated in Figure 3b.
   d. The land use, soil, and slope maps were overlaid using the "overlay" command, and the HRUs were then created by selecting the "define HRU" command.

3.5 Investigation of sediment mitigation and management techniques

An assessment of the technical feasibility of proposed mitigation techniques and the development of ranking criteria for the selection of priority actions were considered to draw the sediment management plan (Yang and WMO, 2003; GIZ, 2021). Sedimentation significantly impacts the efficiency and storage capacity of Wadi Shu'eib Dam. Effective mitigation strategies are crucial to maintain its functionality. This section summarizes the evaluation of mitigation techniques, prioritization criteria, and a comprehensive sediment management plan.

3.5.1 Assessment of Proposed Mitigation Techniques

The evaluation focused on the following factors:

- Technical Feasibility: Suitability based on site-specific conditions (topography, soil type, hydrology).
- Sediment Removal Efficiency: Effectiveness in reducing sediment accumulation.
- Implementation and Operational Requirements: Complexity and technical expertise are needed.
- Economic Viability: Cost analysis for setup and long-term maintenance.
- Environmental Impact: Preference for eco-friendly solutions.

3.5.2 Mitigation Techniques Considered

1. Reforestation: Planting trees on barren land to stabilize soil and reduce sediment yield by 21% (cost: 60,000 JOD).
2. Hydraulic Dredging: Removing underwater sediment near the dam crest, reducing sediment by 38% (cost: 1.4 million JOD).
3. Dry Excavation: Sediment removal during dry periods, reducing 40% of sediment (cost: 1.27 million JOD).
4. Mixed Practices: Integrating all techniques for a 53% reduction (cost: 2.7 million JOD).

3.5.3 Ranking Criteria for Priority Actions

Key criteria for prioritization included:

- Sediment reduction efficiency
- Cost-effectiveness
- Environmental sustainability

- Ease of implementation
- Operational and maintenance requirements

3.5.4 Integration into a Sediment Management Plan

An integrated plan combining multiple techniques was developed to optimize sediment removal and ensure long-term sustainability. This approach balances technical feasibility, economic factors, and environmental preservation to effectively address sedimentation challenges at Wadi Shu'eib Dam.

4. Results and Discussion

4.1 Hydrological Modelling and Analysis

The hydrological analysis conducted using the HEC-1 model within the Watershed Modelling System (WMS 11.1) provides critical insights for flood risk management in the study area. Peak flow rates were computed for design storms with return periods of 25, 50, and 100 years, yielding values of 158, 213, and 277 m³/s, respectively. The SCS hydrographs at the outlet point, as illustrated in Figure 6, demonstrate a consistent time to peak of 16 hours for all three design storms. Runoff volumes for these events were estimated at 4.3, 5.6, and 7.2 million cubic meters (MCM), respectively.

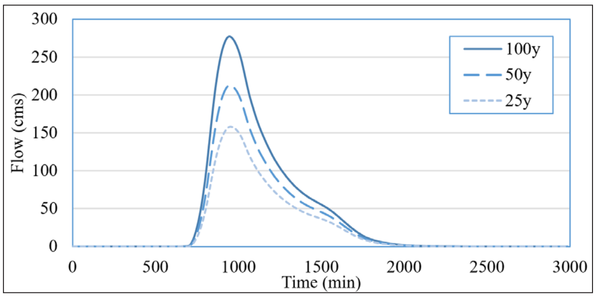

Figure 6. SCS flood hydrographs for 25-, 50- and 100- return years by WMS 11.1

Given the absence of historical flood data due to the ungauged nature of the catchment, these modelled flow rates are vital for establishing baseline flood risk assessments. The computed peak flows suggest a substantial potential for extreme flood events, particularly under the 100-year storm scenario. Climate change is expected to exacerbate such risks by increasing the frequency and intensity of extreme weather events. Consequently, understanding the capacity of existing infrastructure, such as the dam, becomes paramount.

The dam at the outlet was evaluated for its potential to handle runoff from these design storms. Based on the WMS analysis, the dam has a width of approximately 760 meters and a current height of 31 meters, with a possible extension to 40 meters. The dam height cross-section is shown in Figure (7a), while the relationship between dam height and width is depicted in Figure (7b). Given the estimated runoff volume from the 100-year storm (7.2 MCM) and the peak flow rate (277 m³/s), the current dam height of 31 meters may be insufficient to fully mitigate the flood risk from such an extreme event. Raising the dam height to 40 meters could provide a more robust flood control solution, although further detailed hydraulic analyses would be required to confirm its adequacy.

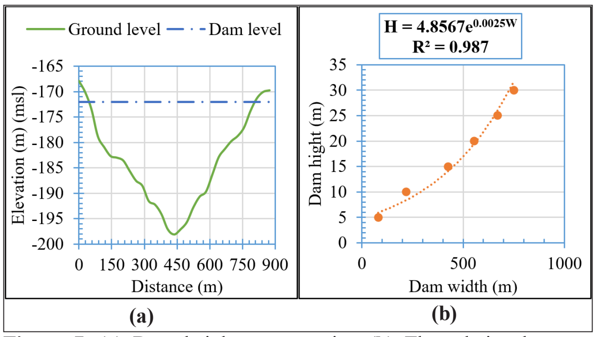

Figure 7. (a) Dam height cross-section **(b)** The relation between dam's height and width

The study underscores the critical importance of integrating accurate hydrological modelling and infrastructure capacity assessments to enhance flood risk management strategies in ungauged catchments. In the face of potential climate change impacts, proactive measures, such as increasing dam capacity and implementing additional flood mitigation strategies, will be essential for safeguarding the study area.

4.2 Practical Implications for Water Management and Policy Recommendations

- Flood Mitigation:

The computed peak flow rates for 25, 50, and 100-year design storms highlight a growing necessity for comprehensive flood management strategies. Authorities should develop comprehensive flood management strategies, update flood hazard maps, and implement early warning systems to reduce risks from extreme runoff events.

- Dam Capacity Assessment:

The current 31-meter dam may be insufficient for handling the 100-year storm runoff of 7.2 MCM and 277 m³/s. Increasing the height to 40 meters or adding an auxiliary spillway is recommended.

- Climate Change Adaptation:

Despite the absence of historical data, the threat of more intense storms requires climate-resilient infrastructure, including design updates and nature-based solutions.

- Integrated Watershed Management:

Erosion control and upstream retention strategies are essential due to the catchment's steep slope and length. Collaboration between agencies is crucial for effective implementation.

- Data Collection and Monitoring:

Establishing a hydrological monitoring network is imperative to collect real-time data for better calibration of hydrological models and more accurate predictions of flood behavior. The lack of historical data in the study area hinders the development of precise water management plans. Investment in automated monitoring stations would bridge this gap.

4.2 Sediment transport analysis

4.2.1 Sediment yield

The Watershed Study Area (WSD) receives an average annual precipitation of 325 mm, equating to more than

57.2 MCM/year, with 60% (188 mm/year) lost through evapotranspiration. Calibration of the SWAT model was essential to improve accuracy, with the curve number (CN) being the most sensitive parameter, adjusted from 87 to 70 to better match observed conditions.

Following calibration, the model estimated an average annual surface runoff of 57.34 mm (10.7 MCM/year). During the 1985-2018 simulation period, the average sediment yield at the dam outlet was 7.6 tons per hectare. Figure (8) shows the distribution of yearly sediment yields, highlighting significant seasonal variations, with peak sediment yields occurring in winter (January, February, and December).

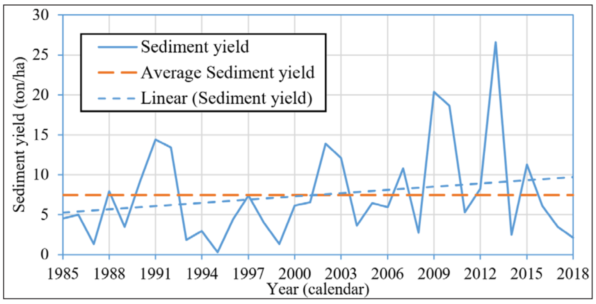

Figure 8. Annual sediment yield fluctuation at WSD (SWAT, 2020)

The results revealed substantial interannual variability in sediment yield, with a maximum of 26.6 tons/ha in 2013 and a minimum of 0.33 tons/ha in 1995. Contributing factors include:

- Climate Patterns: Variations in rainfall intensity and frequency impact runoff and sediment transport.
- Extreme Weather Events: Intense storms, like those in 2013, lead to higher sediment yields.
- Soil Conditions: Changes in soil moisture and saturation influence runoff and sediment mobilization.
- Land Use Changes: Modifications in land cover or agricultural practices contribute to increased erosion.

A linear increase in sediment yields every 10 years suggests progressive land degradation, driven by factors such as deforestation, agricultural expansion, and urbanization. Climate change, including more intense rainfall, likely exacerbates sediment transport.

A strong correlation between surface runoff and sediment yield was found, represented by the following equation Figure (9):

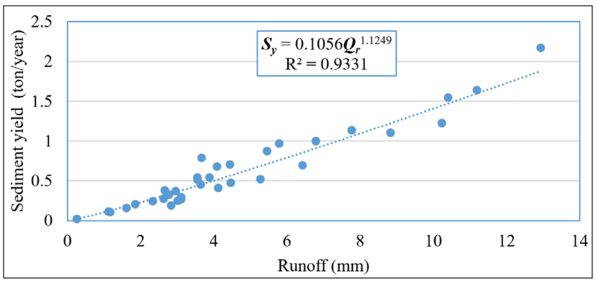

Figure 9. Sediment yield (S_y) and surface runoff (Q_r) correlation

Sy = 0.1056 Qr^1.1249

Where:

Sy = Sediment yield (tons/ha)

Qr = Runoff depth (mm)

$R^2 = 0.9331$

This equation serves as a tool for sediment management strategies, such as:

- Designing Sediment Traps: Estimating sediment volumes based on runoff to guide retention structure design.
- Dam Operation Adjustments: Anticipating sediment inflows for maintenance and flushing schedules.

The Model calibration involved adjusting sensitive parameters, notably the curve number (CN). Performance metrics, including Nash-Sutcliffe Efficiency (NSE), coefficient of determination (R^2), and percent bias (PBIAS), indicated satisfactory performance with NSE values above 0.75 and R^2 above 0.9 for both runoff and sediment yield.

From these findings, several sediment management strategies are recommended:

- Catchment Rehabilitation: Reforestation and soil conservation measures to reduce runoff and sediment yield.
- Structural Controls: Building check dams, silt fences, and vegetative buffers to mitigate sediment transport.
- Monitoring and Adaptive Management: Ongoing monitoring to refine sediment control practices based on observed trends.

In conclusion, the SWAT model provided critical insights into sediment dynamics and their relationship with surface runoff. The results highlight the need for integrated catchment management and effective sediment control to ensure the sustainability of water resources and dam operations.

4.2.2 Sediment Mitigation Measures

This study shows that the west-south areas of the catchment experience the highest surface runoff and sediment yield due to their steep slopes and elevated topography. The sediment management options proposed by GIZ (2021) include:

- Reforestation: Reforestation of approximately 20 ha around the dam could reduce sediment inflow by 21%, lowering the Curve Number (CN) to 65. While it takes years to mature, its long-term impact is positive, but monitoring is needed to address climate and land-use challenges.
- Hydraulic Dredging: Installing a hydraulic dredge near the dam crest would reduce sediment by 38% in about 6 ha. It offers quick results but has high operational costs and could disturb aquatic ecosystems. An environmental impact assessment (EIA) is needed before implementation, along with continuous monitoring downstream.
- Excavation: Excavating 9 ha around the dam would reduce sediment by 40%. This method is effective

but labor-intensive and costly, with potential local environmental impacts, such as soil disturbance. These impacts must be carefully considered during the planning stage.

- Combined Measures: Using all three techniques together could remove up to 53% of sediment. This integrated approach requires careful coordination of resources and time. Details of the mitigation measures are shown in Tables (3) and Figure (10).

Table 3. Proposed sediments removal methods at WSD

Mitigation method	Sediment yield with mitigation (ton/ha)	Sediment reduced (ton/ha)	Area covered (ha)	Removal %
Forestation	6.0	1.6	20	21%
Hydraulic dredging	4.7	2.9	6	38%
Dry excavation	4.6	3.0	9	40%
Mixed	3.6	4.0	35	53%

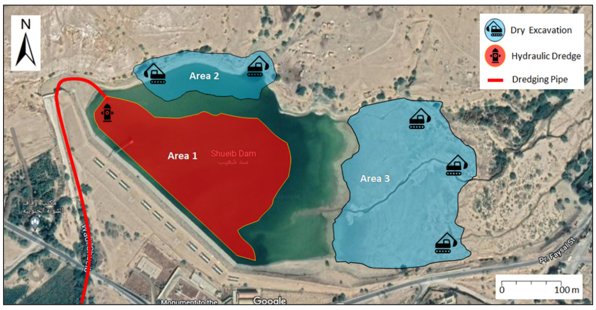

Figure 10. Dry excavation and hydraulic dredging proposed areas (based on GIZ)

- Feasibility and Environmental Considerations

A cost-benefit analysis is essential to evaluate both financial and environmental costs. Reforestation has lower upfront costs but takes time, while dredging and excavation provide quicker results at a higher cost. Complementary strategies, like check dams, terracing, or upstream erosion control can enhance sediment management and reduce dependence on dredging and excavation.

- Environmental Impacts

Hydraulic dredging may disrupt aquatic ecosystems, so an EIA is necessary. Reforestation could be affected by climate and land-use conflicts, requiring careful planning.

- Maintenance and Monitoring

Sediment management requires ongoing maintenance and monitoring. A program should be established to assess the effectiveness of all measures, ensuring the survival of reforested trees and periodic interventions for dredging and excavation.

In conclusion, combining these techniques with complementary strategies offers the most effective long-term solution for managing sediment yield in the catchment area.

5. Conclusions and recommendations

5.1 Conclusions

A sediment mitigation and management analysis was conducted for the WSD catchment by combining the hydrologic model WMS 11.1 and the sediment SWAT model. The most dominant land use in the WSD catchment is agricultural, characterized by loamy soil and steep slopes. Based on hydrological and sediment modeling, the following conclusions can be drawn:

- Peak flow rates for design storms were computed using the WMS 11.1 model with the SCS hydrographs. The peak flow rates were estimated as 158, 213, and 277 m^3/s, respectively.
- Sediment yield in the WSD catchment was estimated using the SWAT model. The results show that, during the simulation period (1985-2018), the average sediment yield at the outlet of the dam was 7.6 tons, with sediment yield increasing over time.
- The relationship between sediment yield and runoff depth can be modeled using a power equation with a high correlation coefficient.
- Various mitigation techniques were investigated to control sediment transport. Reforestation, dry excavation, hydraulic dredging, and mixed practices were found to reduce sediment by 21%, 40%, 38%, and 53%, respectively.
- However, conservative management practices, such as the construction of check dams, terraces, and contour tillage, should be implemented in the catchment to reduce sediment yield.

5.2 Recommendations

1. A combined approach is recommended for effective sediment management due to the complementary benefits of:

- Reforestation: Stabilizes soil and reduces runoff on steep slopes for long-term erosion control.
- Dry Excavation: Efficient removal of accumulated sediment in dry dam areas.
- Hydraulic Dredging: Immediate sediment removal near the dam crest, restoring storage capacity. This integrated approach balances immediate sediment removal with long-term sustainability and reduces reliance on costly single methods

2. To address the risks posed by climate change, including increased storm intensity and prolonged droughts, we need to:

- Enhance reforestation for slope stability and runoff control.
- Construct check dams and terraces to manage extreme rainfall events.
- Utilize climate-resilient vegetation to maintain stability in drought-prone areas.

3. Implement vegetation restoration, contouring tillage, and construction terraces to minimize erosion across the catchment.

4. Install sediment gauges at WSD for real-time monitoring and conduct comprehensive studies on sedimentation across Jordan's dams to sustain water storage capacities amid changing climate conditions.

Acknowledgement

The authors sincerely thank the Deanship of Scientific Research at the University of Jordan for their partial financial support, making this study possible. They also appreciate the valuable insights and assistance provided throughout the research.

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