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Erosion Rates in Dam Catchments in Jordan—Effects of Topography, Geology, and Urbanizations

Elias Salameh[1*], Hakam Al-Alami[1], Ibraheem Hamdan[2,3]

[1]Department of Geology, University of Jordan Amman, Amman, Jordan
[2]Faculty of Earth and Environmental Sciences, Department of Applied Earth and Environmental Sciences, Al al-Bayt University, Mafraq, Jordan
[3]Environment, Water and Energy Research Center, Al al-Bayt University, Mafraq, Jordan
Email: *salameli@ju.edu.jo

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Abstract

Erosion as a natural process produces soils, which are very important natural resources for the fest land plant- and animal kingdoms. Loss of the soil cover reduces agricultural production, biodiversity, and the role of soil as a filter for infiltrating water to replenish the groundwater. It also threatens the food supplies. The knowledge of erosion rates of rocks and terrains is important for developing proactive measures to protect soils from erosion and loss. In this study, erosion rates of catchment areas were calculated based on dams' catchment extensions and the sediment loads transported by flood flows into dams' lakes. The study results show that the chemically, via floodwater, transported quantities of materials are negligible compared to the solid materials transported by the water. It calculates erosion rates ranging from 0.013 to 0.212 mm/yr (13 - 212 m/10^6 yr) for the different catchment areas. Erosion rates in Jordan are, generally, higher than those calculated for the different parts of the world ranging from 2.5 to 60 m/10^6 yr. This fact can be explained by the very steep topography, calcareous rock cover of the catchment areas and the barren rock exposures.

Keywords

Erosion Rates, Jordan, Dams, Sediment Load

1. Introduction

Knowledge of erosion rates in the different climatic zones of the Earth is of scientific and economic interest, and it has practical implication for agriculture, and water structures such as dams, weirs, terraces, drainage canals, roads, bridges and building constructions. In addition, knowledge of actual erosion rates is of importance to calculate historic erosion rates of rocks and terrains in past geologic times.

Direct measurement of erosion rates is a tedious task, complicated by the daily and yearly variations in the weather conditions expressed in changing rainfall rates and intensities, relative humidity, wind speed, temperature, water composition, rock and soil types and composition, topographic constellations, among others. This renders the calculation of erosion rates based on so many variables extremely complicated if not impossible [1] [2] [3] [4].

This study tries to calculate average erosion rates in the different parts of Jordan based on the amounts of accumulated sediments in dam lakes during the last few decades and on the chemical loads transported with the floodwaters. The study assumes that accumulation of erosion products for a few tens of years reflects in a satisfactory way the weathering amounts in a catchment area.

This study considers that dry atmospheric precipitation (dust) and wind erosion compensate each other or their amounts are very small and negligible [5].

2. Previous Studies

Worldwide, many studies dealt with erosion rates by direct measurements using markers on rocks and soils and measuring the changes taking place in series of years (e.g.: [2] [6]-[10]), Other studies concentrated on the erosion of ancient historic marks on rocks, especially on human artifacts of all types (Petra in Jordan). These and other studies calculated erosion rates ranging from 1 - 16 m/Myr for different rock formations ranging from granite and schist to limestone and consolidated marls. The different studies concerned with erosion rates used pin markers in rocks and terrains, erosion of historic sites (changes in their morphology), sediment loads of river courses [11] [12], cosmogenic nuclides data [2], and others. This study concentrates on erosion rates in catchment areas of dams based on the accumulated silt in the reservoirs of dams constructed before many decades and distributed all over the country (**Figure 1**).

3. Methodology

Modern dam construction in Jordan started some five decades ago with the Shueib, Kafrain and Ziglab dams each with a capacity of a few MCM that was followed by the construction of bigger and smaller dams of up to 110 MCM. The quantities of sediments accumulated in these dams during the last few tens of years are used to calculate erosion rates considering the catchment areas' extensions. In addition, the study tries to relate erosion rates to rainfall amounts, geology, topography and land use, especially urbanization and its effects on natural erosion. Comparison with erosion rates in other areas will also be attempted.

4. Analyses and Findings

Data on the quantity of sediments accumulated in dams and other information

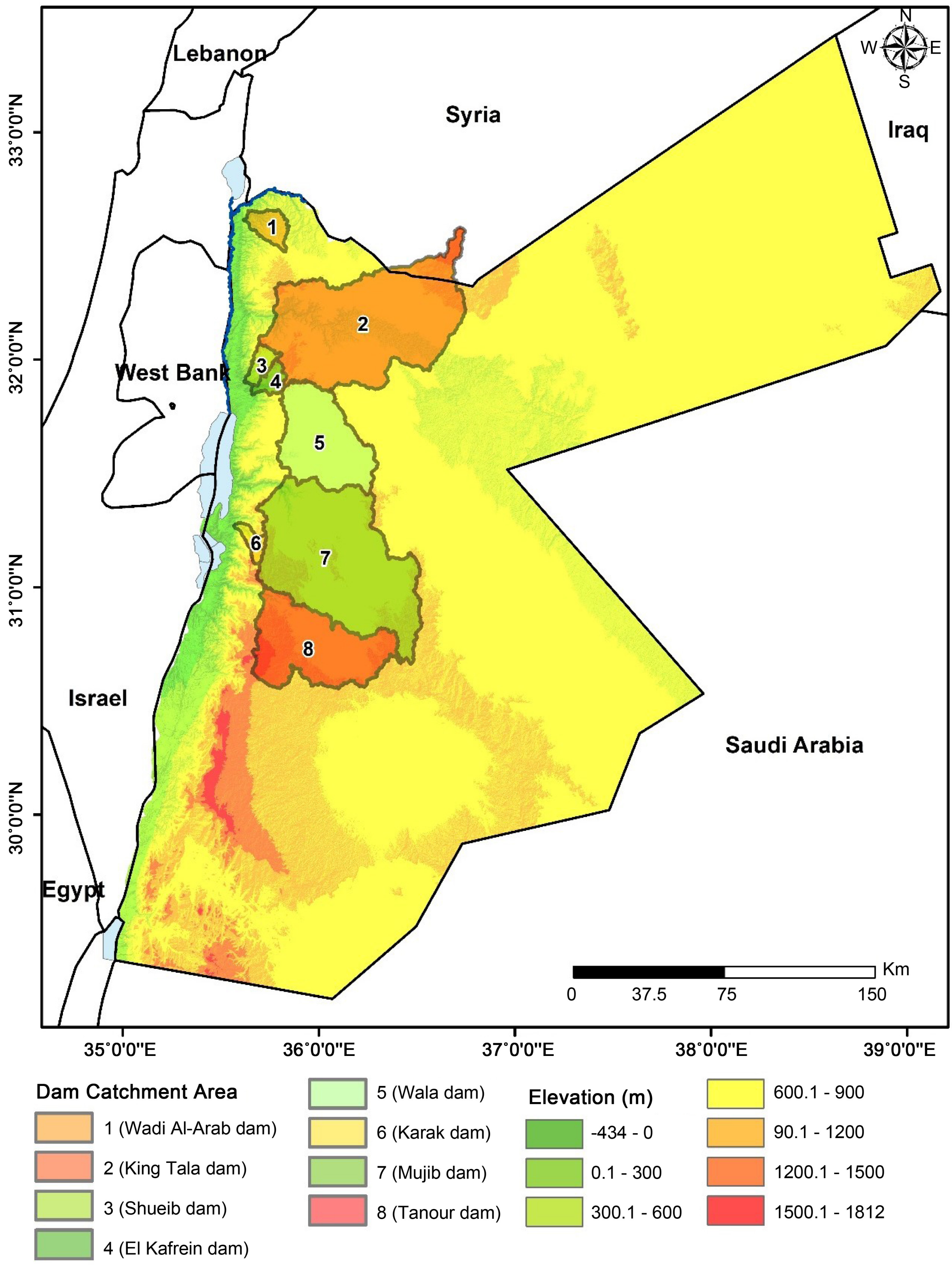

Figure 1. Location map of the dam catchment areas in Jordan (Background ASTER DEM 30 m resolution [13]).

have been obtained from the Jordan Valley Authority [14], the responsible institution for these dams.

Eroded rock materials from catchment areas are transported along watercourses in the form of solid particles and as chemically dissolved compounds of mainly evaporates carbonates, sulfates, and silicates. Generally, the dissolved materials do not precipitate in dams because their concentrations are generally very low and they do not reach the saturation state, and if they do, then in very small negligible amounts.

4.1. Precipitation- and Flood-Water Chemical Contents (Dissolution from Rocks)

A study on precipitation water quality in Jordan [15] concludes that precipitation water contains a weighted average of around 120 µS/cm of dissolved solids differing from one area to another according to precipitation front direction, area in Jordan and quantity of precipitation (**Table 1**). Khashman [16] in the course of his Ph.D. study on the southern part of Jordan reached at the same result obtained by Salameh [15]. Floodwater along wadi downstream areas (without base flow) contains 150 - 250 µS/cm (**Table 2** and **Table 3**). This means that the floodwater dissolves from the respective catchment area an equivalent of around 100 µS/cm of solids mainly composed of carbonates and evaporates [15] that equals around 70 mg/liter, or 70 g/m^3 of floodwater. If King Talal Dam is taken as an example with an average annual flood flow of 30 MCM [17], then the amount of dissolved solids reaching the dam will be 70 mg/l = 70 g/m^3 of water. Divided by an average density of carbonates and evaporates of 2.6 g/cm^3 = 27 cm^3 of dissolved rocks in one m^3 of floodwater and that calculates to 0.0025% m^3 of chemical load per m^3 of floodwater. This amount of dissolved loads is strongly negligible when compared to a solid sediment load of 2.22% weight percent of

Table 1. Precipitation water average weighted composition in different areas of Jordan (EC in µS/cm, all others in meq/l) [15] [16].

Station	Amman	Ruseifa	Azraq	Salt	QAIA	Khalidiya	Irbed	Muwaqqar	Deir Alla	Hasa	Tafila
EC	57.6	136.4	272.7	98.7	200	165	96.2	108	169.8	160	177
pH	7.21	7.58	7.14	7.61	8.05	7.35	7.20	7.48	7.42	7.20	7.10
Ca^{2+}	0.46	0.889	0.742	0.448	1.07	1.165	0.528	1.065	0.808	0.88	0.84
Mg^{+}	0.088	0.174	0.322	0.113	0.203	0.175	0.178	0.207	0.306	0.75	0.76
Na^{+}	0.18	0.271	0.606	0.317	0.483	0.232	0.176	0.344	0.374	0.34	0.39
K^{+}	0.021	0.03	0.058	0.045	0.084	0.080	0.064	0.037	0.370	0.12	0.11
Cl^{-}	0.258	0.275	0.668	0.422	0.909	0.334	0.228	0.684	0.473	0.75	0.77
SO_4^{2-}	0.17	0.443	0.70	0.188	0.794	0.374	0.272	0.329	0.352	0.06	0.05
HCO_3^{-}	0.27	0.527	1.24	0.319	0.455	0.829	0.394	0.627	0.701	1.23	1.06
NO_3^{-}	0.052	0.057	0.11	0.057	0.30	0.114	0.056	0.094	0.0817	0.03	0.01

Table 2. Flood flow composition of the Plateau wadis (EC in µS/cm, NO_3^- in mg/L and all others in meq/L).

Parameter	Daba	Qastal	Zizya	Rweished	Safawi	Khalidiya	Mafraq	Muwaqqar	Azraq	Yutum	Shidiya
EC	123	212	233	229	218	291	220	186	214	135	130
pH	8.55	8.53	8.55	8.25	8.43	7.76	7.8	8.48	7.7	8.21	8.27
Ca^{2+}	1.2	1.53	1.73	1.9	1.28	1.8	0.59	1.1	1.18	0.74	1.3
Mg^{+}	0.4	0.69	0.72	0.4	0.19	0.26	0.45	0.2	0.20	0.13	0.35
Na^{+}	0.27	0.92	0.41	0.31	0.75	0.92	1.08	0.93	0.94	0.25	0.62
K^{+}	0.22	0.05	0.05	0.09	0.05	0.18	0.13	0.11	0.13	0.01	0.16
Cl^{-}	0.15	0.4	0.60	0.4	0.35	0.22	0.2	0.23	0.4	0.35	0.60
SO_4^{2-}	0.35	0.39	0.94	0.41	0.24	0.2	0.23	0.25	0.34	0.10	0.38
HCO_3^-	1.55	1.82	1.46	1.91	1.35	2.45	1.57	1.94	1.65	0.76	1.52
NO_3^-	0.54	10.2	13.8	2.1	4.2	4.8	16.2	6.8	7.2	2.4	3.2

Table 3. Flood flow composition along wadis pouring into the Jordan Rift Valley (EC in µS/cm, NO_3^- in mg/L and all others in meq/L).

Parameter	Yarmouk	Yabis	Kufranja	Abdoun Ras El-Ain	Zarqa Jarash Br.	Hisban	Zarqa Ma'in	Mujib	Karak	Hasa
EC	530	430	307	160	392	235	182	183	165	301
pH	7.91	8.37	8.05	8.42	8.01	7.97	8.36	7.78	7.98	8.38
Ca^{2+}	1.9	2.87	2.46	1.60	2.36	1.58	1.00	1.02	1.16	1.60
Mg^{+}	1.4	1.43	0.59	0.20	0.32	0.29	0.40	0.42	1.57	0.20
Na^{+}	1.70	0.95	1.03	0.29	1.22	0.53	0.59	0.58	1.12	1.02
K^{+}	0.15	0.17	0.41	0.08	0.16	0.10	0.13	0.10	0.22	0.09
Cl^{-}	1.58	1.10	0.40	0.25	1.20	0.50	0.23	0.27	0.78	0.39
SO_4^{2-}	0.85	0.84	0.63	0.41	0.74	0.16	0.13	0.16	1.04	2.04
HCO_3^-	2.97	2.91	2.99	1.42	2.04	1.72	1.73	1.82	2.66	2.04
NO_3^-	18.5	18.2	13.4	5.3	18.0	9.2	4.8	5.8	4.2	6.60

the floodwater quantity (Table 4), making only 1/888 of the latter or 0.0035 of it.

Therefore, chemically dissolved quantities of erosional or weathering products of rocks play only a very negligible role in the erosional rates of rocks and that shows that solely eroded solids transported along river or wadi courses reflect the quantities of the erosion processes.

4.2. Sediments in Dam Lakes

The quantity of deposited rocks in dam lakes in m^3 and as a percentage of the dam capacity, the annual sedimentation rates as well as the size of the catchment area, and the average long-term precipitation are listed in Table 4. This information together with the information on the average annual flood flow amounts

Table 4. Dams, construction, accumulated sediments in their lakes, annual sedimentation rates, catchment area and area's average precipitation [14].

Dam name and year of construction	Sediments (1000 m^3)	% sediments of capacity	Annual sed. rate of capacity	Catchment area (km^2)	Av. catchment precipitation (mm/year)
Wadi Al-Arab 1986	2900	17.2%	0.44	262	462
King Talal 1977	18,000	24%	0.52	3700	272
Wadi Shueib 1969	900	52.9%	0.98	178	400
Al-Kafrain 1967	1900	22.4%	0.4	163	397
Wala 2002	4600	18.2%	0.87	1770	216
Al-Muiib 2003	6500	21.8%	1.09	4380	317
Al-Tannur 2001	2500	17%	0.77	2160	150
Al-Karak 2017	140	7%	1.17	170	273

allow to calculate the sediment loads per m^3 of floodwater and to calculate the erosion rates transported as solids along wadis discharging into the dams as listed in **Table 5**.

In **Table 5**, the average sediment loads as percentages of m^3 of sediments per m^3 of floodwater are calculated. They show a range of 0.88% to 3.0% of sediment load (m^3) transported by each m^3 of floodwater. These rates depend on the characteristics of the catchment area of precipitation, the geologic formations cover, slopes and topographic characteristics, and land use; e.g.: urbanization, managed agriculture, or mining.

4.3. Topographic Effects on Erosion Rates

Certainly, the configuration of a catchment area plays a very prominent role in the erosion process. Some catchments are quite flat others are very steep; some are steep in their highest areas others are steep in their lowest areas and so forth. Nonetheless, all the catchments we are dealing with extend from the highlands of Jordan and end in the Jordan Rift Valley owning very similar topographic configurations. However, the elevation differences between the highest areas and the lowest areas are different and that means different gradients of topographic sloping. Generally, the highest 10% - 15% and the lowest 10% - 15% of a catchment area in the studied catchment areas represent the main differences between the studied catchments. However, the highest 90% and the lowest 10% or the highest 80% and the lowest 20% can also well represent the topographic slopes of areas with minor differences. To account for this topographic factor in the calculation of the erosion rates, the elevations of the highest 15% and the lowest 15% in a catchment area are found to better represent the topographic configuration than the highest and lowest points of a catchment (**Table 6**). **Figures 2(a)-(h)** show the topographic elevations of the discussed 8 dams in Jordan.

Table 5. Average annual flood flow amounts, accumulated sediments, and sediment loads per m^3 of water and calculated erosion rates transported as solids along wadis discharging into dams (Calculated based on [14]).

Dam	Flood flow MCM/yr	Av. accumulated sediments 1000 m^3/yr	Sediment load m^3/m^3 of flood water	Av. erosion rates (mm/yr) transported as solids (mm/yr) = Annual sediment quantity (m^3) divided by the catchment area (m^2)
Wadi Al-Arab	6.5	81.0	1.25%	0.031
King Tala	30.0	667.0	2.22%	0.013
Shueib	1.75	17.0	1.0%	0.046
Kafrein	1.35	34.5	2.56%	0.212
Wala	16	230.0	1.44%	0.177
Mujib	15	342.0	2.28%	0.078
Tannur	3.4	119.0	3.5%	0.055
Karak	3.2	28.0	0.88%	0.0165

Table 6. Calculated elevations of the highest 15% and the lowest 15% of the catchment areas of the studied dams, their differences, and the difference in elevations related to the extent of the dam catchment area.

Dam	Range of catchment elevations (m)	Elevation of the highest 15% (m)	Elevation of the lowest 15% (m)	Difference in elevation between the highest and lowest 15% (m)	Slope as difference divided by catchment area
King Talal	139 - 1578	913 - 1578	139 - 594	319	0.086
El Karak	−172 - 1248	1108 - 1248	−172 - 427	681	4.0
El Arab	−111 - 865	560 - 865	−111 - 255	305	1.16
Shueib	−180 - 1096	919 - 1096	−180 - 174	745	4.19
Al Tannur	359 - 1592	1089 - 1592	359 - 846	243	0.113
Mujib	149 - 1281	945 - 1281	495 - 706	239	0.055
Wala	495 - 978	848 - 978	495 - 706	142	0.08
El Kafrain	−158 - 1077	907 - 1077	−158 - 199	708	4.34

4.4. Effects of Types of Rocks

The rock types covering the catchment areas play a major role in the quantity of eroded and transported materials e.g.: the very high erosion rate in Wadi Kafrain catchment can easily be referred to the outcropping easily erodible friable sandstones covering around 20% of its catchment area [18]. In addition, Wala catchment is partly covered to ~15% by easily erodible naturally combusted limestone [19].

Table 7 lists the erosion rates in relation to prevailing rock cover of the catchment areas, their urbanization and slopes.

4.5. Effects of Urbanization

Urbanization plays a positive role in reducing the sediment loads of floodwater,

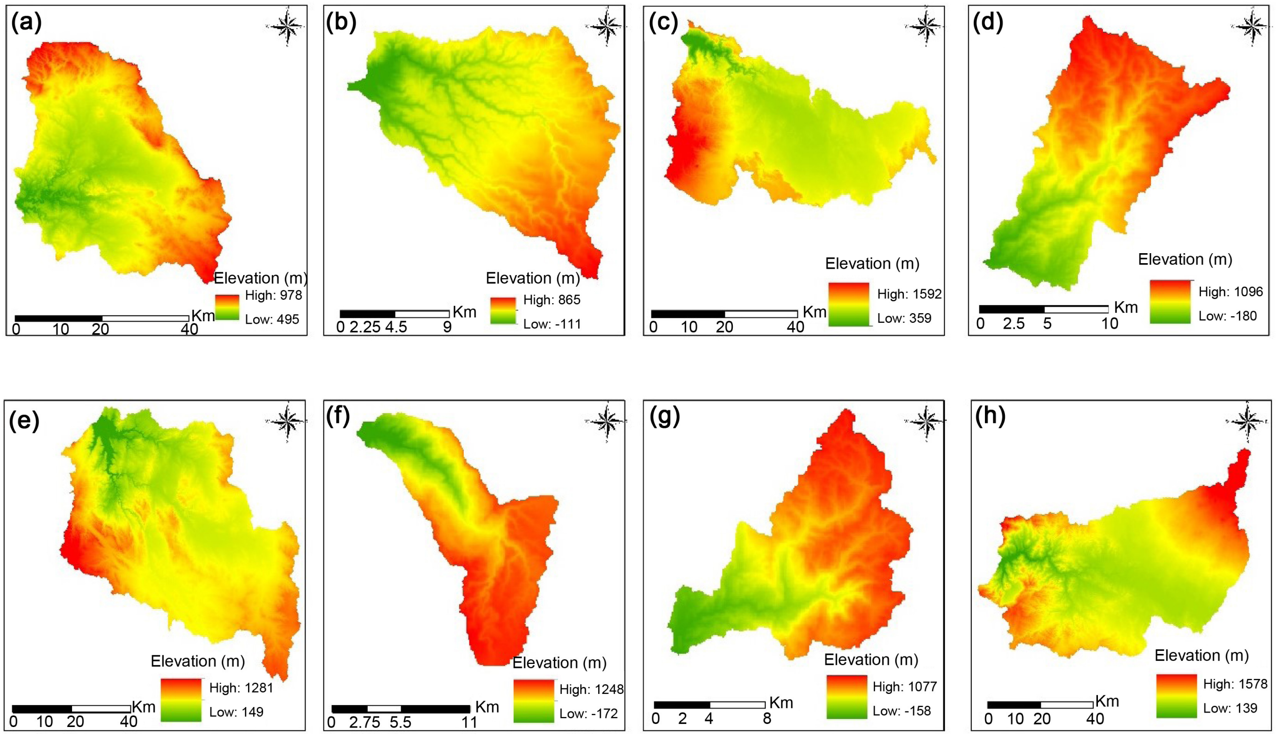

Figure 2. Elevation map for (a): Wala dam, (b): Wadi Al-Arab dam, (c): Tannur dam, (d): Shueib dam, (e): Mujib dam, (f): Karak dam, (g): El Kafrein dam, and (h): King Talal dam.

Table 7. Correlation of the erosion rates (ascending order) and the prevailing rock types in the catchment area and the difference in topographic elevation between 85% and 15% of the catchment area (flatness).

Catchment area	Erosion rate mm/yr	Av. precipitation over the catchment [20]	Prevailing rock cover	Slope catchment area m/km^2	urbanized area %, other land use
King Talal	0.013	272	Limestone, chert, basalt	0.086	25%
El Karak	0.0165	273	Limestone, marlstone	4.0	15%
El Arab	0.031	462	Limestone, chalk	1.16	12%
Shueib	0.046	400	Limestone, marlstone	4.19	15%
Al Tannur	0.055	150	Limestone, chert, phosphate	0.113	2%, heavy quarrying
Mujib	0.078	317	Limestone, marlstone, chert	0.055	2%
Wala	0.177	216	Limestone, chert, combusted limestone	0.08	3%, quarrying
El Kafrain	0.212	397	Limestone, friable sandstone, marlstone	4.34	25%

because built-in areas reduce the erosion of rocks and soils. That is due to increases in cemented and asphalted areas related the urbanization processes. It would not be easy in the course of this study to quantify the effect of urbanization on erosion rates, because of the interplay of the other factors affecting erosion.

4.6. Explanation of the Erosion Rates in the Different Catchments

The erosion rates of the different catchment areas are explained as follows:

- King Talal dam catchment: intermediate precipitation, high urbanization rate of around 25%, erosion resistant rocks covering the catchment area, and intensive agricultural activities can explain the very low erosion rate.
- Wadi Karak dam catchment: the weathering resistant rocks covering the catchment area and the high urbanization can explain the very low erosion rate.
- Wadi Al-Arab dam catchment: the solid rocks composed of chert and limestone, high urbanization rate, and intensively managed agricultural development can explain the low erosion rate.
- Wadi Shueib dam catchment: the solid rocks composed of hard dolomites and limestones, high urbanization rate, and intensively managed agricultural development can explain the low erosion rate.
- Tannur dam catchment: the heavy open cast mining activity of phosphate and gypsum rocks in addition to frequent frost formation in this high latitude area can explain the relatively high erosion rate.
- Mujib dam catchment: the barren nature of the catchment and the very low urbanization rate can explain the relatively high erosion rate.
- Wala dam catchment: the barren and easily erodible combusted rocks covering the catchment area can explain the high erosion rate.
- El Kafrain dam catchment: the very high slope, the high precipitation, and the friable sandstone rocks covering the area can explain the very high erosion rate.

4.7. Comparison with Other Studies

Studies on erosion rates dealt with erosion rates of rocks such as granite 2.5 - 5.5 $m/10^6$ yr., basic rocks 3 - 9 $m/10^6$ yr. [2], and kimberlite 3.5 - 10 $m/10^6$ [3]. Basin-wide erosion rates, according to [21], using cosmogenic ^{10}Be methods, ranged from: 5 - 60 $m/10^6$ yr (in Sierra Nevada, USA, 15 - 60 $m/10^6$ yr, in the Smoky Mountains, USA, 14 - 37 $m/10^6$ yr, in the Blue Mountains, Australia, 10 - 20 $m/10^6$ yr and in Sri Lankan Mountains 5 - 11 $m/10^6$ yr). [1] measured 20 - 40 $m/10^6$ yr in carbonate terrains. In the Namib Desert. [2] measured all over erosion rates of landscape of 1 - 16 $m/10^6$ yr. The obtained erosion rates for the different catchment areas in this study ranged from 13 - 212 $m/10^6$ yr (**Table 5**). In the case of Jordan, it seems that the calcareous types of rocks covering most of the studied catchment areas, the weakly cemented sandstones present in some catchment areas, the very steep topography and the barren rocks are major factors leading to the high erosion rates.

Worth mentioning here is that, natural erosion processes cannot be controlled by alleviating their causative elements (Rocks, weather, topography etc.) nor by their impacted elements (slopes, outcropping rocks, soils). However, some soil conservation measures can reduce the transportation of eroded rocks, but that do not reduce erosion itself.

5. Temporarily Changing Erosion Rates, the Case of the Dead Sea Retreat

Since about five decades, the Dead Sea has been retreating because of diversions of its feeding waters within its catchment area. It drooped from around 390 mbsl (surface area of 1020 km^2) in the sixties of the last century to 420 mbsl in 2005 (surface area of 635 km^2) to reach approximately 500 mbsl in 2050 (surface area of 520 km^2) [22]. **Figure 3** shows the change in water level in the Dead Sea between 1972 and 2019.

Around 320 km^2 of the sea area turned into fest land changing the evacuated area from depositional terrain to erosional terrain (**Figure 4** and **Figure 5**) that change created a temporary disequilibrium in the erosion/sedimentation system. This example tells us much about what has been taking place during the last few million years of the life of the Dead Sea and its ancestral lakes such as Samra and Lisan Lakes.

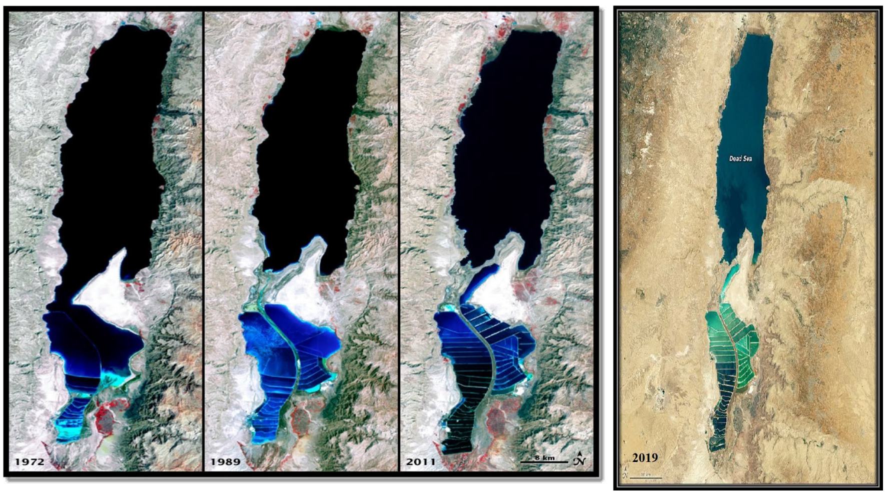

Figure 3. Changing in Dead Sea water level between 1972 and 2019 [22].

Figure 4. Former depositional area and present erosional area due to the recession of the Dead Sea.

Figure 5. Head ward erosion in the immediate surroundings of the Dead Sea shore caused by the retreat of the Dead Sea (at around 500 m east of its present shore).

Erosion rates reflect weathering rates in the respective catchment area. Changes in the base level elevation (lake, sea, playa) play a major role in erosion and sedimentation rates, but that have only little to do with the physical and chemical weathering processes except the role of exposure of additional rock parts to weathering and erosion.

6. Conclusions

In this study, erosion rates of domain rocks are calculated based on dams' catchment areas and the sediment loads transported by flood flows into dams' lakes. The study results show that the chemically, via floodwater transported quantities of materials are negligible compared to the solid materials transported by the water. It calculates erosion rates ranging from 0.013 to 0.212 mm/yr for the different catchment areas.

The slopes of the catchment areas affect the erosion rates and that is exposure of rocks to weathering processes (85% of area's size elevation divided weathering rates by 15% area's size elevation). Weathering rates of the different rock types covering a catchment area are another factor affecting erosion rates. For example, weathering rates of friable sandstone or weakly consolidated marls are higher than those of dolomites or silicified limestones. The high percentage coverage of friable sandstone in the Kafrain catchment or the combusted limestone in the Wala catchment may result in strongly increasing the weathering rates and hence increasing the quantity of eroded materials from the catchment area of a wadi or a river course.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ott, M., Gallen, S.F. and Helman, D. (2023) EGU Sphere.

[2] Bierman, P.R. and Caffee, M. (2001) Slow Rates of Rock Surface Erosion and Sediment Production across the Namib Desert and Escarpment, Southern Africa. *American Journal of Science*, **301**, 326-358. https://doi.org/10.2475/ajs.301.4-5.326

[3] Partridge, T.C. and Maud, R.P. (1987) Geomorphic Evolution of Southern Africa since the Mesozoic. *Transaction of the Geologic Society of South Africa*, **90**, 179-208.

[4] Erwanto, Z. and Lestari, N. (2020) Study of Rainfall Erosivity and Erosion Rate with MUSLE Method Using Geographic Information System in Badeng Watershed. *Advances in Engineering Research Journal*, **208**.

[5] König, R.W. (1994) Grundwassernewbildung in Semiariden Und Ariden Gebieten Jordamiens Berechnet Mit Hilfe der Halogenverteilung in der Ungesättigten Zone. Ph. D. Thesis, University of Würzburg, Würzburg.

[6] Xu, Y. (2022) Coastal Erosion: Factors that Influence Erosion Rates and Its Control Methods. *Journal of Coastal Zone Management*, **25**, 533.

[7] Turowski, J.M. and Cook K.L. (2017) Field Techniques for Measuring Bedrock Erosion and Denudation. *Earth Surface Processes and Landforms*, **42**, 109-127. https://doi.org/10.1002/esp.4007

[8] DiBiase, R.A., Whipple, K.X., Heimsath, A.M. and Ouimet, W.B. (2010) Landscape Form and Millennial Erosion Rates in the San Gabriel Mountains, CA, Earth Planet. *Science Letters*, **289**, 134-144. https://doi.org/10.1016/j.epsl.2009.10.036

[9] Johnson, J.P.L and Kelin, X.W. (2010) Evaluating the Controls of Shear Stress, Sediment Supply, Alluvial Cover, and Channel Morphology on Experimental Bedrock Incision Rate. *Journal of Geophysical Research*, **115**, F02018. https://doi.org/10.1029/2009JF001335

[10] Menard, H.W. (1961) Some Rates of Regional Erosion. *The Journal of Geology*, **69**, 154-161. http://www.jstor.org/stable/30057141

[11] Nitsche, M., Rickenmann, D., Turowski, J.M., Badoux, A. and Kirchner, J.W. (2011) Evaluation of Bedload Transportpredictions Using Flow Resistance Equations to Account for Macro-Roughness in Steep Mountain Streams. *Water Resources Research*, **47**, W08513. https://doi.org/10.1029/2011WR010645

[12] Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J. and Ocakoglu, F. (2011) Sediment Yield in Europe: Spatial Patterns and Scale Dependency. *Geomorphology*, **130**, 142-161. https://doi.org/10.1016/j.geomorph.2011.03.010

[13] USGS Earth Explorer (2023) ASTER Digital Elevation Model 30 m Resolution. http://earthexplorer.usgs.gov

[14] Jordan Valley Authority, Ministry of Water and Irrigation (2023) Open File.

[15] Salameh, E., Rimawi, O. and Abu Moghli, I. (1991) Precipitation Water Quality in Jordan. Water Research and Study Center (WRSC), University of Jordan.

[16] Khashman O. (2002) The Environmental Status of the Area Extending between Wadi El Hasa and Wadi Musa, from the Railway to Wadi Araba. Ph.D. Thesis, University of Jordan, Jordan.

[17] Natural Resources Authority (NRA) (1977) National Water Master Plan of Jordan: Irrigation Water Demand. Vol. 5. National Water Master Plan of Jordan, Amman.

[18] Natural Resources Authority (NRA) (2016) Geology Directorate, Geological Map-

ping Division. Ministry of Energy and Mineral Resources, Open Files.

[19] Khoury, H.N. (2019) 2019 Industrial Rocks and Minerals of Jordan: A Review. *Arabian Journal of Geosciences*, **12**, 619. https://doi.org/10.1007/s12517-019-4750-0

[20] Department of Meteorology (DoM) (2017) Weather Data, Open Files. https://www.meteoblue.com/en/weather/archive/export/amman_jordan_250441

[21] Granger, D.E. (2007) Cosmogenic Nuclide Dating-Landscape Evolution. *Encyclopidia of Quaternary Science*, **2007**, 445-457. https://doi.org/10.1016/B0-44-452747-8/00386-0

[22] Salem, H.S. (2020) Multi- and Inter-Disciplinary Approaches towards Understanding the Sinkholes' Phenomenon in the Dead Sea Basin. *Discover Applied Sciences*, **2**, 667. https://doi.org/10.1007/s42452-020-2146-0