Journal of Geoscience and Environment Protection, 2025, 13(6), 221-240
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

# Hydrologic, Environmental and Socioeconomic Relevance of Small-Scale Water Harvesting Small Scale Versus Large Scale Water Harvesting the Case of Jordan

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**How to cite this paper:** Salameh, E., & Yaseen, M. A.-H. (2025). Hydrologic, Environmental and Socioeconomic Relevance of Small-Scale Water Harvesting Small Scale Versus Large Scale Water Harvesting the Case of Jordan. *Journal of Geoscience and Environment Protection, 13,* 221-240.
https://doi.org/10.4236/gep.2025.136016

**Received:** May 26, 2025
**Accepted:** June 23, 2025
**Published:** June 26, 2025

## Abstract

Small-scale water harvesting seems to be one of the earliest water technologies used by humans in semiarid countries, where water becomes in short supply during the dry season. With advancing technologies, dams started to be the common harvesting facilities. Nonetheless, small-scale water harvesting still has major advantages compared to large-scale water harvesting in dams. This study analyzes and discusses the advantages and disadvantages of small-scale versus large-scale water harvesting from the different aspects such as the quantity and quality of water, agricultural productivity, dams siltation, flooding risks, energy savings, biodiversity and socio-economics. The present status of water harvesting in Jordan, from the different aspects of advantages and disadvantages, is taken as examples to illustrate the findings. This study concludes that small-scale water harvesting in catchments' upstream areas is very rewarding in social, economic, environmental as well as ecological aspects. It also concludes that many legal, administrative, managerial and planning issues have to be advanced for engineered watershed management and small-scale water harvesting projects.

## Keywords

Water Harvesting, Advantages and Disadvantages, Preparatory Studies, Dams, Legal Framework

## 1. Introduction

Rain and floodwater harvesting seems to have started with the start of civilization in the arid to semi-arid climatic zones with the aim of storing available water during the rain events for use in dry times. Ancient water harvesting structures found in the Levant, North Africa, South America and elsewhere give witness of the use practices of water harvesting in the form of capturing water in house cisterns, weirs, pools, excavations along wadi courses, terracing of terrains, and even small dams among others (Frankopan, 2023; Bechers et al., 2013; Bienert & Häser, eds., 2004; Wright et al., 1999; Wright et al., 1997; Wahlin, 1995; Lancaster & Fidelity, 1995; LaBianca, 1994; Gilbertson et al., 1984; Helms, 1981). These old practices were developed and continued to be in use in the semi-arid and arid climatic zones to enable human survival and to save the efforts of water dwelling from the next water source, such as springs, lakes or creeks. **Figure 1** illustrates some of the old techniques used to capture water in the Levant area (Salameh, 2004).

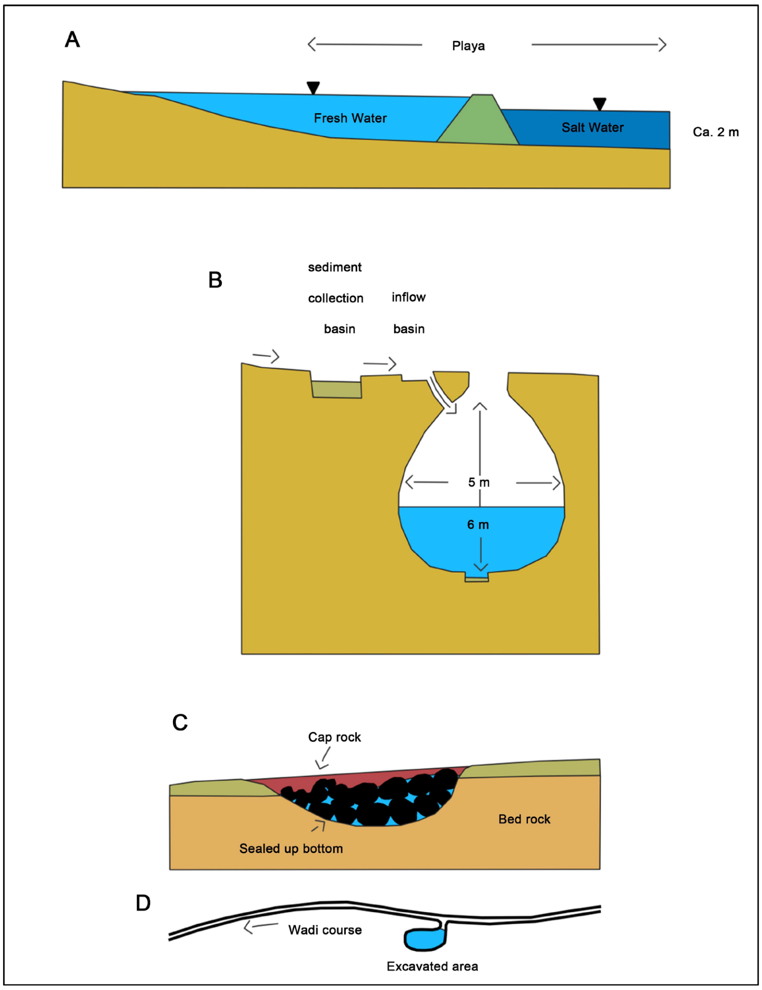

**Figure 1.** (A) Playa weirs (Barriers); fresh floodwater coming along a wadi enters the playa. Here at the entrance, a weir has been built to capture the water and secure it from salinization caused by dissolution of salts from the playa's bottom. (B) General shape of a house cistern. (C) A special type of a wadi cistern. (D) Wadi course and excavated area.

Rainfall amounts in semiarid and arid climatic zones, such as Jordan (**Figure 2**) do not satisfy the water requirements of most crops and therefore, yields are low or even missing. Water harvesting, which incorporates concentrating rain or overland flow water in one spot enables target use for individual or groups of plants. Therefore, water harvesting seems to offer a practical way for increasing the local availability of water and to save that water from being lost to evaporation or from its destiny; flowing into salt-water regimes or becoming polluted.

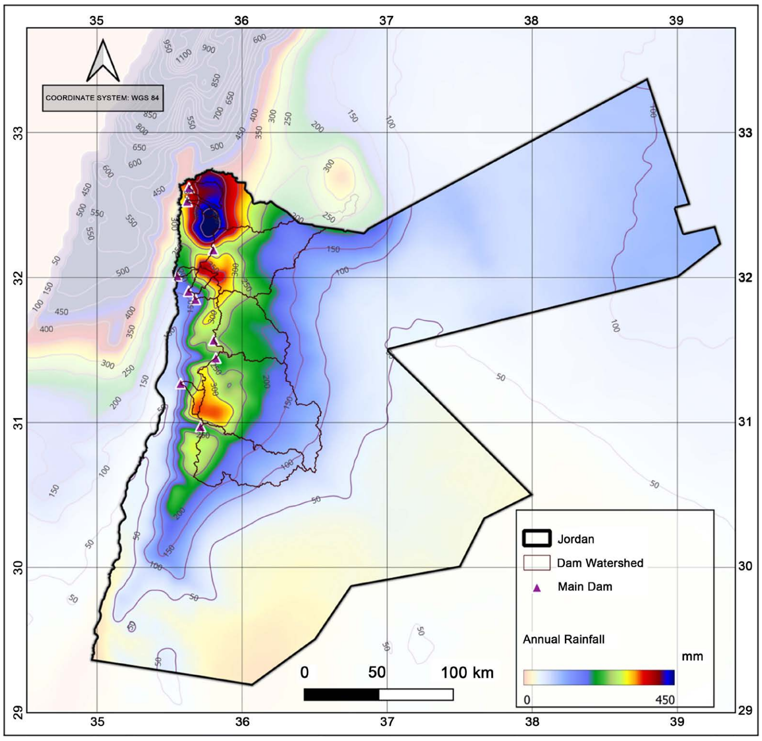

**Figure 2.** The map illustrates the annual precipitation distribution across Jordan, with relatively high values concentrated along the western highlands, ranging from 250 mm to 650 mm. These regions, despite their limited spatial extent, account for a substantial portion of Jordan's total precipitation yield. The remaining areas of Jordan experience significantly lower precipitation levels. The majority of the country records annual rainfall below 200 mm, with a gradual decline observed towards the eastern and southern regions, and a sharp decrease to below 50 mm annually in the southern regions and extreme western regions in Jordan Valley. The map was generated using data from TerraClimate (Abatzoglou et al. 2018).

Historic water harvesting used to deal with small and, limited amounts of the water available for harvesting. Local water harvesting seems to have very high advantages to users and negligible disadvantages to the environment as compared with big water harvesting in dams. **Figure 3** shows the sites of dams in Jordan, which have been constructed during the last 5 decades. Future water harvesting in general, due to their large scales, has to weigh, in all details, advantages against disadvantages in order to maximize the first and minimize the latter. However, most implemented small-scale harvesting projects lack the detailed studies on their environmental, health, and socio-economic viabilities. **Figure 4** illustrates the sites of water harvesting constructed in Jordan. Most of these sites have not underwent hydrological, environmental and socio-economic studies on their advantages or disadvantages.

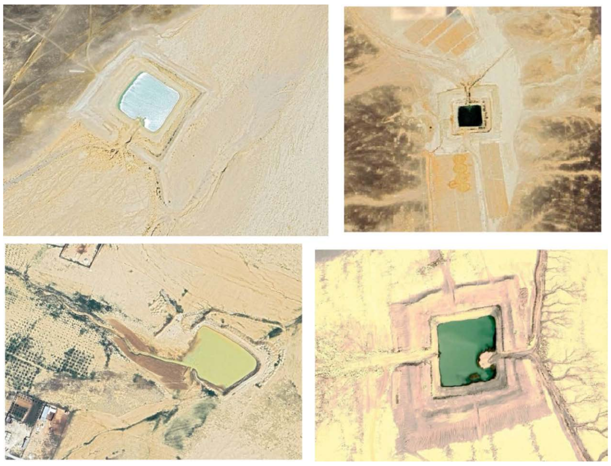

**Figure 3.** The images illustrate examples of rainwater harvesting ponds utilized in Jordan. Most of these ponds are characterized by a square design, with a side length reaching approximately 150 meters, and a storage capacity of up to 100,000 cubic meters. However, many of these ponds require near-annual rehabilitation due to slope failures and sediment accumulation, which diminish their effective storage capacity.

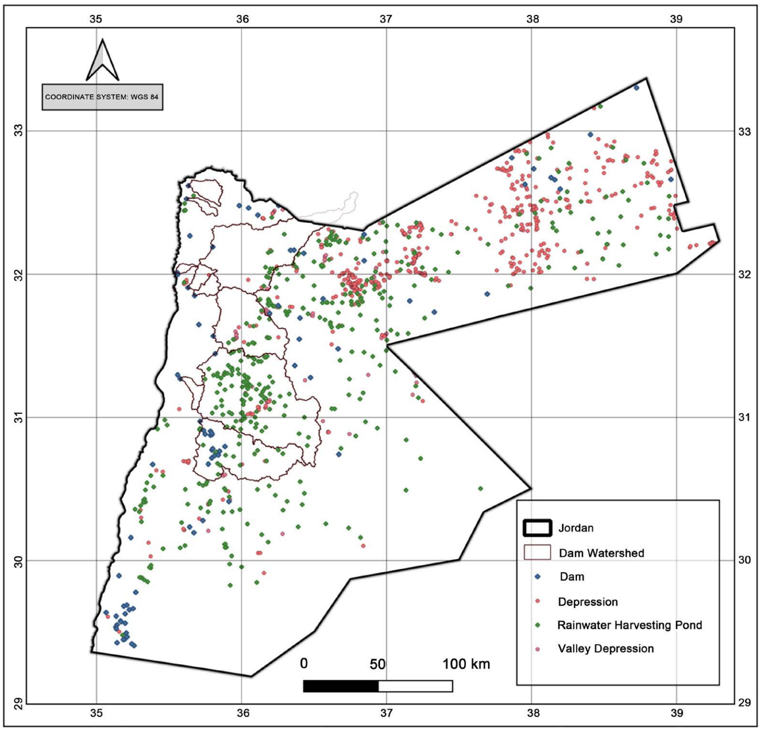

**Figure 4.** The map illustrates a comprehensive geographical distribution of 95 dams, including approximately 20 classified as major dams due to their substantial storage capacity and annual water yield. Furthermore, the map highlights the presence of 444 rainwater harvesting ponds, the majority of which were constructed within the past decade. The map also depicts 536 natural depressions and 82 valley depressions, which play a vital role in mitigating the volume of surface water runoff directed towards the major dams.

During the last few decades driven by population growth, global and climate changes, and rising living standards, the need for additional water has increased. Small-scale water harvesting remains a very effective way and an environmentally friendly option to obtain additional amounts of water on a local scale and to conserve soils from erosion.

This article deals with the issue of advantages and disadvantages of water harvesting on examples from Jordan, an area with a semi-arid to arid climate with precipitation rates of generally less than 300 mm/yr.

## 2. Water Harvesting Conditions and the Balance of Advantages and Disadvantages

**-The Case of Jordan-**

**Figure 5** shows the drainage system, which indicates the numerous sites along wadis, where water harvesting can be implemented, especially along those wadis draining east and south outside the country.

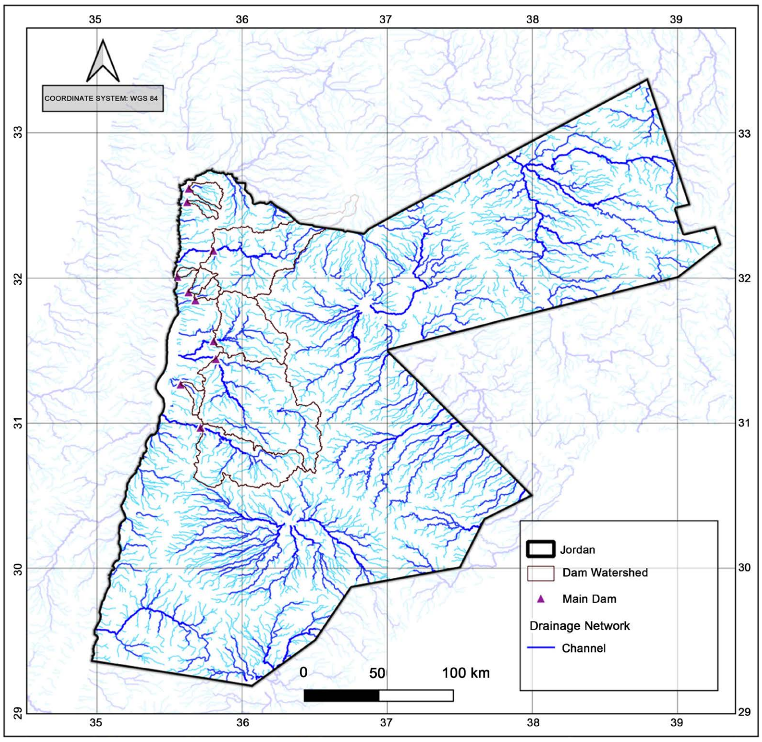

**Figure 5.** Drainage system in Jordan shows the many wadis draining outside the country in the east and south, where a high potential of water harvesting is provided.

### 2.1. Harvesting Rainwater Where It Generates Has the Following Advantages

- Storage of high quality water;
- High potential energy of the harvested water (at high altitudes);
- Capturing the sediments, which become eroded by flood water and hence affect downstream areas (soil conservation and reduction of siltation od dams’

lakes);

- When the harvested water is used in irrigation, lower water consumption per unit land due to lower potential evaporation rates of the cooler and more humid air in the high latitude areas of water harvesting facilities than in the lower latitude areas, where the water flows down to (**Figure 6**);
- Creation of jobs especially in irrigated agriculture, in the areas where the water generates and finds use in irrigation, supplementary or complimentary irrigation, and where the owners of land are indigenous and lack jobs. That will lead to sustainability and have its positive social, economic and political implications of fostering inhabitants' identification with the land they develop.

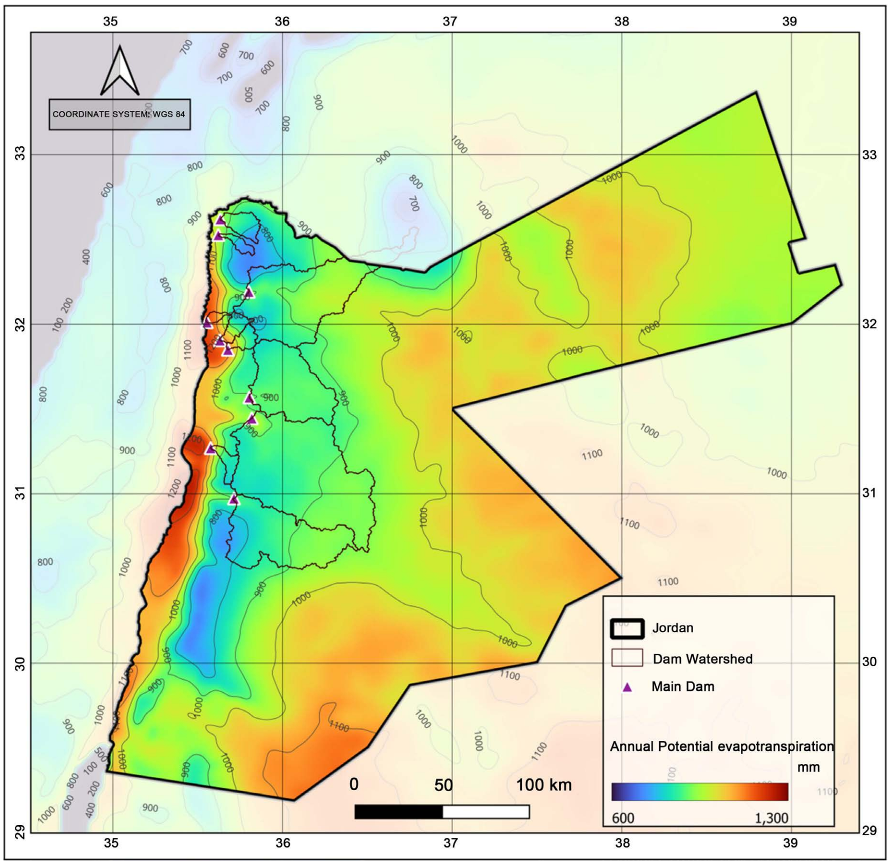

**Figure 6.** Potential evaporation in Jordan, the map was generated using data from TerraClimate (Abatzoglou et al., 2018).

## 2.2. Harvesting Rainwater Where It Generates Has the Following Disadvantages

Medium and large-scale water harvesting projects where the water is generated have a variety of disadvantages such as:

- Reduction in their downstream flood flow quantities and hence in the amounts of stored water in downstream storage facilities lowering their water benefits and their potential hydraulic energy.
- Reduction in downstream natural groundwater recharge amounts.

- Lowering the soil water content along wadi courses and flooding plains accompanied by reduction in plant growth and biodiversity.
- Reduction in the dilution effects of downstream impaired water qualities.
- Negative impacts on existing floodwater uses.

The above advantages and disadvantages will be discussed in the following paragraphs on examples from Jordan.

## 3. Discussion of the Advantages of Small-Scale Water Harvesting

### 3.1. High Quality Water

Surface and groundwater quality starts to develop in the atmospheric air where precipitation water forms and reacts with gases of the atmosphere, mainly composed of nitrogen, oxygen, carbon dioxide, and a variety of low-concentration gases differing from one area to another. In addition, atmospheric natural and man-made dust and sooth contribute to the composition of precipitation water (Salameh et al., 1991; König, 1994). **Table 1** gives the composition of rainwater in the different areas in Jordan; **Figure 7** illustrates the geographic coordinates of these stations.

Table 1. Chemical composition of precipitation water for stations distributed in Jordan (averages of 3 years sampling, generally, collected on a biweekly basis) (EC in µS/cm, all others in mg/l (Salameh et al., 1991 and recent analyses). *QAIA: Queen Alia International Airport.

| 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 | 7.2 | 7.48 | 7.42 | 7.2 | 7.1 |
| $Ca^{2+}$ | 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 | 0.08 | 0.064 | 0.037 | 0.37 | 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 | 0.7 | 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 | 0.3 | 0.114 | 0.056 | 0.094 | 0.0817 | 0.03 | 0.01 |
| $PO_4^{3-}$ | 0.12 | 1.78 | 0.097 | 0.039 | 0.7 | 0.71 | 0.043 | 0.061 | 0.0848 | 0.88 | 0.09 |

The mountainous stations such as Amman, Salt and Irbed receive precipitation with low EC values whereas, in the Plateau area further east the dust-loaded atmosphere contributes to the salt content of precipitation (Ruseifa, Azraq, QAIA, Khalidiya and Muwaqqar) (**Figure 6**, **Figure 7**). Towards the Jordan Rift Valley in the west, the salt content increases also as a result rainfall interception and re-evaporation in the atmosphere due to the thick atmospheric air column and generally higher temperature in the Rift Valley than on the highland areas by an average of around 10˚C (Khashman, 2002; Salameh et al., 1991; König, 1994).

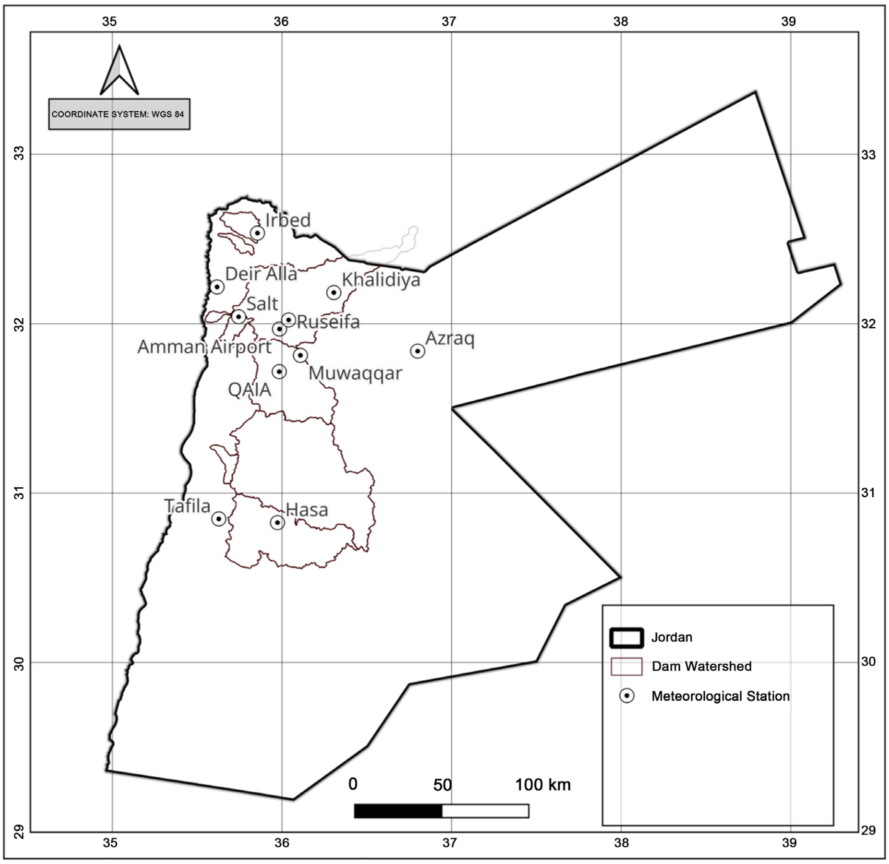

Figure 7. Geographical locations of meteorological observation stations.

Upon contact with the ground surface, rainwater starts to react with the rock and soil covers and dissolve minerals, mainly because rainwater naturally contains the acidic bicarbonates ($HCO_3$), which have capabilities to dissolve salts. Along the water overland flow, (channels, creaks, wadis, rivers) and during infiltration into soils and rocks, the water reacts with the encountered rocks and soils, especially, because it dissolves more carbon dioxides from the air and from the soils. Table 2 and Table 3 list the composition of floodwater along wadis pouring into the Jordan Rift Valley and wadis flowing in the Plateau area. The Plateau floods are generally composed of floodwater alone and hence their low salinity, compared to floods flowing towards the Jordan Rift Valley, which mix with base flow waters having higher salinities than flood precipitation water as explained above. Nonetheless, the salinity expressed in EC terms remains low, generally, below 250 µS/cm.

It can be stated here that the salinity of rainwater increases gradually from the highlands with altitudes of 700 - 1000 masl (Amman, Irbed, Salt, Karak, Shoubak) eastwards, towards the desert area as a result of, generally, more dusty atmosphere and lower ground surface altitudes of 500 - 750 masl (Ruseifa, Azraq, QAIA,

**Table 2.** Flood flow composition along the plateau wadis (EC in µS/cm, $NO_3$ and $PO_4$ in mg/l and all others in meq/l) High $NO_3$ and to a certain extent $PO_4$ concentrations can be correlated with the EC values indicating the effects of urbanization and accompanying waste production in the catchment areas of these watercourses.

| Parameter | Yarmouk | Yabis | Kufranja | Abdoun Ras El-Ain | Zarqa River 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 | 1.6 | 2.36 | 1.58 | 1 | 1.02 | 1.16 | 1.6 |
| $Mg^{+}$ | 1.4 | 1.43 | 0.59 | 0.2 | 0.32 | 0.29 | 0.4 | 0.42 | 1.57 | 0.2 |
| $Na^{+}$ | 1.7 | 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 | 0.1 | 0.13 | 0.1 | 0.22 | 0.09 |
| $Cl^{-}$ | 1.58 | 1.1 | 0.4 | 0.25 | 1.2 | 0.5 | 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 | 9.2 | 4.8 | 5.8 | 4.2 | 6.6 |
| $PO_4^{3-}$ | 0.73 | 0.12 | 1.37 | 0.55 | 0.53 | 0.38 | 0.84 | 0.252 | 0.24 | 0.87 |

**Table 3.** Flood flow composition along wadis pouring into the Jordan Rift Valley (EC in µs/cm, $NO_3$ and $PO_4$ 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 | 0.2 | 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 | 0.6 | 0.4 | 0.35 | 0.22 | 0.2 | 0.23 | 0.4 | 0.35 | 0.6 |
| $SO_4^{2-}$ | 0.35 | 0.39 | 0.94 | 0.41 | 0.24 | 0.2 | 0.23 | 0.25 | 0.34 | 0.1 | 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 |
| $PO_4^{3-}$ | 2.8 | 0.92 | 0.62 | 0.16 | 0.09 | 0.96 | 0.61 | 0.72 | 0.81 | 0 | 0.62 |

Khalidiya and Muwaqqar), (Figure 8 and Figure 9). In addition, the salinity increases also towards the Jordan Valley area (Deir Alla) because of its low latitude at 235 m below sea level and the re-evaporation (precipitation interception) of parts of the rainwater during precipitation leading herewith to concentration of salts in the falling water than in the escaping water (out raining water). The pH of the water is 7 - 8, quite normal for earth alkaline-carbonate water.

Water collected in dams in Jordan, even where the catchment area is not or, only very sparsely urbanized contains higher amounts of dissolved materials than

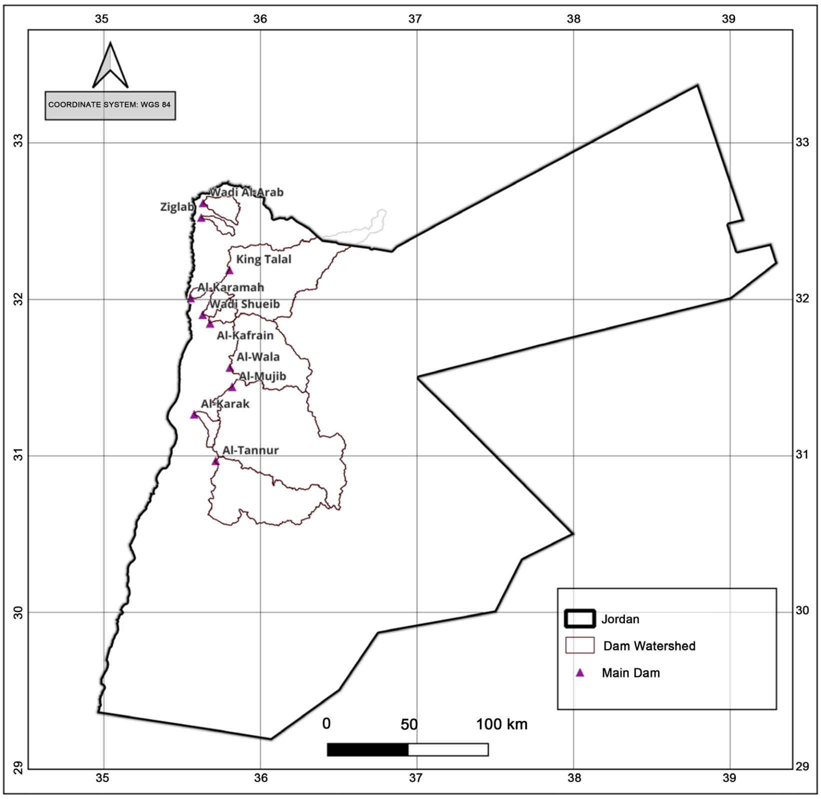

Figure 8. Location sites and watersheds of the main dams in Jordan.

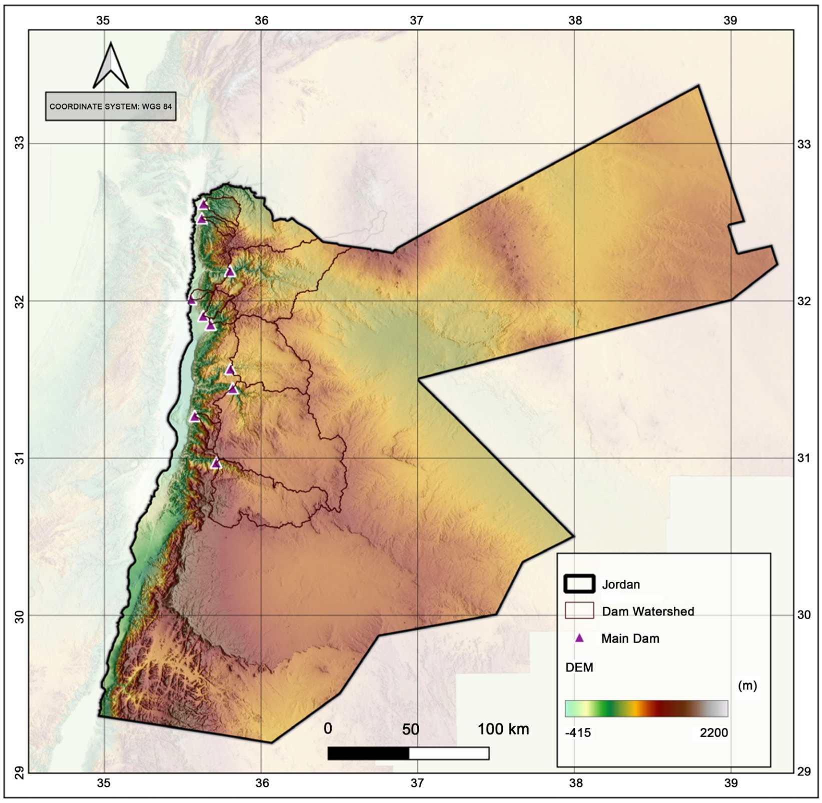

Figure 9. Digital elevation model.

floodwater. That is because dams receive base flow waters with increased salt contents and because water collected in dams is exposed to both evaporation and reaction with the accumulated bottom sediments, which is in addition to urban, irrigation and industrial leachates (**Table 4**).

As can be seen from **Table 4**, the water collected in the dams of Yarmouk, Wadi Arab, Kufranja, King Talal, Kafrain and Shueib have increased salinities. These dams receive urban wastes and treated and untreated wastewater (**Figure 10**). Floods reaching Tannur dam contain mining byproducts of phosphates and Zarqa Main, Shueib, Kafrain and King Talal dams receive phosphates of household use and therefore, they are suffering of eutrophication processes (**Figure 11**).

Harvested water in areas, where it generates, is of far lower salt content than that collected in dams (Compare **Tables 1-4**). Water harvested in high altitude areas, is saved from mixing with higher salinity base flow and other impaired water qualities along the flow course and from water reactions with dams' bottom sediments (Salameh, 1996).

Low salinity water of precipitation and floods is of higher value and productivity value when used in irrigation, and can in addition, be used in sectors requiring its high qualities such as drinking uses.

**Table 4.** Composition of dams' water constructed on the Jordan Rift Valley side wadis (EC in µs/cm, $NO_3$ and $PO_4$ in mg/l and all others in meq/l) (Own analyses, RSS & JVA, 2024).

| Dam/Parameter | Yarmouk | Arab | Kufranja | KTD | Kafrain | Shueib | Wala | Mujib | Tannur |
|---|---|---|---|---|---|---|---|---|---|
| **EC** | 830 | 1120 | 869 | 1900 | 1170 | 830 | 494 | 481 | 680 |
| **pH** | 8.7 | 8.4 | 8.1 | 8.11 | 8.05 | 8.41 | 7,72 | 8.03 | 8.05 |
| **$Ca^{2+}$** | 1.6 | 2.3 | 3.49 | 5.05 | 2.75 | 3.8 | 2,40 | 2.3 | 2.71 |
| **$Mg^{+}$** | 1.7 | 1.95 | 3.25 | 2.25 | 4.4 | 4.32 | 1.2 | 1 | 1.89 |
| **$Na^{+}$** | 3.43 | 5.32 | 2.26 | 11.74 | 4.07 | 4.39 | 1.49 | 1.43 | 2.11 |
| **$K^{+}$** | 0.14 | 0.23 | 0.25 | 1 | 28 | 0.35 | 0.016 | 0.2 | 0.28 |
| **$Cl^{-}$** | 2.3 | 6.2 | 2.75 | 10.63 | 5.66 | 4.6 | 2.3 | 1.23 | 1.47 |
| **$SO_4^{2-}$** | 1.8 | 1.98 | 2.1 | 4.42 | 4.08 | 2.88 | 0.57 | 1.35 | 2.71 |
| **$HCO_3^{-}$** | 3.32 | 2.45 | 3.93 | 5.75 | 3.15 | 4.52 | 2.18 | 2.08 | 2.29 |
| **$NO_3^{-}$** | 12 | 10.6 | 8.6 | 10.55 | 4.3 | 26.6 | 14 | 5.2 | 3.3 |
| **$PO_4^{3-}$** | 0.11 | 0.2 | 0.12 | 19.3 | 0.08 | 0.75 | 0.03 | 0.02 | 15.3 |

## 3.2. Energy

Water at high altitudes possesses potential energy compared to low altitudes. Hence, capturing water at high altitudes is quasi-gaining energy, which in case of natural floodwater becomes lost by friction with the flow channel and erosion and transportation of the sediment load. Capturing one cubic meter of water at 100 m above a certain level is equivalent to gaining 1 Mega Joule or around 100 Newton and that saves soils and rocks from erosion and transportation. In addition, if the harvested water is used in irrigation at these higher altitudes, it means energy gains in the form of potential energy, saving the transportation cost of agrarian products.

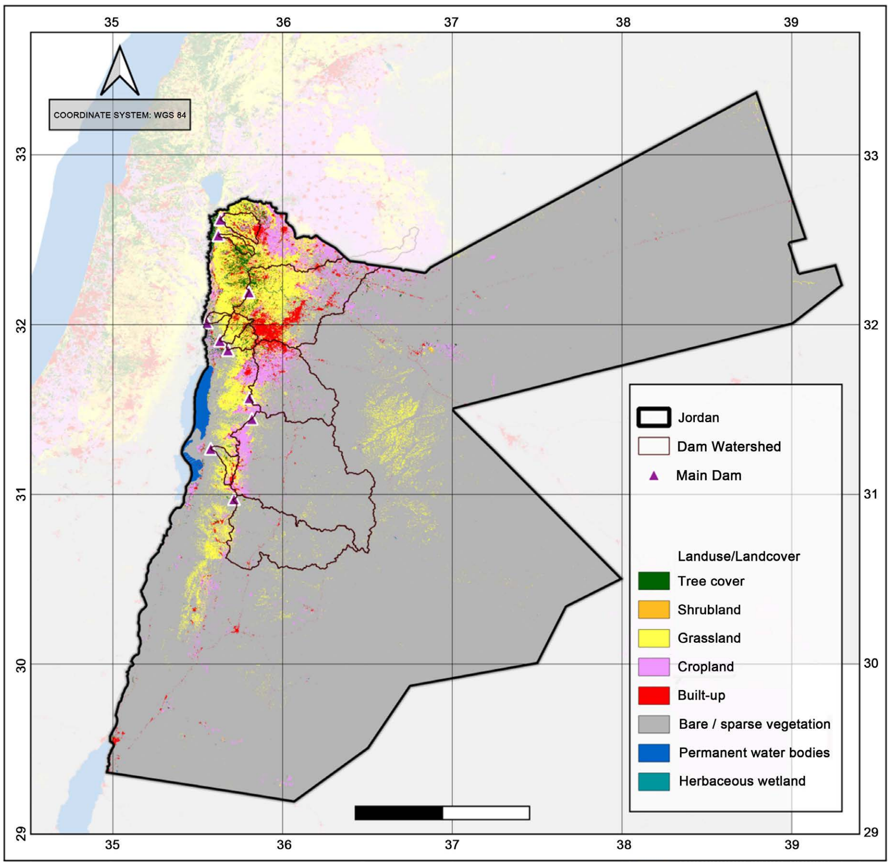

**Figure 10.** The land cover and land use map of Jordan illustrate the concentration of anthropogenic activities within the watersheds of the Yarmouk, Wadi Arab, Kufranja, King Talal, Kafrain, and Shueib dams. Conversely, phosphate mining areas are primarily located within the drainage basins associated with the Zarqa Main, Shueib, Kafrain, and King Talal dams, the map was generated using data from ESA World Cover (Zanaga et al., 2021).

**Figure 11.** Picture of Zarqa Ma'in Dam Lake showing the green color resulting from eutrophication processes (2024).

### 3.3. Sediment Loads

Jordan is located in the semi-arid to arid climatic zone, where day to night temperatures differ by about 10˚C, in addition to hot summers and cool winters, where temperatures rise in summer days beyond 40˚C and drop to below zero in wintertime. Hence, physical weathering is very strong and results in the disintegration of rocks. Thus, making the small rock pieces available for transportation by rain and floodwater. In addition, wind storms coming from the desert areas of the Arabian Peninsula in the south and east and Sinai Peninsula in the southwest carrying dust affect the area and these storms deposit their solid particles there (Salameh et al., 1991; König, 1994). These particles are easily eroded and transported with the floodwater in a downstream direction. Capturing floodwater in high altitude areas results in the deposition of their sediment loads in the capturing structure and by that reducing downstream siltation of floodwater collection facility.

Here, it is worth mentioning that one of the major problems facing existing and planned dams in Jordan is siltation (Salameh et al., 2024). For example, King Talal Dam has been filled by silt to around 25% of its storage capacity after 46 years of its construction, and Wadi Al-Arab dam to 18% after 40 years (**Table 5**, JVA open files). Muwaqqar three successive weirs distanced less than 200 m from each other along Wadi Mugheir with capacities of 15.000 - 25.000 m$^3$ silted up totally after around 10 years of their construction.

**Table 5.** Dam name, construction year, accumulated sediments, annual sedimentation rate, catchment area and precipitation over the catchment area (JVA, open files, 2023).

| Dam name and year of construction | Sediments in 1000 m$^3$ | % sediments of capacity | Annual sed. rate | Catchment area km$^2$ | PPT mm/year |
|---|---|---|---|---|---|
| **Wadi Al-Arab 1986** | 2900 | 17.20% | 0.44 | 262 | 460 |
| **Ziglab 1967** | 335.7 | 8.60% | 0.15 | 106 | 455 |
| **King Talal 1977** | 18 | 24% | 0.52 | 3700 | 272 |
| **Al-Karamah 1997** | 2 | 3.60% | 0.0005 | 62 | 150 |
| **Wadi Shueib 1969** | 900 | 52.90% | 0.98 | 178 | 400 |
| **Al-Kafrain 1967** | 1.9 | 22.40% | 0.4 | 163 | 397 |
| **Al-Wala 2002** | 4.6 | 18.20% | 0.87 | 1770 | 216 |
| **Al-Muiib 2003** | 6.5 | 21.80% | 1.09 | 4380 | 317 |
| **Al-Tannur 2001** | 2.5 | 17% | 0.77 | 2160 | 150 |
| **Al-Karak 2017** | 140 | 7% | 1.17 | 170 | 272 |

### 3.4. Flood Damage

Harvesting water at high altitudes reduces the quantity of floodwater flowing to downstream areas and causing damage to human life, natural environment, and to infrastructure. In Jordan, some big floods have resulted, during the last decade, in human and animal casualties, damage to buildings, dam spillways, streets, bridges and to the natural landscape and habitat (**Figure 12**). Water harvesting in high altitudes will certainly reduce flooding risks in downstream areas.

Figure 12. (a) Flood damage undercutting the mainroad along the Dead Sea Suweima area. (b) Flood undercutting the spill way of Wuheidi Dam in Maan area (2023).

### 3.5. Agricultural Productivity

Figure 6 shows that the potential evaporation rates in the Highlands and Plateau areas of Jordan decrease with increasing altitude. Therefore, irrigation water requirements at high latitudes, where rain and floodwater can be harvested, are lower than those requirements in the downstream areas (Taimeh, 2016; Evans, 1990; NRA & GTZ, 1977). This means that a unit of irrigation water at high latitudes produces more agricultural products than at lower latitudes due to higher evaporation rates. For example, the potential evaporation rate in Azraq area is around 1050 mm/yr whereas, in the headwater area further north, near the borders to Syria, it is only 900 mm/yr.

In addition, some salinity-sensitive crops such as asparagus and hydroponic plants require low water salinity; <450 µS/cm, which is provided by flood water in the upper reaches of water catchment areas.

Water harvesting and use in the high altitude areas, where the water generates creates needed new jobs, reduces unemployment and poverty, and fosters peoples' identification with their land and hence, with the country, which contributes to security, safety and sustainability. Knowing that indigenous population owns and inhabits these areas, compared to the areas irrigated by dams' water, where workers are generally foreigners.

## 4. Discussion of Disadvantages of Harvesting Water Where It Generates at High Altitudes

### 4.1. Reduction in Downstream Flood Flows, Storage in Downstream Water Facilities, and Lowering Their Potential Hydraulic Energy

The hydropower energy of some dams in Jordan produces electricity, such as the case of King Talal Dam. Although the produced quantity of energy is small, harvesting some of the head floodwater will reduce the hydropower production of such dams. Nevertheless, water harvested at higher altitudes possesses potential energy, which can be exploited in an efficient way. In addition, water storage at higher altitudes, for whatever use purpose, is an energy-gain process. Worth mentioning here is that, each cubic meter of water has a potential energy of 1 Mega Joule or around 1/3 kw·hr for every 100 m difference in head.

### 4.2. Reduction in Downstream Natural Groundwater Recharge Amounts

Wadis and river courses in the Plateau area of Jordan are generally influent, which means water flowing along them infiltrates into the ground to recharge the underlying groundwater bodies. The longer the watercourse, the more permeable its bottom rocks, the larger the wetted wadi course area and the lower the wadi gradient, the more floodwater infiltrates and recharge the groundwater. Therefore, capturing floodwater in upstream areas may deprive the groundwater in the downstream areas of some recharge. Hence, the importance of detailed studies in this context, knowing that capturing of floodwater in storage facilities in high altitude areas also results in groundwater recharge. This, forces developers of water harvesting projects, to carry out detailed studies to weight advantages versus disadvantages of upstream water harvesting on the natural groundwater recharge aiming not to cause damages to the environment and downstream water uses.

### 4.3. Lowering Soil Water Contents Along Wadi Courses and Flooding Plains Accompanied by Reduction in Natural Plant Growth and Biodiversity

The higher the discharged rate of flood flow the larger the wetted area along the watercourse and in its destination collection facility, whether the latter is a natural or artificial water body. Therefore, upstream water harvesting lowers the wetted areas along watercourses and in terminal lakes and hence, it lowers the soil moisture, the biodiversity, and the natural plant production, which serves grazing and production of desert vegetation. The natural service provided by flood flows require intensive studies during the planning stages of water harvesting projects, especially because the natural vegetation may include area-specific species, medicinal and aromatic plants, which may be very special species and restricted in their distribution to certain watercourses. Therefore, remediation measures must be developed, planned, and implemented aiming at conserving natural vegetation and biodiversity.

### 4.4. Reduction in the Dilution Effects of Downstream, Impaired Water Qualities

Rain and head-flood water, as discussed above, are of very low salinity and generally of very good quality. When flowing down along their natural courses, they serve as diluting factors for other downstream waters containing higher salt contents or pollutants, such as animal manure, treated wastewater, polluted spring water, and lower quality water stored in dams or weirs. Harvesting and consuming the harvested water in upstream areas reduces the downstream water quality. Therefore, detailed water quality appraisals must be carried out before decisions are taken to harvest flood and rainwater in the up-stream areas. Corrective measures can be developed and implemented to protect the environment.

Examples: floodwater reaching King Talal dam has an EC value of 390 µS/cm, the treated wastewater in Khirbet es Samra ~2000 µS/cm, the floodwater quantity ~20 MCM/yr, and the treated wastewater quantity ~120 MCM/yr. If all the floodwater becomes captured in the upstream area, the salinity of the water stored in King Talal Dam will increase by, around 230 µS/cm, which is expected to reduce the agricultural water productivity of King Talal Dam water in the Jordan Valley area.

### 4.5. Negative Effects of Upstream Water Harvesting on Existing Floodwater Uses

In many areas in Jordan, especially those along wadi courses draining into the Rift Valley area, floodwater has been, since decades, stored in dams for the different use purposes. However, along many other wadis and small catchments floodwater is still being lost to desert playas where it salinizes and evaporates, to areas outside the borders of the country, or to the open sea (Red Sea) and the Dead Sea.

Here, it can be recommended to capture all not used floodwater, after studying the effects of capturing that water on the other environmental elements, such as soil moisture, grazing land, natural groundwater recharge, biodiversity, etc.

Harvesting floodwater, which is presently under use in the downstream areas, must underlie rigorous, hydrological, hydrochemical, economic, social and environmental studies on its viability, and its benefits, which should be weighed against disadvantages. Fair compensation of existing downstream users and environmental elements must be of a major concern in the design phase of any water-harvesting project otherwise; the benefits of such projects remain illusionary.

## 5. Status of Water Harvesting in Jordan

In Jordan, the present status of water harvesting can be summarized as follows:

- Laws, by-laws and regulations have to be clarified and extended to support the legality of water harvesting planning and implementation.
- The existing poor strategic, institutional, and sound management support require water harvesting institutionalization.
- Integrated water and soil conservation projects are still not a part of local water harvesting although they are direct positive results, which should be targeted during all stages of planning and implementation of water harvesting projects.
- Water harvesting is still suffering of inadequate and inappropriate use of scientific and technological know-how.
- Almost a total lack of capacity building.
- Almost a total absence of tailored knowhow and financial support for water and soil conservation projects applying local water harvesting techniques.

Therefore, it, by now, has become mandatory for water harvesting projects to ensure the following:

1) ***Management issues***

- Establishing legal, policy, and institutional support.
- Prepare for the individual water catchment areas water management strategies taking into consideration all water, climatic, agricultural, social, economic and environmental advantages and disadvantages into due consideration.

2) ***Technical issues***

- Study water and soil resources for each water catchment area on its own.
- Develop engineered water and soil conservation and management projects through local water harvesting.
- Study advantages and disadvantages of local water harvesting and balance between them for sustainability and environmental soundness, economic viability and social acceptance and impacts.
- Develop water harvesting programs for each watershed area based on the principle of maximizing positive impacts and minimizing negative ones.
- Practice water harvesting through establishing pilot plants to serve as successful examples for duplication.
- Develop programs to compensate and correct any negative impacts water harvesting whether economic, social or environmental including biodiversity.
- Offer scientific and technological support for water harvesting and soil conservation undertakings.
- Secure access to cheap inputs of water harvesting and agricultural devices and other needs of water harvesting projects.

3) ***Implementation of water harvesting***

- Implement water harvesting projects simultaneously with rehabilitation programs for all the negative impacts of projects.
- Develop training programs.
- Establish individual watershed knowledge base for scientific, technical, and gained experience issues.
- Evaluate implemented water harvesting projects on their social and economic returns and their environmental and ecological soundness and benefits.

4) ***Prevailing situation in the dry lands of Jordan***

- Low rainfall rates and hence, low agricultural productivity of natural rain-fed systems.
- Soils suffering degradation in quality and thickness.
- No satisfactory information is available on the potentials of engineered development to conserve water and soil and maximize their productivity.
- Increasing demand for food, jobs, environmental and ecological conservation with all their socio-economic implications.

5) ***Main obstacles facing water harvesting and use***

- Inadequate institutionalization of water and soil conservation programs for beneficial purposes.
- Inadequate planning of engineered water harvesting programs.

- Inadequate use of technology in water and soil conservation.
- Almost total absence of use of scientific findings.
- Poor capacity building and societal participation.
- Resorting to big structures such as big dams.
- Needs to establish and restore water and soil conservation programs.
- Clarification of the legal responsibility of water harvesting policies and implementation.

## 6. Conclusion

Before the era of large dams, water harvesting was developed in the arid and semi-arid climatic zones to store available water during the rainy season for use in the dry season. Ancient water harvesting structures in the Levant, North Africa, South America and elsewhere give witness of the applied practices of water harvesting in the form of capturing water in house cisterns, weirs, pools, excavations along wadi courses, terracing of land and small dams among others (Frankopan, 2023; Beckers et al., 2013; Bienert & Häser, eds., 2004; Wright et al., 1999, 1997). During the last century, these old practices have been replaced by dam construction in many parts of the globe.

This current study shows, on examples from Jordan, that water harvesting, which incorporates concentrating rain or overland flow water in one spot, seems to offer a practical way for increasing the local availability of water and to save that water from being lost to evaporation or from its destiny to salt-water regimes or to becoming polluted.

Local, small-scale water harvesting projects seem, in addition, to have very high advantages to users and negligible disadvantages to the environment as compared with big water harvesting in dams. Nonetheless, small-scale water harvesting has to balance, in all details, advantages against disadvantages in order to maximize the first and minimize the latter and as compared with large-scale water collection in dams, knowing that, most implemented big dam projects lack the detailed studies on their environmental, health, and socio-economic viabilities.

This study concludes that small-scale water harvesting in catchments' upstream areas is very rewarding in social, economic, environmental and ecological aspects. It also concludes that many legal, administrative, managerial and planning issues have to be advanced for engineered watershed management and small-scale water harvesting projects.

## Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

## Authors' Contribution

The authors contributed to the study conception and design, material preparation, data collection and analysis. Both authors read and approved the final manuscript.

## Conflicts of Interest

The authors have no relevant financial or non-financial interests to disclose.

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