



**A SOCIO-ECOLOGICAL APPROACH TO COMBAT
DESERTIFICATION FOR SUSTAINABLE FUTURE**

EcoFuture

Work Package 3

Deliverable 3.4 Ecosystem Services Modeling of the JV

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Executive Summary

This deliverable presents the outcomes of Task 3.4: Ecosystem Services Assessment, which focuses on evaluating the ecosystem services provided by the Jordan Valley (JV) through geochemical simulations and modeling efforts across Jordan, Palestine, and Israel.

This deliverable, in addition to assessing the ecosystem services, describes the present-day, baseline conditions of the WEFE Nexus and represents the “Do-Nothing” scenario that will be compared with other scenarios that will aim at improving the WEFE Nexus and address/reverse the impacts of desertification. EcoFuture will examine two scenarios; one that optimizes the Nexus at the national level (development separate, nationally based strategic plans to address desertification) and the other, the “Blue-Sky” scenario where full cooperation is assumed between the 3 territories and the JV is considered as a whole with full cross-border collaboration.

The JV is a critical region where the interplay of water, energy, food, and ecosystem dynamics presents both challenges and opportunities for sustainable development and climate change mitigation and adaptation. The valley’s unique geographical and climatic conditions have historically made it a focal point for agriculture, requiring intensive water management strategies to overcome its arid climate. Water scarcity in this region is acute, with sources such as the Jordan River and Yarmouk River and underground aquifers under increasing pressure from over-extraction and pollution, directly impacting agricultural productivity and food security. Energy is another critical component, heavily intertwined with water through the energy-intensive processes of water pumping, treatment, and distribution, as well as in agricultural operations and food processing. The food sector in the JV is highly dependent on the sustainable management of water and energy resources, with agriculture accounting for a significant portion of employment and food supply in the three territories yet facing the challenges of limited water availability and the need for energy-efficient technologies. The ecosystem of the JV, characterized by its rich biodiversity and unique habitats, plays a crucial role in supporting agricultural activities. However, these ecosystems are under threat from overuse of natural resources, habitat destruction, and climate change impacts, necessitating integrated approaches to management. The WEFE nexus emerges as a vital framework in this context, emphasizing the interconnectedness of these sectors and the need for a holistic management approach to achieve socioeconomic welfare for the people of the valley. Ecosystems in the JV provide regulating, cultural and heritage services and most importantly, provisioning services.

The assessment of the ecosystem services integrates results from two key models: the Karst-SWAT hydrologic model and the ID-Integrated Critical Zone (ICZ) model. The methodology employed for this assessment was structured in three phases:

1. **Baseline Assessment** – Analysis of the current status of the WEFE Nexus in the JV. This phase established the foundational data for subsequent modeling.
2. **Models Setup and Calibration** – The ID-ICZ model was configured using data from the Jordanian pilot site to assess ecosystem services related to food production and soil structure. Simultaneously, the Karst-SWAT model simulated hydrological dynamics, sediment transport, and water quality, contributing to an understanding of water-related ecosystem services.

3. **Scenario Analysis** – Nature-Based and Hybrid Solutions (NB&HS) were modeled as scenarios to evaluate their potential impact on ecosystem service provision.

The SWAT hydrological model was used to assess nitrate and sediment concentrations in the Jordan River. The model accurately simulated nitrate behavior, particularly at the Jordan Baptism Site, where the average simulated nitrate concentration (39.3 mg/L) closely matched observed values (39.5 mg/L), with an NSE index of 0.76 indicating strong model performance. Upstream validation also confirmed the model's reliability in reproducing tributary patterns and concentrations. However, nitrogen use efficiency was low: while 101.65 kg/ha of total nitrogen (inorganic and organic) was applied, crop uptake accounted for only 25.69 kg/ha. Substantial nitrate losses occurred via denitrification and leaching, while organic nitrogen levels increased, suggesting that a large portion of nitrogen remains unused or is lost from the system, highlighting the need for more efficient nitrogen management strategies.

Sediment simulation results showed good alignment with observed trends, though the model slightly overestimated average sediment concentrations (2,540 mg/L simulated vs. 2,200 mg/L observed), with an NSE of 0.4. Discrepancies in peak values likely stem from differences in temporal resolution between simulation and measurement. Spatial analysis revealed that sediment yield is highest in steeply sloped sub-basins, particularly in the Yarmouk area and parts of Palestine, with some locations experiencing extreme erosion (up to 219 Mg/ha), far exceeding the critical erosion threshold of 10 Mg/ha. Additionally, a net deposition of sediment in stream channels was observed, indicating sediment accumulation in valley floors and possible degradation of channel capacity. These findings point to urgent needs for erosion control and improved land management, such as vegetative buffers and sustainable soil practices, to reduce sediment losses and enhance watershed resilience.

The simulations showed that the implementation of land management scenarios can significantly reduce sediment production, with noticeable differences across regions. In Jordan, the average annual sediment yield decreased from 71.48 to 22.92 tons/ha, achieving a 67.9% reduction in the optimal scenario. In Israel, the reduction reached 84.8%, dropping from 34.99 to just 5.31 tons/ha. In Palestine, a substantial decrease of 53.8% was also recorded, from 100.10 to 46.23 tons/ha. In contrast, at the Jordan Baptism Site, management scenarios failed to reduce sediment production, with values remaining nearly constant (26.70–26.61 tons/ha), while the optimal scenario even recorded a slight increase to 27.15 tons/ha (+1.7%). This failure is attributed to intense bank erosion, which dominates over surface interventions and is not effectively addressed by conventional erosion control measures. These findings emphasize the need for specialized anti-erosion strategies that account for strong lateral erosion and the unique hydro-morphological conditions of the area.

To address this type of erosion, the CH_COV coefficients related to full bank vegetation cover were specifically adjusted to enhance natural protection against lateral erosion. The application of this bank erosion reduction scenario led to a remarkable decrease in sediment production. Specifically, the baseline scenario exhibited significant fluctuations in annual sediment yield, with peaks reaching up to 14 tons/ha during intense rainfall events. In contrast, with the implementation of the bank protection scenario, sediment yield was drastically reduced, maintaining near-zero levels throughout the entire study period. As recorded in the table, the average annual SED_OUT dropped from 3.16 tons/ha in the baseline scenario to just 0.04 tons/ha, representing an impressive 98.73% reduction. This result confirms that enhancing bank vegetation cover is a critical intervention for limiting erosion and restoring the stability of riverine systems.

The analysis of manure reduction scenarios revealed that decreasing manure application leads to a gradual decline in nitrate (NO_3^-) concentrations over time. Four levels of reduction were considered: none, 25%, 50%, and complete elimination. Nitrate levels showed notable fluctuations throughout the study period, with some peaks during certain years. Compared to the baseline average nitrate concentration of 195.30 mg/L, a 25% manure reduction resulted in a modest 3% decrease, a 50% reduction led to a 6% decrease, and complete elimination lowered nitrate concentrations by 13% to 170.66 mg/L. These results suggest that while reducing manure use helps mitigate nitrate pollution, the overall reduction remains moderate, indicating that existing nitrate contamination in the system takes a very long time to flush out.

The 1D-ICZ model effectively simulated tomato production under three plastic house management scenarios, Control, WH (with water harvesting), and RO (with reverse osmosis), with extremely low error margins ($\leq 0.05\%$) compared to measured gross primary production (GPP). Among the three, RO plastic houses achieved the highest GPP (4,527 gC/m²), followed by WH (4,171 gC/m²), and Control (3,337 gC/m²). Soil organic carbon (SOC) remained stable in the Control setup, while it declined in both WH and RO setups over the growing period, though WH retained the highest final SOC value (34.31 tC/ha). The majority of water-stable aggregates (WSA) were found in the micro-aggregate fraction across all setups, and particulate organic matter (POM) varied significantly, constituting 9% of SOC in Control, 40% in WH, and 20% in RO systems.

Soil moisture observations from November 2024 to April 2025 showed that both WH and RO systems maintained relatively high and stable moisture levels, with simulated values closely matching field measurements. Ecosystem service quantification highlighted clear improvements in managed systems: WH and RO plastic houses demonstrated significantly higher GPP (41.71 and 45.28 tC/ha) and increased soil nitrogen stocks (4.42 and 3.57 tN/ha, respectively) compared to Control. These results suggest that WH and RO systems enhance productivity and improve key soil health indicators, supporting their potential for sustainable intensification in arid agricultural contexts.

1. Introduction

This deliverable presents the outcomes of **Task 3.4: Ecosystem Services Assessment**, which focuses on evaluating the ecosystem services provided by the Jordan Valley (JV) through geochemical simulations and modeling efforts across Jordan, Palestine, and Israel.

The assessment integrates results from two key models: the **Karst-SWAT hydrologic model** and the **ID-Integrated Critical Zone (ICZ) model**. The Karst-SWAT model is a watershed-based tool that captures the spatial variability of the JV by subdividing the area into sub-catchments. It is calibrated at the level of Hydrologic Response Units (HRUs), enabling the estimation of available water in each sub-basin and the simulation of future climate change scenarios to assess their impact on water availability.

Coupled with Karst-SWAT, the **ID-ICZ model** simulates the ecosystem services derived from soil-water-plant interactions in the JV. This process-based model links soil aggregate formation and soil structure development with nutrient dynamics, plant nutrition, water flow, and mass transport. It quantifies four key soil ecosystem functions: biomass production, carbon and nutrient sequestration (linked to soil structure), water filtration and microbial (bacteria–fungi) dynamics.

The ICZ model is composed of several interconnected sub-modules—**HYDRUS**, **CAST**, **PROSUM**, and components for chemical weathering and bioturbation—designed to simulate both above- and below-ground biotic and abiotic processes. Central to this system is the **CAST module**, which models the dynamics of soil formation (aggregation/disaggregation), soil structure, and nutrient cycling. Soil Organic Carbon (SOC) plays a critical role, as it directly influences soil hydraulic properties such as conductivity and water holding capacity. Ecosystem service quantification in the ID_ICZ model was based on data obtained from the first-year experiment of the Jordanian pilot site.

The methodology employed in Task 3.4 (Figure 1) was structured in three phases:

4. **Baseline Assessment** – Analysis of the current status of the WEF E Nexus in the JV (see Section 1-Chapter 2), drawing on existing references such as **Deliverable D1.1 (WEFE Nexus Mapping)** and **Deliverable D3.2 (Water Distribution Modeling)**. This phase established the foundational data for subsequent modeling.
5. **Models Setup and Calibration** – The **ID-ICZ model** was configured using data from the Jordanian pilot site to assess ecosystem services related to food production and soil structure. Simultaneously, the **Karst-SWAT model** simulated hydrological dynamics, sediment transport, and water quality, contributing to an understanding of water-related ecosystem services.
6. **Scenario Analysis** – Nature-Based Solutions (NBS) were modeled as scenarios to evaluate their potential impact on ecosystem service provision.

Together, these tools and approaches provide an integrated, spatially-explicit assessment of ecosystem services in the JV, supporting evidence-based strategies for sustainable management within the WEF E Nexus framework.

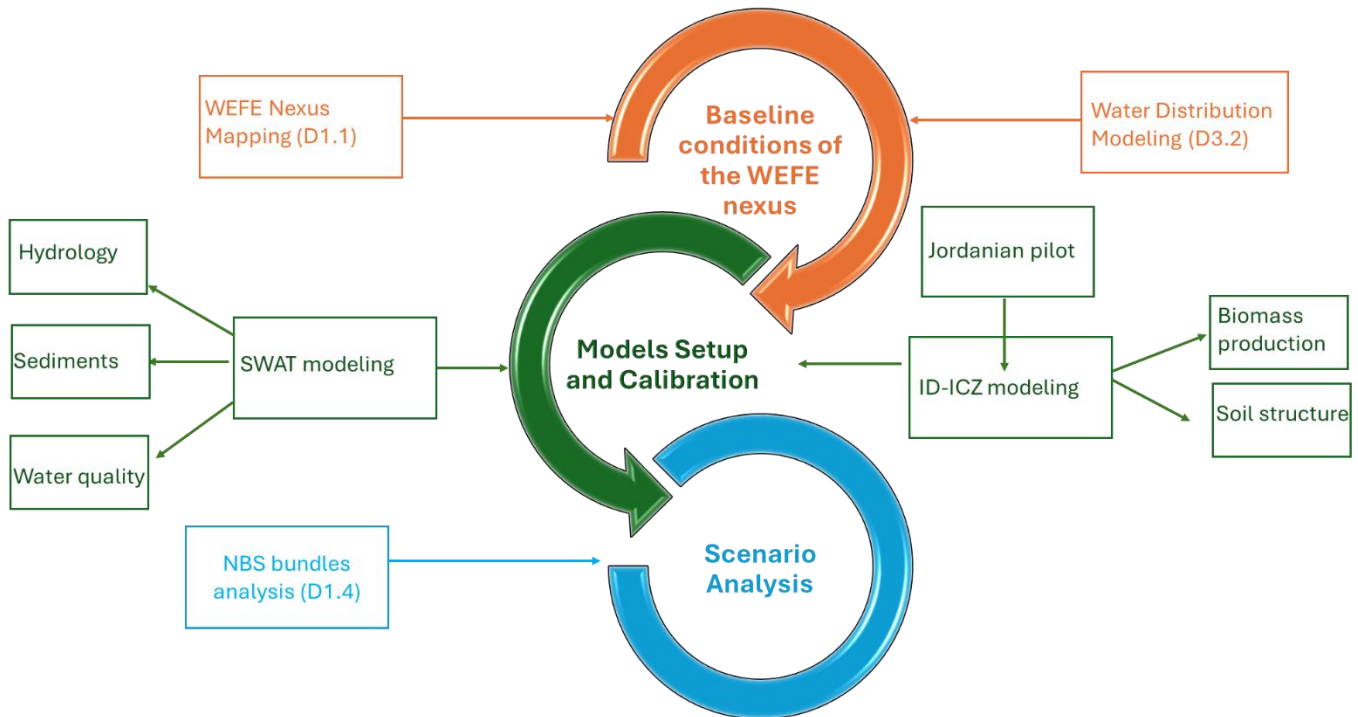


Figure 1. Methodology of Task 3.4.

2. Baseline conditions of WEFE Nexus

2.1 Water

2.1.1 Water supply and demand

The major water sources in the JV are Jordan River, Lake of Tiberias (or Sea of Galilee) and Yarmouk and Zarqa rivers. Lake Tiberias is the largest surface freshwater reservoir in the region. The Lower part of the Jordan River originates from the Sea of Galilee. Historically, the Lower Jordan River received around 600 MCM/yr from the Sea of Galilee and about 470 MCM/yr from Yarmouk River. Additional inflow was from Zarqa River and nine major Jordanian streams entering the valley from east, resulting in an outflow of 1,250 MCM/yr into the Dead Sea. Due to water diversion projects the outflow has decreased to 40-100 MCM/yr (Royal HaskoningDHV and MASAR, 2015). The Yarmouk River is the main water source of the King Abdullah Canal (KAC), which carries water for irrigating crops in the JV and for domestic use in Amman. Moreover, water from Yarmouk River is diverted by dams, including the Wehdah dam (or Unity Dam) which is located at the border with Syria. KAC has a total length of 110 km and receives water from Lake Tiberias and a discharge from King Talal Dam (KTD), which is a mix of freshwater from the Zarqa River and effluent from the As Samra wastewater treatment plant (WWTP).

KAC includes two sections: a) North KAC and b) South KAC. North KAC is 65 km long and receives water from Yarmouk River, Wehdah and Kufranja dams, Mukheiba Wells and the KAC conveyor (water supplied from Lake Tiberias under the Peace Treaty since June 1995). More specifically, North KAC receives 46.5 MCM/yr from Lake Tiberias, 50.0 MCM/yr from Wehdah dam, 16.3 MCM/yr from Mukheiba wells, 21.3

MCM/yr from Yarmouk/DS Wehdah dam and 5.0 MCM/yr from Kufranja dam. North KAC provides water for irrigation in North Shouna (73.0 MCM/yr) and drinking water in Amman (66.1 MCM/yr). South KAC is 45 km long and obtains water from As Samra WWTP (118 MCM/yr), several WWTPs (WWTP Al Baqaa: 5.8 MCM/yr, WWTP Wadi Al Seer: 3.5 MCM/yr, WWTP As Salt: 2.8 MCM/yr, WWTP Fuheis: 1.5 MCM/yr, WWTP Kufranja: 1.4 MCM/yr) and KAC North (3.4 MCM/yr). South KAC provides water for irrigation in Deir Alla (52.0 MCM/yr) and South Shouna (81.0 MCM/yr). The total supply of irrigation water for the Jordanian part of the JV is 206.0 MCM/yr while the demand is 400.0 MCM/yr (Table 1).

Drinking water in the Jordanian part of the JV is provided by groundwater (GW) resources. More specifically, North Shouna receives GW (8.9 MCM/yr) from Wadi Al Arab (2.5 MCM/yr), Shaq Al Bared (2.2 MCM/yr), Mkaimnat-Kraimeh (2.2 MCM/yr) and Tabaqet Fahel (2.0 MCM/yr). Deir Alla receives GW (5.8 MCM/yr) from Wadi Rajieb (2.6 MCM/yr), Abu Ezzeighan (2.3 MCM/yr) and As Samaheyat (0.8 MCM/yr). South Shouna receives GW (8.8 MCM/yr) from private wells (4.0 MCM/yr), Zara Maeen (2.4 MCM/yr) and Kafrain (2.4 MCM/yr). The total supply of drinking water for the Jordanian part of the JV is 23.5 MCM/yr while the demand is 26.0 MCM/yr (Table 1).

For the Israeli part of the JV, the freshwater supply system is mixed. The National Water Carrier (NWC) supplies Israel with drinking water (7.1 MCM/yr) that originates from Tiberias Lake in the north and desalinated water. In addition, the NWC provides 70.9 MCM/yr of freshwater which is mixed with 6.9 MCM/yr treated wastewater and it is used for irrigation (in total 67.8 MCM/yr). Aquaculture uses 67 MCM/yr saline water provided by GW. The total supply of drinking water for the Israeli part of the JV is 7.1 MCM/yr (same as the demand) and the total supply of agricultural water (water for irrigation and aquaculture) is 134.8 MCM/yr (same as the demand).

For the Palestinian part of the JV, Mekorot, the Israel Water Company supplies water which is mixed with water from wells, and it is used for domestic consumption (6.4 MCM/yr). Lastly, groundwater (48.1 MCM/yr), harvested rainwater (2.7 MCM/yr) and treated wastewater (0.7 MCM/yr) are used for irrigation purposes in Palestine (51.5 MCM/yr). The demand for drinking water is 10.0 MCM/yr and the demand for irrigation water is 182.0 MCM/yr (Table 1).

Table 1. Supply and demand for drinking and agricultural water and water deficit.

Drinking water (MCM)	Supply	Demand	Deficit
Jordan	23.48	26.00	-2.52
Israel	7.09	7.09	0
Palestine	6.40	10.00	-3.60
Agricultural water (MCM)			
Jordan	206.00	400.00	-194.0
Israel	134.84	134.84	0
Palestine	51.50	182.00	-130.5

2.1.2 Water quality

The water quality in the JV has undergone significant changes over time, primarily due to over-extraction, pollution from agricultural runoff, and wastewater discharge. Surface water in the Jordan River has seen increased salinity levels. Similarly, groundwater quality has been affected by overuse, leading to lowering of water tables and the intrusion of saline water in some areas, which complicates its use for drinking and agriculture without adequate treatment (WHO, 2017; FAO, 2017).

Jordanian part of the JV: The quality of water in the Lower Jordan River has severely deteriorated (Al-Mashagbah, 2015). While the headwaters upstream are unaffected, the lower sections of the river consist primarily of untreated sewage and agricultural return flows, groundwater seepage, as well as brackish water from springs diverted into the river away from Tiberias Lake (Royal HaskoningDHV and MASAR, 2015). Regarding the Jordanian dams, most of the water samples have high salinity and low sodium. KTD is one of the most nitrate-concentrated dams in Jordan due to its role in wastewater storage (from As Samra WWTP) and runoff collection (from Zarqa river). Moreover, the water samples from all dams fall within the rock (weathering) dominance zone. This suggests that surface water chemistry is influenced by geological conditions and chemical weathering of various rocks (Gharaibeh et al., 2024). Regarding groundwater resources, the water from Yarmouk River to the Dead Sea has some restrictions on use because of the high electrical conductivity (Salameh and Tarawneh, 2017). Irrigation with highly saline water can cause soil salinization and can affect plant growth and yield, nutrient availability and soil properties (Sheferia et al., 2021).

Israeli part of the JV: The quality of water in the three sub-basin aquifer system (Eastern Mountain, Northeastern Mountain and Lower Galilee) surrounding the JV area of interest is very heterogeneous. The groundwater extraction is generally of good quality, whereas the spring flow discharge is predominantly saline. Groundwater wells in the Lower Galilee sub-basin in the JV area demonstrate a sharp increase in both chloride and nitrate levels over time. These salinization processes are primarily attributed to agricultural activities and unregulated wastewater discharge upstream.

Palestinian part of the JV: The groundwater quality in the West Bank is generally acceptable with localized high concentrations of nitrates and chlorides. Approximately 20% and 30% of the samples in 2005 and 2009, respectively, contain nitrate concentrations above the Maximum Allowable Concentration (50 mg/L) of Palestinian and WHO guidelines (PWA, 2013). Data on groundwater quality in West Bank are limited to selected wells located in the Jordan Valley, Qalqiliya and Tulkarm. In Tulkarm and Qalqiliya, water testing shows that the nitrate concentration exceeds the WHO allowable limit (50 mg/L) in some wells, while the chloride concentration in these wells remains within the acceptable limits. Most of the wells in the Jordan Valley have high concentrations of chloride, exceeding the acceptable guideline set by the WHO (250 mg/L) while the nitrate concentration is quite low. Brackish water exists in the West Bank in Jericho Governorate with the chloride and EC increasing while going east (chloride values above 1,000 mg/L and EC values above 5,000 mS/cm).

The detailed information on the water quality of the Jordanian, the Israeli and the Palestinian part of the JV is described in the section 4.2.2 “Pressures and Impacts”.

2.1.3 Losses, irrigation rate and water use

For the Jordanian part of the JV, the Ministry of Water and Irrigation (MWI, 2014) estimates that 50% of the water is lost due to leakage in the drinking water network, attributed to inadequate maintenance. For the Palestinian part of the JV, losses in the drinking water supply network are in excess of 40-50% of the supply.

Table 2 presents the irrigation rate, and the drinking water use per capita for the three territories in the JV. The irrigation rate for Jordan was estimated to be 621.6 mm/dunum, for Israel 385.2 mm/dunum and for Palestine 565.9 mm/dunum. The differences in irrigation rates can be explained by the water losses/leakages in the network (about 40% for Jordan and 50% for Palestine). The drinking water use per capita has been estimated to be 248 L/d/cap for Jordan, 443 L/d/cap for Israel and 205 L/d/cap for Palestine. By accounting for the water losses in the distribution network in Jordan and Palestine, only half of this water is reaching the consumers.

Table 2. Irrigation rate and drinking water use per capita for the Jordanian, Israeli and Palestinian part of the JV.

	Units	Jordan	Israel	Palestine
Agricultural Area	km ²	348.9	249	173
Irrigated agricultural area	km ²	331.4	176	91
Irrigation water	MCM/yr	206.0	67.8	51.5
Irrigation Rate	mm/dunum	621.6	385.2	565.9
Drinking water	MCM/yr	23.5	7.1	6.4
Population	cap	260,000	43,900	70,000
Water use per capita	L/d/cap	248	443	205

2.1.4 Impacts on water

Surface water flow declines have been observed in the Jordan River and the discharge to the Dead Sea has been decreasing dramatically leading to the water level declines over the years. This decline is primarily due to withdrawals of water above the Sea of Galilee and diversion for other uses. The Dead Sea, a critical component of the JV ecosystem, faces severe threats due to declining surface water flow, particularly from the Jordan River. Extensive water withdrawals upstream, especially above the Sea of Galilee, for agriculture, domestic, and industrial uses have dramatically decreased the water reaching the Dead Sea, leading to a rapid decline in its water levels, dropping over one meter per year.

Impacts on Jordan River: The flow rates in the Lower Jordan River (LJR) have decreased sharply in the last 50 years due to the construction of a series of infrastructure used for storage and water diversion in the basin. The LJR had historically an annual flow of around 1,250 MCM. Today, the annual flow ranges between 40 to 100 MCM per year. Moreover, the average annual historic flow of the Yarmouk that was estimated at 450-500 MCM in the 1950s has today decreased to 83-99 MCM (Figure 2). The current annual discharge of the Lower Jordan River into the Dead Sea is estimated at 30–100 MCM compared to the historic 1,300 MCM (Royal HaskoningDHV and MASAR, 2015; UN-ESCWA and BGR, 2013).

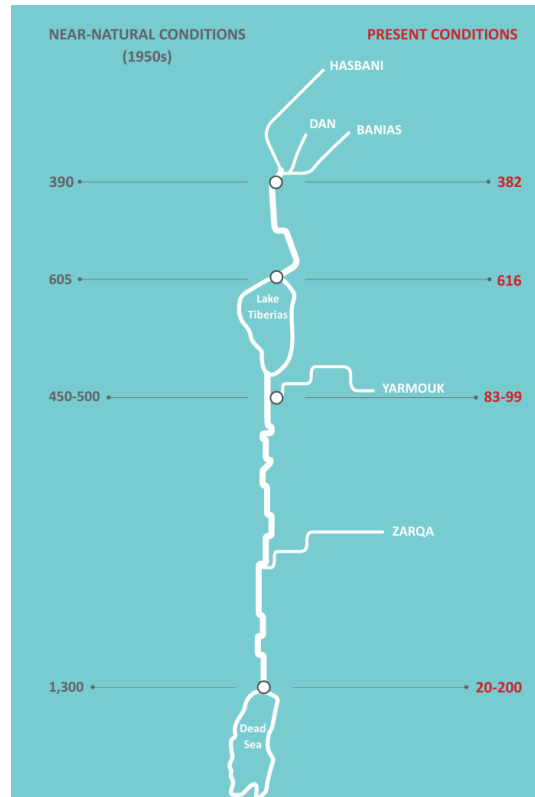


Figure 2. Annual water flow of the Jordan River (MCM) in near-natural conditions and in present conditions (UN-ESCWA and BGR, 2013).

Impacts on Dead Sea: The construction of large water diversion schemes in the Jordan River Basin since the 1960s has caused a sharp decline in inflow into the Dead Sea (DS) which has in turn led to a lowering of the sea level from -392 m asl prior to 1960 to approximately -436 m asl at the end of 2022, with an average decline of 0.7 m/yr. Likewise, the area of the Dead Sea shrank from around 950 km² prior to 1960 to a current value as of August 2021 of approximately 600 km² (40% shrinkage) (UN-ESCWA and BGR, 2013; Oroud, 2023).

However, the rate of the DS recession changed during the last 90 years. Five periods with different elevation reduction rates can be identified (Figure 3).

1. From 1932 to 1955; the DS level dropped relatively slowly from -389 to -392 m asl with a drop rate of 0.1 m/yr. This recession was associated with the foundation of the Palestine Potash Company in the early 1930s south-west of the DS that extracted only a small volume of water. However, before 1930 the DS level stayed stable because the freshwater inflow was equal to the evaporation rate. Therefore, the -389 m terrace documents the onset of regression of the DS caused mainly by human activity.
2. From 1955 to 1978; DS receded fast from -392 to -400 m asl with a drop rate of 0.35 m/yr. This was caused by the diversion of the Upper Jordan by the Israel National Carrier between 1950 and

1960 in addition to diversion of the Yarmouk River by the same carrier and by water extraction by Jordan and Syria in the early 1970s.

3. From 1978 to 1995; the DS level declined from -400 to -409 m asl with a drop rate of 0.5 m/yr. During this period, the southern basin completely dried up, the Arab Potash Company was established on the eastern side, the salt ponds were expanded and pumps were used since then to fill them.
4. From 1995 to 2009; the DS level declined with the alarming rate of 1 m/yr from -408 to -422 m asl. This fast regression resulted from expansion of the salt pans that are consuming an average of approximately 0.3 km³/yr (pumping minus return flows). The peace treaty signed between Jordan and Israel in 1994 has entitled Jordan to use an additional amount of approximately 0.1 km³/yr from the Upper Jordan and the Yarmouk River which also contributed to speeding up DS level decline (Ghazleh et al., 2011).
5. From 2009 to 2022; the DS level declined from -422 to -436 m asl with a drop rate of 1.1 m/yr.

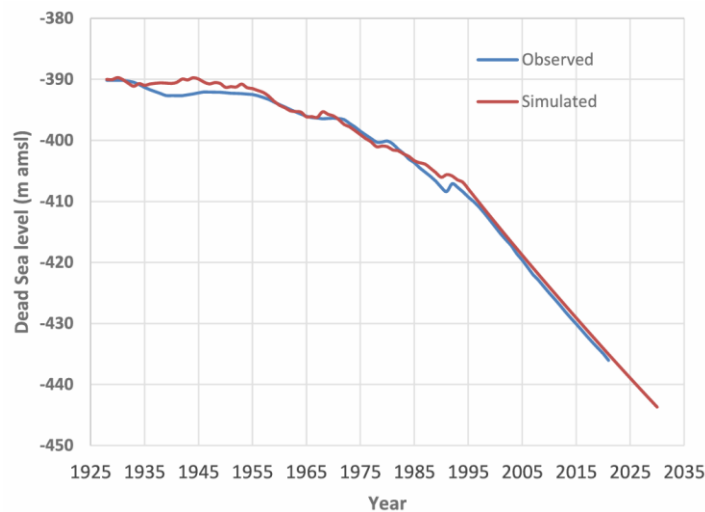


Figure 3. Decline in Dead Sea water levels from 1928 to 2022 (Oroud, 2023).

Impacts on groundwater in Jordan: Of the 121 groundwater wells in northern JV (Irbid governorate) only 14 are active as of 2016. Of these, 5 are legal, with a total abstraction of 0.533 MCM in 2016 due to the high dependency on KAC's water for irrigation and the presence of some illegal wells (Figure 4a, b).

Groundwater level decline is recorded across Jordan because of over exploitation and climate variability. Records in the Highland region indicate a yearly decline of up to five meters in the limestone aquifers (BGR, 2015). Five of eight monitoring wells had sufficient data for analysis of water-level trends in the study area. The maximum rate of groundwater-level decline was 0.2 m/yr at wells AB3146 and AB3147, while the minimum decline was recorded in wells AB3144 and AB3145 with 0.06 m/yr (Figure 4c). The groundwater hydrographs for the wells AB3144, AB3145, AB3146 and AB3147 are presented in Figure 5. The high lateral flow from the mountainous area and the high dependency on the KAC for irrigation has contributed to the relatively low decline in the groundwater levels in the northern part of the JV.

Of the 1,174 groundwater wells in southern JV (Balqa governorate) only 301 were active in 2016. The total groundwater abstraction from the active private wells in 2016 was 11.22 MCM.

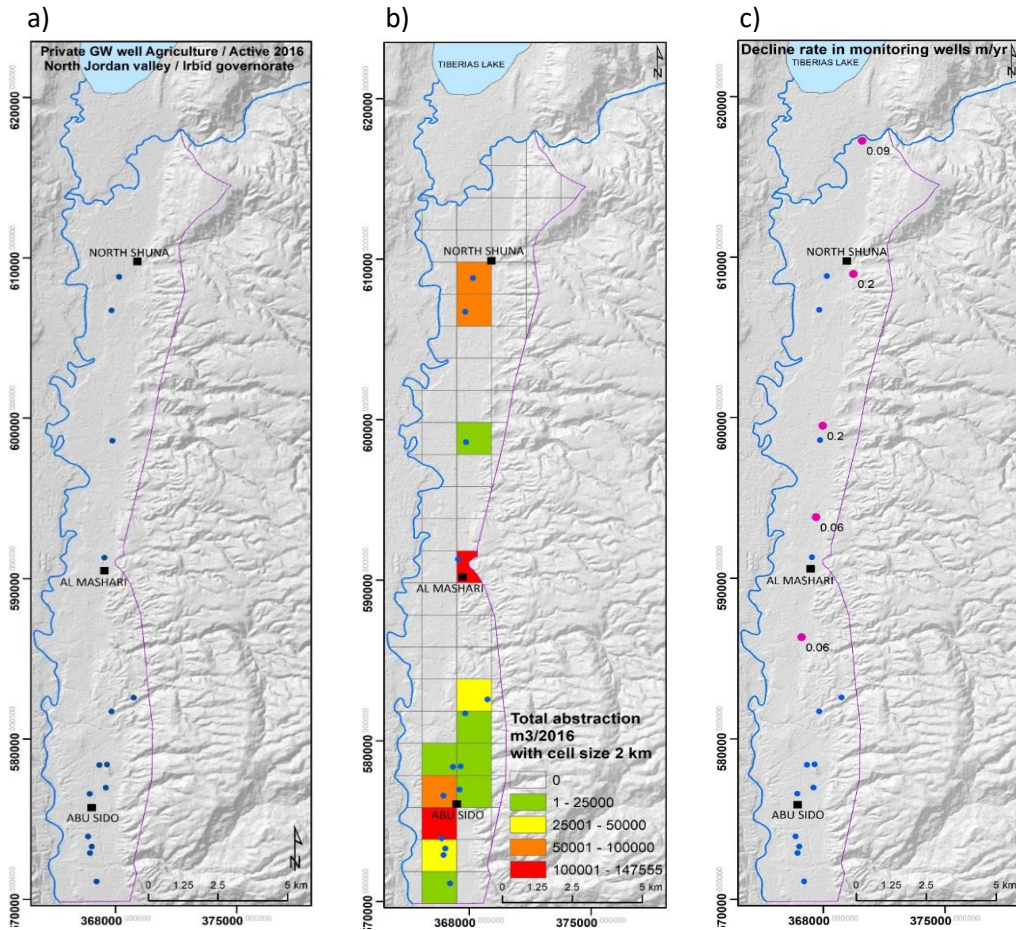


Figure 4. a) Active private wells including illegal wells, b) Total abstraction in 2016 (m³/yr) and c) Yearly decline in groundwater levels as recorded by monitoring wells (Al-Raggad, 2018).

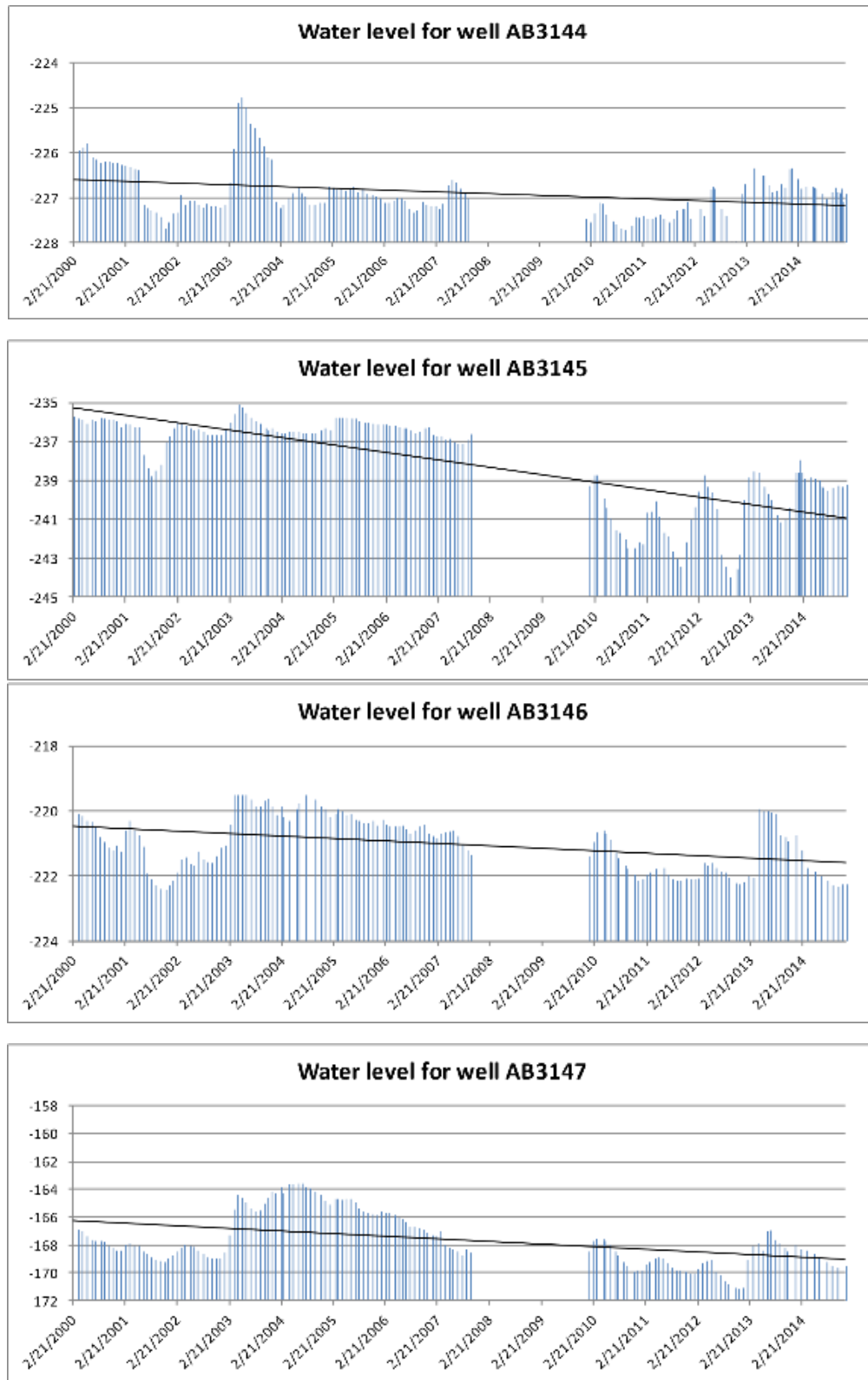


Figure 5. Groundwater hydrographs for wells AB3144, AB3145, AB3146 and AB3147 (Al-Raggad, 2018).

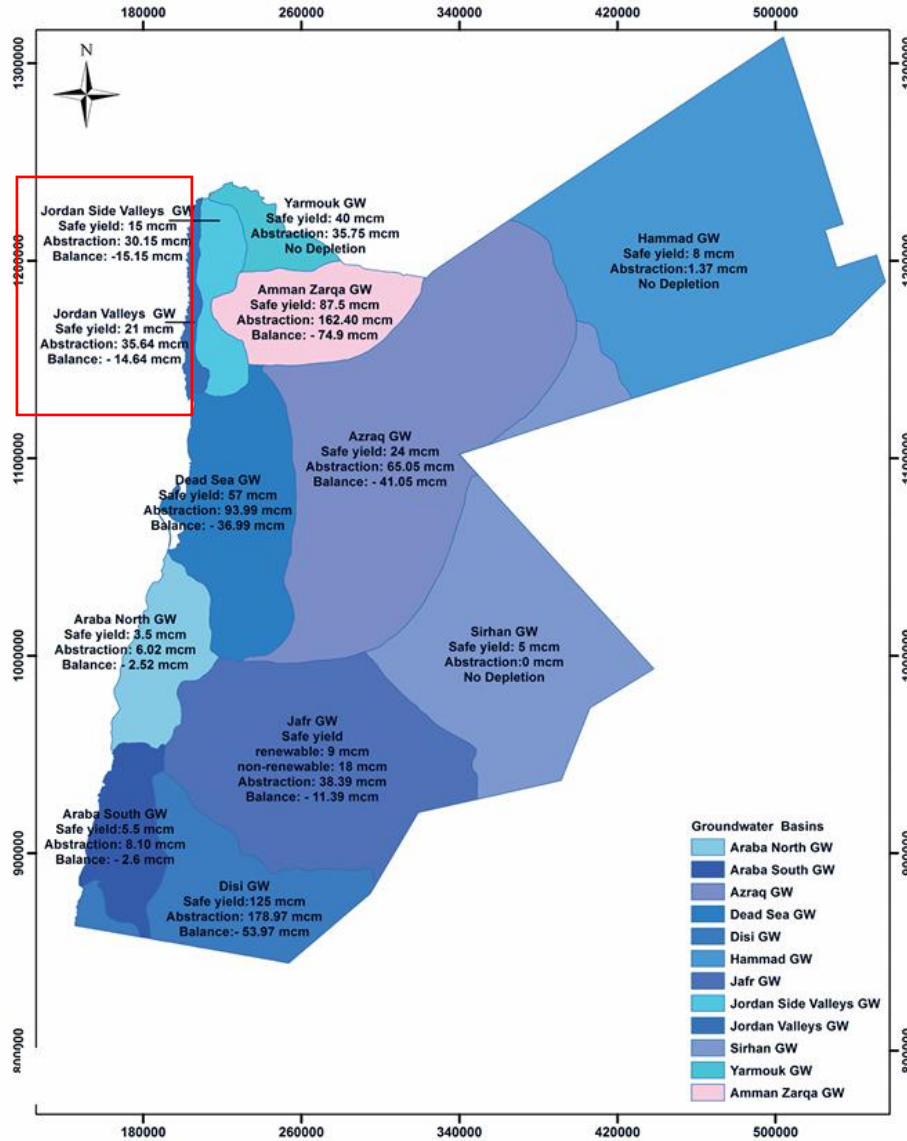


Figure 6. Groundwater Aquifers in Jordan, Safe Yield, Abstraction and Deficit for 2022 (MWI, 2022).

Impacts on groundwater in Palestine: Water abstraction by the Israelis already exceeds the thresholds agreed in Oslo and many sub-aquifers are mined and suffer from depletion. This depletion is due to abstraction by Israeli wells that are significantly affecting the nearby, downgradient Palestinian wells. In addition, the continuation of severe drought also has a negative impact on the aquifer recharge. As a result, the drawdown has been more than 70 m in just ten years in some places in the southern part of the West Bank and this constitutes a great threat to the groundwater system in this area (PWA, 2016). Figure 7 shows the water level decline trend in the Eastern aquifer basin. The water level dropped from approximately -268 in 2001 to approximately -341 m asl in 2010 (drop rate: 7.3 m/yr).

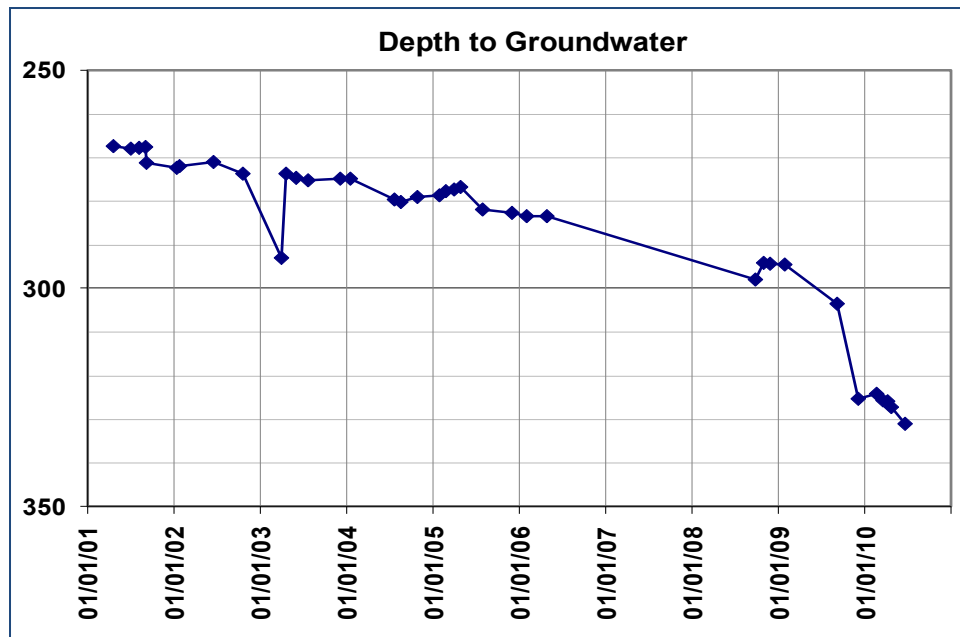


Figure 7. Water level decline trend in the Eastern Aquifer in meters b.s.l from 2001 to 2010 (piezometer monitored by PWA Water Resources Department).

Impacts on groundwater in Israel: Groundwater aquifer system surrounding the JV area is divided according to the Hydrological Service (HS) of the Israeli Water Authority (IWA) into 3 main sub-basins (Eastern Mountain, Northeastern Mountain and Lower Galilee) and an additional group of small aquifers with relatively low hydrological connectivity. According to the most recent report by the HS (HS, 2023), the total groundwater extraction in the hydrologic year of 2020 from the three sub-basins was about 196 MCM (twice the amount pumped in the 1970's). Extraction is divided to about 11 MCM pumped in the Lower Galilee aquifer, solely utilized by Israel, and the remaining quantity is equally divided between the Israeli and Palestinian extractions from the mutually pumped Eastern and Northeastern sub-basins (HS, 2023).

Of the 11 MCM extracted in the Lower Galilee aquifer, only 5.7 were extracted in the JV area of interest. Groundwater levels in that area have mostly increased compared to their levels in the 1970's due to reduction in the quantities pumped over time starting at around the year 2000 (HS, 2023). In the Valley of Springs, an area of rural communities specializing in agriculture (bordering the West Bank in the south and Jordan in the east) and relying on the Northeastern Mountain aquifer system, groundwater levels as well as springs' flows have significantly dropped over the years (Figure 8).

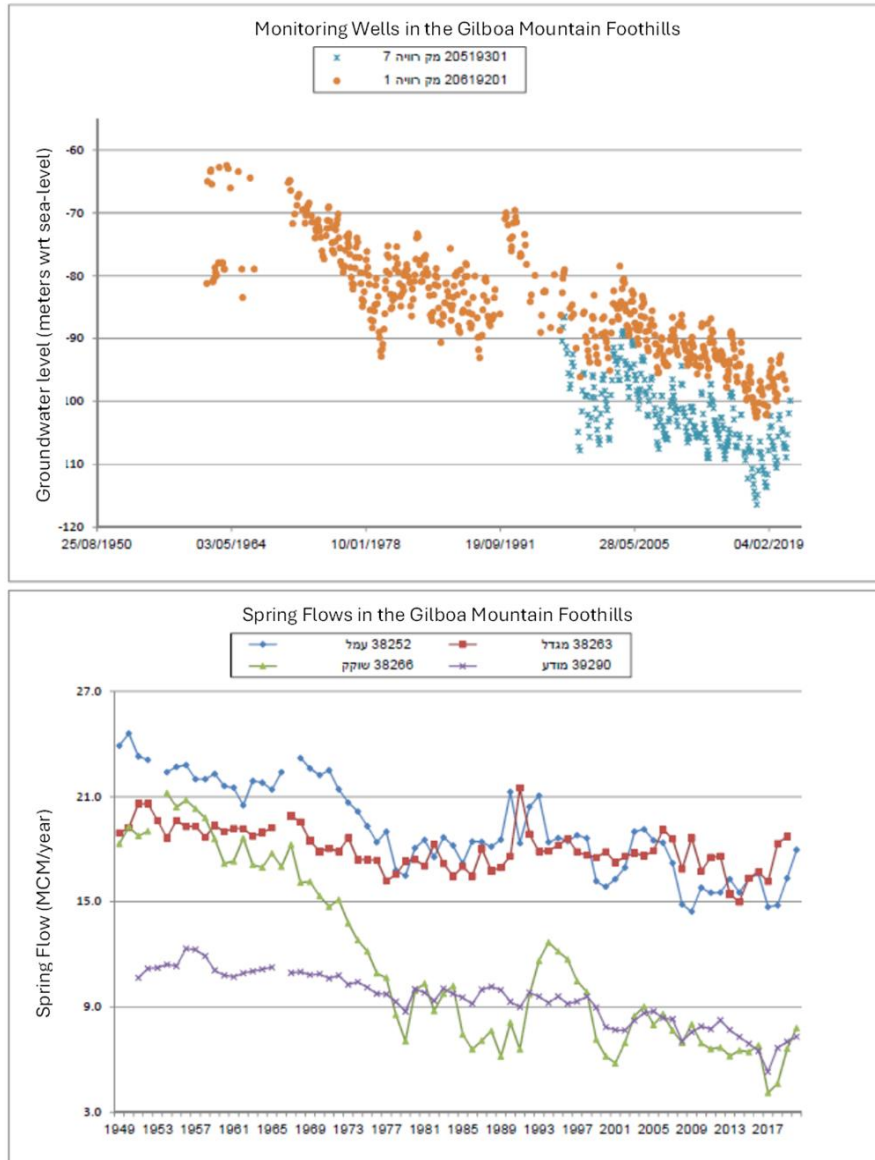


Figure 8. Groundwater level and spring flow decline trends in the Northeastern Aquifer (HS, 2023).

2.1.5 Vulnerability assessment

Climate change, following the more general Mediterranean trend of water resources shortages, has been projected as a serious threat to the area. The region's climate is changing, with the potential for increased droughts, higher temperatures, and more extreme weather events, posing significant challenges to water security and the preservation of ecosystem. Climatically, the JV is characterized by hot dry summers and mild wet winters, becoming progressively drier moving southward through the valley towards the Dead Sea. It is predicted that the Eastern Mediterranean will continue to face a reduction in annual precipitation, longer hot summer dry season, and shorter cool wet winter season due to climate change (Hochman et al., 2018).

Climate change affects every aspect of the water sector. Higher temperatures, less rainfall, and more extreme heat waves, flood and drought have broad implications for the water cycle. Climate change poses a major risk, with potentially significant consequences, to people, the economy, and ecosystems; particularly for the water sector, which is considered the most vulnerable sector to climate change.

For the Jordanian part of the JV, the impacts on water resources are (MWI, 2023):

- Everlasting patterns of changing rainfall amounts, higher temperatures, and sometimes, more extreme floods
- 15% less surface runoff from Wadis by 2040
- 15% less groundwater recharge by 2040
- Reduced water quality – the decrease in groundwater recharge due to the lack of precipitation, accompanied by high temperatures, leads to high salinity levels
- Damage to water and wastewater infrastructure from more frequent and severe floods and droughts
- Higher water demand during hotter summers
- Less water for rainfed and irrigated agriculture

Similarly, for the Israeli and Palestinian part of the JV, the impacts on water resources are:

- Reduction in precipitation amounts, surface runoff and groundwater recharge
- Extreme weather events (droughts, floods etc.)
- Damage to water and wastewater infrastructure from floods and droughts
- Reduced water quality
- Lengthening of the summer season (warmer and drier summers)
- Shortening of the winter season

Figure 9 presents the vulnerabilities in terms of water security due to climate change in the Jordanian, Israeli and Palestinian part of the JV. More specifically, drinking water (24 MCM/yr) in the Jordanian part of the JV is provided by GW resources. Groundwater recharge is expected to be reduced by 15% by 2040 posing a threat to the supply.

In general, the decrease in groundwater recharge due to the lack of precipitation, accompanied by high temperatures, can lead to high salinity levels which result in water quality deterioration and the need for desalination. Moreover, reduced precipitation amounts will result in less surface runoff which will provide less water for irrigated agriculture. In addition, extreme weather events such as floods change the distribution of precipitable water during the year and thus reduce the amount of water available for agriculture.

To conclude, water security in the Jordanian and Palestinian part of the JV is more vulnerable than the water security in the Israeli part JV due to climate change. Jordan and Palestine rely solely on local surface and ground water sources and in the case of Jordan on WWTP reuse, while the Israel incorporates a significant fraction of desalinated water in addition to local sources.

2.2.2 Current energy infrastructure

Electrical energy is supplied to customers via their national grids. Heat and power customers may use natural gas distributed by pipes or fuel supplied mainly by ground transportation and marginally by pipes. The electricity standards in Jordan are slightly different than in Israel and Palestine but the differences have no effect on the actual and future possibility of grid connection and sharing electricity.

Jordanian part of the JV: The Jordanian national interconnected grid transmits electricity from the power stations to the distribution substations and transformer substations in the Jordan Valley via 400-kV and 132-kV power lines. The grid has a clearly identifiable north-south axis. The national 400-kV power line runs outside the Jordan Valley from Aqaba via Amman and up to the Syrian border. In the north, the power grid is connected to the Syrian grid through a 230-kV and a 400-kV power line. In the south, there is a 400-kV connection to the Egyptian grid. The interconnected grid feeds the local distribution systems that serve most of Jordan's population, including that in the Jordan Valley (Kool, 2016).

Israeli part of the JV: Currently, most of the electrical energy is supplied by a 600 MW combined cycle natural gas power station at Alon Tabor situated on the border of the JV region. The power station is connected to the national transmission grid and the JV consumes about 100 MW from this station. The electricity from the national transmission grid is distributed to grids through 4 substations that can support between 100 MW to 150 MW each.

The Israel Electric Corporation (IEC) is the sole integrated electric utility in Israel and generates and transmits all of the electricity used in the country, including in the Jordan Valley (Kool, 2016). According to the current regulations, all the photovoltaics (PV) production is sold to the IEC at approved tariffs and the prosumers buy from the IEC the amount of energy they consume at the market price which is lower than the purchase feed-in tariffs. This arrangement is economically beneficial to the prosumers, but it reduces the security of the energy supply, which is the primary objective.

A major disadvantage is that there is a cap on the renewable energy supply to the IEC distribution network as the IEC currently limits the total consumption of electricity, including the renewables' access, to the substation access point to 60% of the interconnection capacity of these parts of the grid. Therefore, no new supplier with a total capacity exceeding 15 kW of installed capacity may currently receive a supplier license unless the grid and the transformation substation are upgraded.

Palestinian part of the JV: Palestine is heavily dependent on Israel for meeting its energy requirements. Almost all petroleum products and most of the electricity are imported from Israel and the possibility of diversifying the energy development and imports from other countries is currently limited due to political constraints as Israel controls area C (60% of the West Bank).

According to the Palestinian Central Bureau of Statistics (PCBS), Palestine's total electrical energy consumption in 2019 was reported to be 5,929.5 GWh. This quantity is almost entirely imported from outside sources, mainly from the IEC. While a share of 5% of the total electricity supply was imported from Jordan and Egypt, the largest electricity supplier was the IEC. The IEC operates 2 substations (SS) on the Israeli transmission grid that are supplying power to the West Bank. The first SS is in Maale Efraim, near Nablus, with the capacity of 150MW. It supplies energy to Area C which includes most of the JV. The second SS is in Jericho (Area A) and can provide 50MW. The total capacity is available for the JV consumption.

2.2.3 Energy potential

The three territories hold the same strategy and face the same obstacles on the way to accomplishing their national energy plans. Most of the land in the JV is rural, the primary energy consumer is the residential sector, and the secondary is the water sector which is the main resource for agriculture. The current situation is that, in the JV, the three territories can provide satisfactory energy supply and demand services by mainly non-renewable sources. Most of the non-renewable energy resources are located outside the JV, but it is not an issue since currently the JV is not a focal point for the 3 nations' energy policies.

JV can be a great source of renewable energy, far more than the local JV demand. The surplus can be sold to the national grid and can help reach the national renewable target. This is clear for Israel and Palestine. In Jordan, renewables, as a source of income to the JV inhabitants, is not so evident since there are much larger areas on the upper Jordan that are better suited for solar energy production. Nonetheless, the local JV consumption can easily be achieved in the Jordanian JV.

In the short term, each territory can follow the recommendations given below separately. However, the segregation of three national plans is not optimal. They do not consider the great advantage of common tri-national regional collaborations sharing the JV WEFE resources. Nevertheless, the regional collaboration between the 3 countries is extremely problematic due to the century-old political conflict between nations.

Energy for water: The water supply in agricultural areas like the Jordanian and Israeli JV areas is a major electricity consumer. The energy is needed for pumping wastewater treatment and desalination. The amount of water used in the region may not grow much since the designated agricultural areas in the region are nearly exhausted. However, if we wish to use treated wastewater and to preserve all the region's environmental services, the quality of the treated water must be improved. With enough water storage ponds, most of the energy for the waste-water treatment plants can be supplied by solar systems.

Energy shift between sectors: The large, forecasted increase in population on one hand and the limited expansion of agricultural areas combined with the increasing automatization in agriculture and declining enthusiasm of the young generation for agricultural work on the other, may cause substantial changes in the labor market. Specifically, we may expect a large increase in the industrial and commercial sectors. Those are currently less presented in the JV, but their future contribution needs to be studied and estimated. Maybe, advanced food industries have to be promoted. This is based on the importance of post-harvesting to food security and environmental preservation.

Grid vs. off-grid and behind-the-meter energy usage: In the three territories, the current transmission grid and even distribution grids may not be developed enough to absorb a significant growth in energy demand. The plans to add and/or increase the capacity of the existing and future substations feeding the JV are not mature and the future ability of the national grids to absorb a lot of renewables cannot be trusted. Selling and buying energy from the national providers may be economically justified. But such agreements may be at odds with the quest for maximal energy security. Therefore, self-usage of the energy produced by consumers behind the grid is advocated. Total off-grid installation is less favorable since the grid connection provides flexibility and better security of supply.

Heat and Power resources: In view of the expected growth in the industrial and commercial sectors, more attention should be given to the needs of industries, especially food industries, to the needs of heat and

power resources. For example, many food industries use low-temperature steam that can easily be achieved by thermo-solar panels, by biogas heaters, waste-heat recovery from Combined Heat & Power (CHP) facilities etc. The efficiency of thermal energy production is much higher than that of PV electricity production and waste heat is also very important. Diverse type biofuels produced from waste can contribute to the CHP resources and act as a primary energy resource (PER) for dispatchable electricity production.

Natural gas and biogas: To overcome the intermittency and the non-dispatchability of renewable energy biofuels and mainly biogas can serve as PER for electricity and Heat & Power. Lack of biogas can be compensated for by natural gas (NG) supply. The easiest way to employ this option is to feed regional distribution lines at low pressure (6-8 bar) from the Israeli Pressure Reduction and Metering Station (PRMS) near Beit Shean. Biogas and NG can be mixed and used by the customers.

2.3 Food

2.3.1 Food status baseline

Jordanian part of the JV: The agricultural production and crop pattern reflect a combination of environmental challenges and evolving agricultural practices. Recent years have seen a decline in vegetable production. This drop is attributed to various factors including rising production and labor costs, the soaring cost of inputs like fertilizers and pesticides, and challenges related to irrigation and water availability. The region has also been affected by unstable weather conditions, which have led to successive losses for farmers. Furthermore, external factors such as regional market dynamics have impacted the export potential of the valley's production.

Date palm cultivation in the JV has seen significant growth and development over the last years. This shift in agricultural focus is driven by the climatic suitability of the region for date palms, the high market value of dates and the challenges faced in traditional vegetable farming.

Animal production in the JV has evolved significantly over the years, reflecting changes in agricultural practices and adaptation to environmental conditions. The valley, known as the Ghor, offers a year-round agricultural climate and a reliable water supply, which have made it a key area for agriculture, including animal farming.

In the past two decades, there has been a noticeable shift in dairy farming. Farmers have largely transitioned from local cow breeds to international cattle due to their higher productivity. The local Baladi cows, which are well-adapted to the harsh environment, have seen a decrease in numbers. Small-scale farming often involves an interdependency between crop and livestock production, with farmers utilizing a portion of their land for dairy farming and the rest for crop production.

The dairy industry in Jordan has also seen growth, with the per capita consumption of dairy products reaching 78 kg. Most milk produced is delivered to dairy factories, which process it into various products, including yogurt, labaneh, cheese, and ghee.

The Jordan Valley's animal production is also influenced by its history as a migratory route for animals and birds, which has contributed to the biodiversity of the region. Today, the valley continues to play a role in

animal migration, including significant bird populations that rely on the valley during their migratory seasons. Overall, the animal production in the JV is characterized by a mix of traditional practices and modern developments, with an increasing focus on sustainability and efficiency in the face of environmental and economic challenges.

Fish production in the Jordan Valley has emerged as a vital sector for local economic development, job creation, and food security. The region has seen significant efforts to establish aquaculture and aquaponics systems that are both sustainable and efficient. Aquaculture in the JV has been largely dominated by the private sector. The most farmed fish in the valley are tilapia and the common carp due to their profitability and reproductive capabilities. As of 2018, fish farms in Jordan produced approximately 1,300 tonnes of fish, substantially more than the output from maritime fishing, which was 264 tonnes for the same period.

Import and export patterns: The nation is highly dependent on food imports due to its water scarcity, with agriculture consuming a substantial portion of Jordan's water resources yet only contributing to a small fraction of the Gross Domestic Product (GDP). The country imports up to 98% of its consumable items, including staples such as wheat, barley, sugar, rice, powdered milk, tea, coffee, corn, vegetable oil, cheese, chickpeas, vermicelli, and lentils. Imports have increased to meet the demands of a population that has nearly doubled in the past decade. On the export side, Jordan has seen an increase in agricultural exports, including horticultural products, poultry, and small-scale herding. Jordan's import and export patterns in food production exhibit strengths in its ability to produce a variety of fruits and vegetables in the Jordan Valley, supported by infrastructure. However, the dependence on food imports due to water scarcity and the economic limitations of expanding agricultural land are challenging.

Israeli part of the JV: The Israeli agricultural sector uses 25% of the Israeli land, 50% of the water and provides most of the vegetables and fruits for the population. However, the relative importance of the agricultural sector in the Israeli economy has declined over the last decades, with its share in total employment and in domestic product falling to just 2.5% and 1%, respectively. In monetary terms, total production amounts to about 9 billion \$ (60%: product of the vegetation subsector, 40%: animal products). Israeli agriculture supplies 90% of the domestic consumption of vegetables and fruits and most of the demand of animal products. However, 90% of cereals consumption for both human food and animal feed is based on import. Considering that the domestic livestock sector relies on imported feed, the Israeli agriculture supplies only 30% of the total calories consumed by the population (Almador, 2020; Kislev, 2005; Kan et al., 2023).

Cultivated land and water use for vegetative agricultural products in the region of interest accounts for about 8% of the total cultivated land and water use in the country. Crop specialization varies across the landscape of the region. In the area closest to the Sea of Galilee, avocado, banana and mango groves cover the majority of cultivated lands. The central part of the region grows primarily field crops, about a third of which are purposed for animal feed. Dates plantations cover about 10% of the area cultivated and a variety of vegetables for industrial use, or of lower value, such as tomatoes for industry, onions and garlic, and watermelons for seeds comprise the rest of the land. Further down south in the region, dates are predominantly the most important crop grown followed by field crops.

Aquaculture is predominantly the largest agricultural activity in the region, accounting for about 80% of the local fresh fish production in the country (Southern Jordan River Drainage Authority, 2017), covering almost 10% of the agricultural land in the region and accounting for about half of the water use in it. This industry is suffering from growing global competition, specifically after the removal of protective import tariffs, starting from 2016, actively reducing consumer prices by almost 30% (Bar-Nahum, 2019; Orlev-Sharon, 2023). As a result, the local production share of national consumption decreased from 15% to 8% in less than a decade. Farms' production and revenues also dropped significantly even though direct and indirect support were administered to farmers by the country during the tariff abolishment period and concurrently per capita national consumption of fish increased by about 50% (Bar-Nahum, 2019; Orlev-Sharon, 2023).

The livestock agriculture in the region is primarily dairy production—out of the 40 communities included in the area of interest, 25 operate a dairy farm. The total regional production is about 6.5% of the dairy production in the country. Other dairy farming (from sheep or goats), poultry and cattle for meat activities in the region account for very small shares of their respective national industries.

Import and export patterns: Israel highly depends on imported cereals for both animal feed and direct human consumption. The import of most fruit and vegetables is still limited due to a system of protective tariffs. Still some crops are imported in relatively larger shares like apples, tomatoes, cucumbers and onions, all in the magnitude of about 10% of the total local market consumption.

Fish consumption levels in the country are on a rising trajectory, where the source of supply is primarily imports, and local production only accounting for small and decreasing share of the market following the removal of protective import tariffs in that sector almost a decade ago.

The value of exported agricultural products for year 2022 was about 1.1 billion \$ and accounted for about 12%, and 22%, of the total value of agricultural production, and vegetative agriculture, respectively (Katz and Bar-Nahum, 2023; Orlev-Sharon and Katz, 2023). Fruit and vegetables products together account for more than 60% of total exports, about additional 20% are herbs and seeds, the rest are flowers (about 8%), field crops (mainly cotton and peanuts, about 5%), and animal products (about 3%). Primary crops exported are avocados, dates, mangos, easy peelers and grapefruit in the fruit category; and potatoes, carrots and capsicum in the vegetable category (Katz and Bar-Nahum, 2023; Orlev-Sharon and Katz, 2023). The European union is still the largest export market for Israel, followed by former USSR (Union of Soviet Socialist Republics) countries, primarily Russia.

Palestinian part of the JV: The total agricultural area is 55,053 dunams (as of 2021). Permanent (tree) crops accounted for 29,298 dunams (53.2% of land area), while vegetables and field crop cultivation accounted for 20,852 dunams (37.9%). The remaining areas comprised as follows:

- 19 dunams of temporary pastures
- 1,366 dunams of fallow
- 318 dunams of permanent pasture
- 658 dunams of agricultural buildings
- 21 dunams of forest or wooded areas
- 2,458 dunams other uses including parks

- 63 dunams of aquaculture

The total area of land cultivated (as of 2021) was 52,780 dunams. 22,042 dunams were cultivated with field crops (41.8%) while tree crop area was 29,103 dunams (55.1%). 1,635 dunams (3.1%) were cultivated with field crops of which 965 dunams were harvested that year. For the field crop area, the rainfed crops comprised 562 dunams (34.4% of field crops) while 1,073 dunams were irrigated (65.6%).

Official data indicate a significant decline in the agricultural sector's contribution to the economy of the Palestinian Territory over the past few decades. In 1967, agriculture contributed about 53% of the total GDP. By 2016, this figure had dropped to approximately 2.8% in the West Bank and 4% in the Gaza Strip (UNSCO, 2016). However, these figures can be misleading, as they suggest that agriculture's economic importance is now minimal. They fail to account for informal agricultural activities and do not include agricultural industries like dairy processing, olive oil production, and cucumber pickling. Additionally, agricultural activities on plots smaller than 1,000 m² and part-time farming are not included. Despite the dramatic reduction in GDP contribution, the agricultural sector remains crucial to the economy.

According to an FAO report in 2021, the structure of production in the agriculture sector of Palestine in 2019 comprised as follows: approximately 50% comes from livestock products, including meat from chickens (22%), sheep (5%), goats (3%), and cattle (1%); milk from cows (4%), sheep (4%), and goats (1%); and eggs (4%). Notable shares also come from olives (13%), tomatoes (8%), cucumbers and gherkins (5%), grapes (4%), and almonds (3%), along with other fruits and vegetables.

Preliminary results from the latest agriculture census (PCBS, 2022) show that olive tree cultivation now occupies the largest agricultural area, covering approximately 57% of the cultivated land in the Palestinian Territory, and 85% of the horticulture area. Field crops, vegetables, and other fruit trees make up the remaining areas, at 19.8%, 18.5%, and 9.3%, respectively. Compared to the 2010 census (PCBS, 2010), the area cultivated with vegetables has increased by about 58%.

The livestock sector accounts for approximately 45% of the total agricultural value in the Palestinian Territory (FAO, 2021). Over the past decade, the poultry industry has seen notable growth, with the number of birds being more than doubled between 2010 and 2021 (PCBS, 2022). Apiculture has also seen remarkable expansion, with the number of beehives increasing by 68% between 2010 and 2021 (PCBS, 2022). Dairy farms are expanding as well, although they have not reached the same level of mechanization as poultry farms.

Another crucial element is the food processing industry. Although still in its early stages in the Occupied Palestinian Territory, this sector has seen steady development, particularly in the production of dairy products, olive oil and pickled goods. A significant portion of the raw materials, including cucumbers, dates, tomatoes, eggplants, almonds, and grapes, are sourced locally.

Import patterns: Population growth and rapid urbanization have increased the pressure on the agriculture sector. The growing gap between local production and consumption has made imports increasingly essential to meet food needs. While the Occupied Palestinian Territory is largely self-sufficient in vegetables, grapes, figs, olive oil, poultry, meat, eggs, and honey, it remains highly food insecure at the national level. The territory relies on imports for 40% of its main food items and more than 95% of its cereals and pulses.

2.3.2 Land use

The total agricultural land in the JV covers 87,378 ha and accounts for 34 % of the total area. The distribution of agricultural land in the three territories is 51.7 % for Jordan, 28.5 % for Israel and 19.8 % for Palestine. Regarding aquaculture, the Israeli territory uses 1,690 ha for fish farming while the Jordanian uses 73 ha and the Palestinian 30 ha (Table 4).

The area designated as uncultivated land or nature reserves is 81,029 ha for Jordan, 2593 ha for Israel and 67,130 ha for Palestine. The built-up area, which includes residential, commercial, and industrial zones, is currently 4,462 ha for Jordan, 3,025 for Israel and 2,530 for Palestine. The water reservoirs which are essential for water storage and management in the valley, cover 555 ha in Jordan, 165 ha in Israel and 26 ha in Palestine.

Table 4. Land use of the three territories of JV.

Land use (ha)	Jordan	Israel	Palestine
Agriculture	45,183	24,895	17,300
Built Area	4,462	3,025	2,530
Fish farming	73	1,690	30
Natural/Uncultivated	81,029	2,593	67,130
Reservoirs	555	165	26
Wadis	2,416	-	1,380
GRAND TOTAL	133,718	32,368	88,396

2.3.3 Food production

Crop production

Jordan: According to the Ministry of Agriculture (Figure 10), in 2021 were produced: 291488 tonnes of greenhouse vegetables (68,517 dunums), 159475 tonnes of citrus (64,682 dunums), 248902 tonnes of winter vegetables (85,971 dunums), 84789 tonnes of summer vegetables (31,173 dunums) and 85400 tonnes of fruits (27,747 dunums).

Israel: According to the Israeli Ministry of Agriculture (Figure 11a), in 2021 were produced: 188454 tonnes of vegetables (75,282 dunums), 9745 tonnes of citrus (1,951 dunums), 218095 tonnes of fruits (82,397 dunums) and 56410 tonnes of cereals (52,214 dunums).

Palestine: According to the Palestinian Central Bureau of Statistics (Figure 11b), in Tubas and Jericho in 2020/2021 were produced: 19915 tonnes of field crops (36,720 dunums), 335304 tonnes of vegetables (58,677 dunums), 40456 tonnes of fruits (39,951 dunums) and 2009 tonnes of citrus (922 dunums).

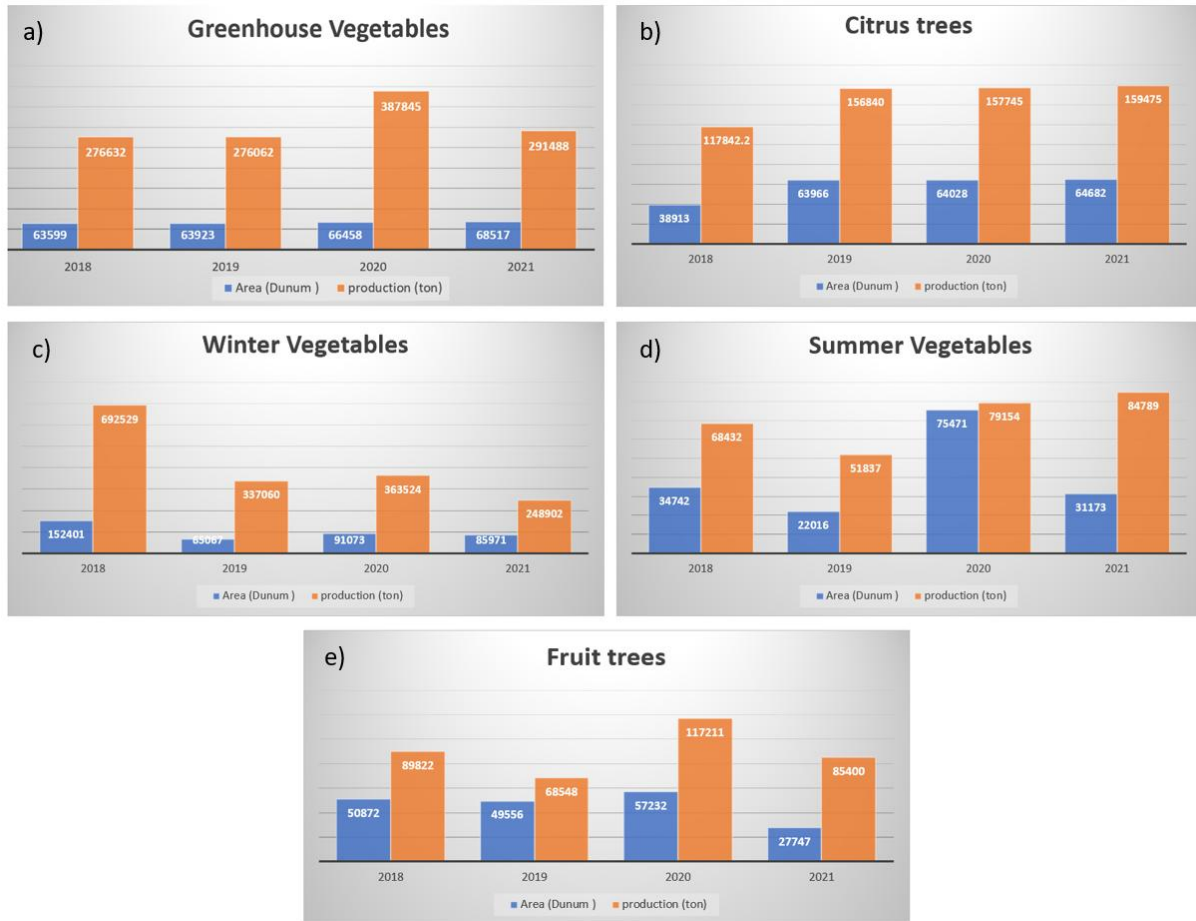


Figure 10. Area in dunum and crop production in ton in the Jordanian part of the JV from 2018 to 2021 for a) greenhouse vegetables, b) citrus trees, c) winter vegetables, d) summer vegetables and e) fruit trees (Ministry of Agriculture, annual reports).

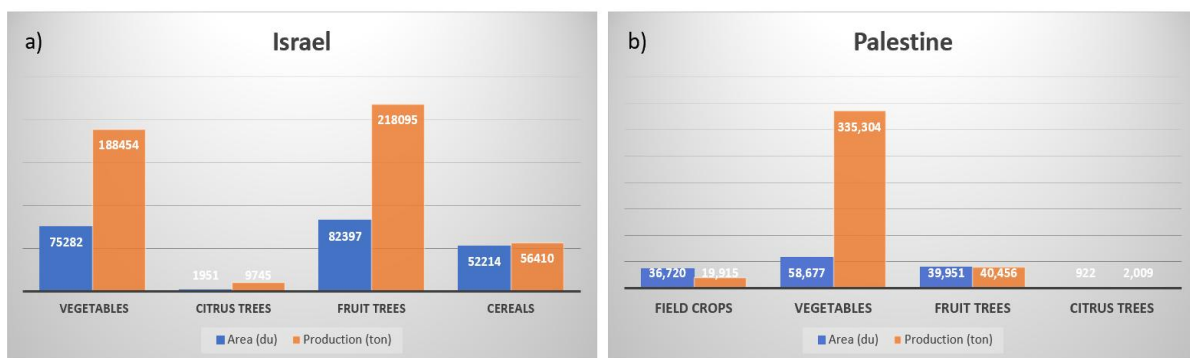


Figure 11. Area in dunum and crop production in ton a) in the Israeli part of the JV for vegetables, citrus trees, fruit trees and cereals (Israeli Ministry of Agriculture) and b) in the Palestinian part of the JV (Tubas and Jericho) for field crops, vegetables, fruit trees and citrus trees.

Animal production

Jordan: According to the Ministry of Agriculture (annual report, 2023), the production of a) beef and sheep was 2325 tonnes, b) poultry was 360 tonnes, c) milk was 40 tonnes, d) eggs was 700 tonnes, e) honey bees was 6445 tonnes (heaves) and f) fish was 954 tonnes (Table 5).

Israel: According to the Statistical Abstract of Israel (2021), the production of a) poultry was 50433 tonnes, b) milk was 95940 tonnes, c) eggs was 1316 tonnes and d) fish was 10000 tonnes (Table 5).

Palestine: According to the Palestinian Central Bureau of Statistics (2021), the production of a) beef and sheep was 158731 tonnes, b) poultry was 5358287 tonnes and c) honey bees was 4506 tonnes (Table 5).

Table 5. Animal production in the three territories of JV.

Animal production (ton)	Jordan	Israel	Palestine
Beef and sheep	2,325	No data	158,731
Poultry	360	50,433	5,358,287
Milk	40	95,940	No data
Eggs	700	1,316	52,150 (chicken)
Honey bees	6,445 (heaves)	No data	4,506
Fish	954	10,000	No data

2.3.4 Soil salinity and its impacts on crop productivity

Climate change and several biotic and abiotic stresses challenge the growth and production of agricultural crops. Among abiotic stresses, soil salinity is considered as one of the leading limiting factors responsible for growth and production decline of agricultural crops (Majeed and Muhammad, 2019).

Soil salinity induced by climate change refers to a significant increase in the concentration of soluble salts in the soil column caused by various climate change aspects including increasing air temperature, changing rainfall patterns, rising sea level, and accelerating droughts (Haj-Amor et al., 2022). The accumulation of water-soluble salts in the plant rooting zone, thereby impacting water and soil quality, and inhibiting plant growth. Osmotic changes in soil water caused by total salinity reduce the ability of plants to take up water from the soil. In addition, specific ions such as Na and Cl negatively impact plant physiology and become toxic when absorbed by the plant at higher than beneficial amounts. In addition, saline soils can reduce plant nutrient uptake or cause ion imbalances (Hopmans et al., 2021).

The overuse and misuse of fertilizers can contribute to significant soil salinity buildup. Shifts in the soil microbial community in response to salinity stress could have implications for C cycling. Salinity also affects microbial diversity and richness directly and/or indirectly by changing soil edaphic characteristics. Lastly, soil salinity can cause a decrease of SOC content.

In general, in very low salinity levels, the crop yield remains unaffected, whereas moderate and high salinity levels ($EC= 4 \text{ dS m}^{-1}$) may affect crops growth. Many studies found out that soil salinity can induce significant crop yield reduction ranging from 13.3 to 58.3% (Haj-Amor et al., 2022).

Sustainability of irrigated agriculture in the JV, particularly in the central and southern regions, is threatened by progressively increasing soil salinity. The progressive increase in soil salinity in the JV is attributed to unsustainable agricultural practices and inputs, quality of irrigation water, lack of advanced irrigation technologies and efficient drainage systems, and improper land management.

Agricultural operations in the JV are characterized by intensive open field, low tunnel, and greenhouse production with animal manure input of 10-20 t ha⁻¹ year⁻¹ and chemical fertilizer input (N, P, K) exceeding 3-7 t ha⁻¹ season⁻¹; some with high salt indices. The mismanagement of fertilizers contributed to the current unfavorable status of salinization (Ammari et al., 2013).

2.3.5 Crop yields

Jordanian part of the JV: Table 6 presents the crop yields for the year 2021 in the three areas (North Shouna, Deir Alla, South Shouna) of the Jordanian part of the JV in comparison with the maximum yields worldwide. More specifically, the crop yield for lettuce growing in winter in North Shouna is 20 ton/ha, in Deir Alla is 11.67 ton/ha and in South Shouna is 15 ton/ha while the maximum crop yield is 117.46 ton/ha. The crop yield for potato growing in winter in North Shouna is 59.84 ton/ha, in Deir Alla is 40 ton/ha, in South Shouna is 23.9 ton/ha with the maximum yield being 50.64 ton/ha. The crop yield for tomato growing in winter in North Shouna, Deir Alla and South Shouna is 40, 30 and 50 ton/ha respectively while the crop yield for tomato growing in summer in North Shouna is 30 ton/ha and in South Shouna is 40 ton/ha while the maximum yield is 475.68 ton/ha. The crop yield for peas growing in winter in North Shouna and Deir Alla is 10 ton/ha each, with the maximum yield being 5.26 ton/ha. Lastly, the crop yield for beans growing in winter in Deir Alla and South Shouna is 10 ton/ha each while the crop yield for beans growing in summer in North Shouna is also 10 ton/ha with the maximum yield being 10.04 ton/ha (Ritchie et al., 2022).

Table 6. Crop yields (2021) in the Jordanian part of the JV.

Crop	Crop yield (ton/ha)			Max yield (ton/ha) (Ritchie et al., 2022)
	North Shouna	Deir Alla	South Shouna	
Lettuce	20.00 (W)	11.67 (W)	15.00 (W)	117.46 (Puerto Rico)
Potato	59.84 (W)	40.00 (W)	23.90 (W)	50.64 (New Zealand)
Tomato	40.00 (W)	30.00 (W)	50.00 (W)	475.68 (Netherlands)
	30.00 (S)	-	40.00 (S)	
Peas	10.00 (W)	10.00 (W)	-	5.26 (Burundi)
Beans	-	10.00 (W)	10.00 (W)	10.04 (Mali)
	10.00 (S)	-	-	

** (W): winter, (S): summer

Israeli part of the JV: Table 7 presents the crop yields for the year 2021 in the Israeli part of the JV in comparison with the maximum yields worldwide. The crop yield for almonds is 1.78 ton/ha while the maximum yield is 27.31 ton/ha. The crop yield for bananas is 62.90 ton/ha while the maximum yield is 71.91 ton/ha. The crop yield for cotton is 5.44 ton/ha while the maximum yield is 5.73 ton/ha. The crop

yield for maize is 24.46 ton/ha while the maximum yield is 30.40 ton/ha. The crop yield for oranges is 49.25 ton/ha while the maximum yield is 62.15 ton/ha. The crop yield for potatoes is 48.97 ton/ha while the maximum yield is 50.64 ton/ha. The crop yield for tomato is 120.04 ton/ha while the maximum crop yield is 475.68 ton/ha. Lastly, the crop yield for wheat is 8.00 ton/ha while the maximum yield is 10.08 ton/ha (Ritchie et al., 2022).

Table 7. Crop yields (2021) in the Israeli part of the JV.

Crop	Crop yield (ton/ha)	Max yield (ton/ha) (Ritchie et al., 2022)
Almonds	1.78	27.31 (United Arab Emirates)
Bananas	62.90	71.91 (Turkey)
Cotton	5.44	5.73 (China)
Maize	24.46	30.40 (Saint Vincent and the Grenadines)
Orange	49.25	62.15 (Guyana)
Potato	48.97	50.64 (New Zealand)
Tomato	120.04	475.68 (Netherlands)
Wheat	8.00	10.08 (Ireland)

2.3.6 Potential nutrient supply and demand

The potential C, N, P, K supply and demand of the three territories of the JV was estimated using the Bio-residue/Excreta calculator (Bio-REX). Bio-REX calculates the potential fertilizer demand and the biomass nutrient fluxes from the following sources: livestock excreta/manure, biosolids from wastewater treatment plants, composting of the organic fraction of municipal solid wastes and olive mill waste water (Nikolaidis, 2011).

Jordanian part of the JV: Recycling of biomass covers the N, P and K fertilization needs. More specifically, the N demand is 3,629 ton N/yr and the potential N supply is estimated at 26,013 ton N/yr. Moreover, the P demand is 3,629 ton P/yr and the potential P supply is estimated at 7,208ton P/yr. Lastly, the K demand is 3,629 ton K/yr and the potential K supply is estimated at 12,252 ton K/yr (Figure 12).

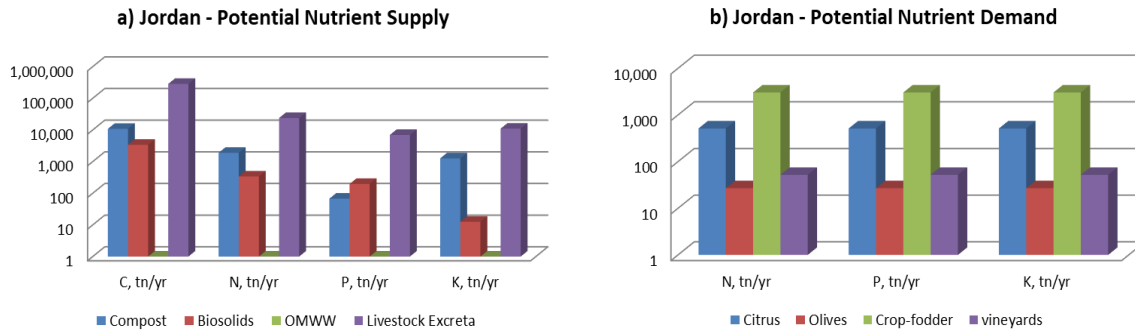


Figure 12. Potential nutrient a) Supply and b) Demand for the Jordanian part of the JV.

Israeli part of the JV: Recycling of biomass covers the N fertilization needs as the N demand is 1,701 ton N/yr and the potential N supply estimated at 5,157 ton N/yr. On the contrary, recycling of biomass doesn't cover the P and K fertilization needs. More specifically, it falls short by 25% of the P needs (P demand: 1,701 ton P/yr and potential P supply: 1,269 ton P/yr) and 27% of the K needs (K demand: 1,701 ton K/yr and potential K supply: 1,234 ton K/yr). Fertilizer demand in Israel can be satisfied by the recycling of compost and livestock excreta (Figure 13).

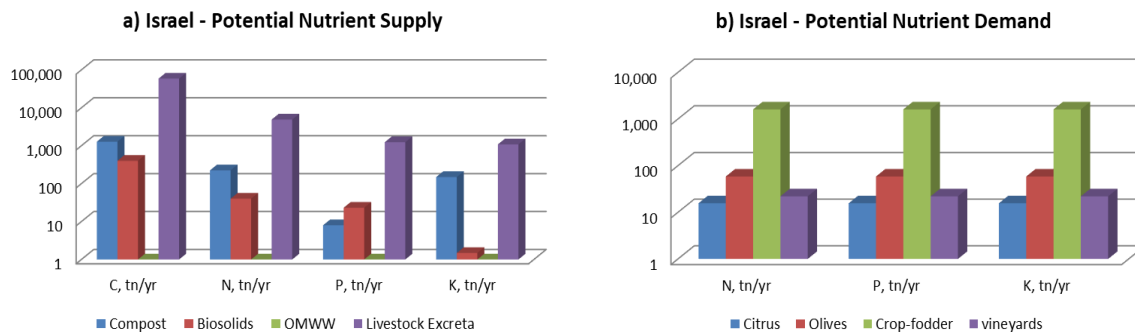


Figure 13. Potential nutrient a) Supply and b) Demand for the Israeli part of the JV.

Palestinian part of the JV: Recycling of biomass covers the N fertilization needs as the N demand is 2,090 ton N/yr and the potential N supply estimated at 3,699 ton N/yr. On the contrary, recycling of biomass doesn't cover the P and K fertilization needs. More specifically, it falls short by 34% of the P needs (P demand: 1,447 ton P/yr and potential P supply: 954 ton P/yr) and 29% of the K needs (K demand: 2,573 ton K/yr and potential K supply: 1,828 ton K/yr). Fertilizer demand in Palestine can be satisfied by the recycling of compost and livestock excreta (Figure 14).

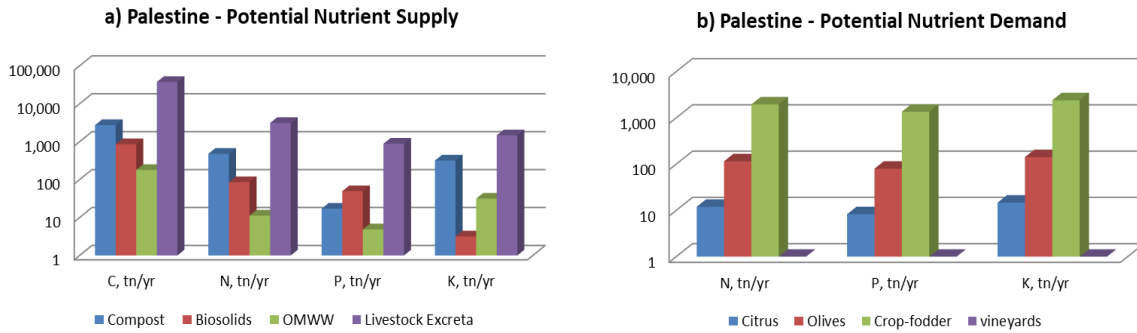


Figure 14. Potential nutrient a) Supply and b) Demand for the Palestinian part of the JV.

2.4 Ecosystem

2.4.1 Ecosystem status baseline

The Jordan Valley (JV) is a vital and diverse environment, encompassing various ecosystems, including freshwater, shrublands, drylands, agricultural and urban ecosystems in a sub-tropical climate. It serves as the biological heart of the Middle East, supporting its unique flora and fauna, and acting as an important migratory pathway for birds travelling between Africa and Europe. The JV is characterized by a wide range of bio-climatological and physical conditions supporting all human activity, vegetation, and wildlife (Kool, 2016).

The JV stands as a vital repository of freshwater ecosystems, prominently exemplified by the winding course of the Jordan River and its tributaries. These freshwater habitats play a pivotal role in sustaining the region's biodiversity, offering a sanctuary for numerous plant and animal species uniquely adapted to the aquatic environment. The Jordan River, originates from the Dan and Hasbani streams, located at the northern of Israel, and flowing into the Hula Valley, the Sea of Galilee, to then cross the JV, forming a complex network of interconnected ecosystems. These freshwater ecosystems are critical breeding grounds for various aquatic species, fostering biodiversity and supporting the delicate balance of the entire ecosystem. Endemic species, such as the indigenous fish populations and migratory birds, rely on these habitats for their survival. In addition to the Jordan River, several other freshwater ecosystems within the JV contribute to its high biodiversity. Seasonal streams and wetlands, often fed by runoff from the surrounding hills, provide dynamic environments that host a variety of flora and fauna.

Historically, the Valley of Springs and the surrounding forests served as an important habitat for a large variety of species in the region including mammals such as wild boar, foxes, jackals, and porcupines. Humans have been living in this valley from the beginning of the agricultural revolution, and it has been the cradle of urbanization for over 11,000 years. The wetlands, as an aquatic ecosystem, have been playing a major role for the biodiversity conservation in the region, which remained for the most part, intact until the 1920s when the kibbutzim (communal farming settlements) were established. The Israeli farmers drained the swamps (wetlands), turning them into agricultural land and fish farms. While many of the wetlands have disappeared from that area, fishponds provide habitats for local species and feeding stations for over a billion migrating birds from Asia to Africa in the winter and back again in the fall. Today, over 70% of the Israeli aquaculture industry is located in the Valley of Springs.

Predicted changes in ecosystem health and services are likely to be influenced by ongoing challenges such as food insecurity, water scarcity, and energy dependence. Integrated approaches that address the WEFE Nexus are essential to mitigate potential threats and ensure the sustainable management of ecosystem.

The role of ecosystems in supporting future Water, Energy, and Food (WEF) demands in the JV is critical, encompassing various aspects that are integral to the region's long-term sustainability and resilience. Healthy ecosystems support a diverse range of plant and animal species that contribute to pollination, pest control, and soil fertility. This biodiversity enhances the overall resilience of agricultural landscapes, making them less vulnerable to pests, diseases, and climate-related challenges.

Beyond their instrumental value, ecosystems in the JV hold cultural and recreational significance for local communities. Preserving these natural spaces not only sustains traditional practices and cultural heritage but also provides opportunities for recreation and tourism. This, in turn, can contribute to local economies and enhance the overall well-being of communities.

Wetlands and riparian ecosystems act as natural filters, purifying water before it enters larger water bodies. Preserving these areas is crucial for maintaining water quality, especially in the context of increasing urbanization and industrial activities. Healthy ecosystems contribute to the availability of clean water resources for both human consumption and agricultural use.

Ecosystems support sustainable resource management by providing a basis for traditional and sustainable land-use practices. Incorporating Indigenous knowledge and practices into ecosystem management helps ensure the longevity of resource utilization, without depleting essential natural assets.

2.4.2 Driver-Pressure-State-Impact-Response (DPSIR) analysis of JV

Drivers

The main drivers that affect the system in the area are climate change, population growth, land use change and pollution. The environmental pressures exerted in the JV are the result of intensive agricultural activities (agriculture, livestock and aquaculture), tourism, climate change, geogenic pollution, population, migration and invasive species. These pressures have resulted in significant impacts to the WEFE Nexus with surface water flow decline, groundwater depletion, high groundwater salinity, pollution and loss of biodiversity.

Climate change, following the more general Mediterranean trend of water resources shortages, has been projected as a serious threat for the area. The region's climate is changing, with the potential for increased droughts, higher temperatures and more extreme weather events, posing significant challenges to the preservation of ecosystem. Climatically, the JV is characterized by hot dry summers and mild wet winters, becoming progressively drier moving southward through the valley towards the Dead Sea. It is predicted that the Eastern Mediterranean will continue to face a reduction in annual precipitation, longer hot summer dry season, and shorter cool wet winter season due to climate change (Hochman et al., 2018). This change in climatic conditions for the region will have a major impact on the local instrumental value ecosystem of the Harod and Beit Shean Valleys including the Valley of the Springs. Such a dramatic change in the length of the seasons means that many crops will no longer be feasible to grow in the valley. Natural ecosystems will also be impacted as rapid changes in the climate may impact endemic species, which have

found their niche in the unique ecosystem of the JV. Rapid changes in climate, especially changes in precipitation patterns and season length may encourage the spread of generalist species, which can thrive in changing environments. Invasive species and eruptive species may push out native and endemic species, impacting the biodiversity of the region.

Population growth is affected significantly by the political instability in the region that is fueling refugee movements into the area and causing additional pressure on water, energy and food resources.

Land use distribution has been stabilized in the region to a large extent. It is not expected to have increases in the cultivated areas in Jordan and Palestine, however, there is the potential for conversion of agricultural land to urban areas in the Israeli sector. On the other hand, further intensification of agriculture in Jordan and Palestine is expected, especially if more water becomes available in Palestine for irrigation.

The main sources of pollution in the JV are wastewater from treatment plants and unsewered areas, fertilizer, pesticide and herbicide pollution from agriculture, urban solid waste disposal sites, aquaculture water use, and small “industrial” facilities mostly related to agriculture. In addition to the above, the impact to water quality due to saline bedrock, which increases the chloride concentration in the irrigation water, all provide a complete picture of the anthropogenic and geogenic pollution in water and soil (Royal HaskoningDHV and MASAR, 2015; Kool, 2016).

Pressures and impacts

Surface water flow declines have been observed in the Jordan River and the discharge to the Dead Sea has been decreasing dramatically leading to the water level declines over the years. This decline is primarily due to withdrawals of water above the Sea of Galilee and diversion for other uses. The Dead Sea, a critical component of the JV ecosystem, faces severe threats due to declining surface water flow, particularly from the Jordan River. Extensive water withdrawals upstream, especially above the Sea of Galilee, for agriculture, domestic, and industrial uses have dramatically decreased the water reaching the Dead Sea, leading to a rapid decline in its water levels (Ghazleh et al., 2011; Oroud, 2023). This decline has exposed large areas of the Sea’s bed, disrupted its unique saline ecosystem, caused dangerous sinkholes, and posed risks to surrounding infrastructure. The shrinking sea also threatens the tourism industry, vital for local economies, and challenges mineral extraction operations. Apart from the surface water flow declines, a dramatic **groundwater level decline** has been observed due to **over abstraction** (approximately 3 times the amount of recharge). Recent studies have shown that this extreme overexploitation has led to average groundwater level declines of up to 10 m/yr in some areas and 4-5 m/yr in most well-field areas (Al Absi et al., 2020). The surface and groundwater flow declines are described in detail in the “Water” section.

Point sources such as WWTPs and industries, and non-point sources including fertilizer, pesticide and herbicide pollution from agriculture and livestock farming have impacted on the water quality of surface and groundwater resources. In the Jordanian part of the JV, there are 6 operating WWTPs (Al-Baqaa, As-Salt, As-Samra, Fuheis, Kufranja and Wadi Al Seer) while in the Israeli part of the JV there are 3 (Lower Tiberia (Bitanyia), Beit-Shean, and Jerusalem (east)/Nabi-Mosa). In Israel almost 100% of the wastewater generated is collected and treated in centralized treatment plants, and roughly 90% is then reused for irrigation of agricultural crops. In the JV area though, all Israeli communities within the West Bank are not

connected to central sewage collection systems, and about 0.5 MCM/year of wastewater flows to the environment, or deep percolates into the ground. On the contrary, in the Palestinian part of the JV, the wastewater treatment levels are extremely low. Wastewater collection and treatment was neglected since higher priority is given to securing a safe water supply and protecting reliable resources for domestic use. All the Palestinian communities lack wastewater collection networks and rely on cesspits for the disposal of wastewater, with the exception of Jericho (Kool, 2016). Regarding the industries, in the Jordanian part of the JV, there are industries related to agriculture (industries supplying greenhouses, on-farm water management equipment and agricultural inputs), construction (quarries), metal and food processing, crafts and handicrafts processing minor agricultural products like grains, olives and dates (Kool, 2016). In the Israeli part of the JV, there are industries related to agriculture, waste and sewage, metals, energy, and minerals (Israeli Ministry of Environmental Protection, 2023). In the Palestinian part of the JV, there are industries related to agriculture (crop production and livestock farming), tourism (religious and archaeological sites), food processing and packaging (olive oil production, packaging of fruits and vegetables), handicrafts and artisanal goods (pottery, woven goods, embroidery), construction materials (extraction of stones and gravel) and renewable energy initiatives (small solar energy projects).

Non-point sources include agricultural return flows polluted with phosphates, salt, nitrates, pesticides, herbicides and chemical fertilizers, and animal husbandry which generates pollution sources in terms of manure (solid and fluid) and animal carcasses, which are potential threats for the environmental and public health (Kool, 2016). Ammari et al. (2013) present the type and amounts of fertilizers used in JV in 2008 and 2009. Farmers in the Jordan Valley commonly use a balanced NPK fertilizer with a 20-20-20 ratio, applying it at rates of 80-80-80 kg per hectare for nitrogen (N), phosphorus (P) and potassium (K) (Mashatleh et al., 2024).

The presence of saline bedrock often leads to the **development of saline groundwater**, affecting both the quality and availability of water resources (Hötzl et al., 2009). In conjunction with saline bedrock, the surrounding soil may also become saline (Richards, 1954). Soil degradation resulting from salinity is a major environmental constraint with severe adverse impacts on soil productivity, agricultural sustainability and food security (Ammari et al., 2013). **Soil salinization** can negatively impact plant growth and soil fertility (Sheferia et al., 2021). More specifically, Ammari et al. (2013) found out that in the southern and central regions of the valley (81% and 75% of top-soils were saline, respectively) compared to the northern JV where only 37.5% of soils were saline. Results showed that 17.5% and 28.6% (46.1% in total) of saline top-soils in the northern and southern JV, respectively, were strongly saline, whereas 35% of saline soils in the central JV were moderately saline. In sub-soils of the three regions of the valley, the majority of saline soils were moderately saline.

Highly Saline and Sodic water qualities can cause problems for irrigation, depending on the type and amount of salts present, the soil type being irrigated, the specific plant species and growth stage, and the amount of water that is able to pass through the root zone (Sheferia et al., 2021). The combined effects of saline bedrock and saline soil can disturb local ecosystems. Native flora and fauna may struggle to adapt to the changing conditions, leading to shifts in biodiversity and potential ecological imbalances. Monitoring and conservation efforts are crucial to mitigate the impact on the environment.

The impacts on the water quality of KAC, JR, the Jordanian dams and the groundwater resources in Jordan, Israel and Palestine are described below.

Water quality of King Abdullah Canal and Jordan River: The requisite data of various water quality parameters (based on monthly analysis) were obtained from Royal Scientific Society (RSS) between January 2012 and December 2012. Each of the surface water samples was analyzed for 12 parameters such as pH, electrical conductivity, total suspended solids, bicarbonate, chloride, sulphate, nitrate, fluoride, calcium, magnesium, sodium and potassium. The mean, minimum and maximum values of different selected physico-chemical parameters of the surface water samples of the study area are shown in Table 8.

Regarding the pH, it varies from 7.53 to 8.79 which indicates that water is slightly alkaline. 99% of mean samples did not exceed the permissible limit prescribed by WHO. Regarding electrical conductivity (EC), the values in the canal varied from 585 $\mu\text{S}/\text{cm}$ in the upper part of the canal to 17,450 $\mu\text{S}/\text{cm}$ among the stations in the Jordan River. The value of conductivity was recorded lowest in JV1 at KAC and maximum in JR1 at Jordan River which shows poor quality of water according to the classification of WHO. The results show that EC values of river water are increasing from upstream towards downstream. Prescribed standard values by WHO for EC is 1,400 $\mu\text{S}/\text{cm}$. The value of EC is extremely high in Jordan River which exceeded the WHO maximum limit. Regarding the total suspended solids, the TSS of the river water samples range from 2 mg/L at KAC to 1,518 mg/L at JR, with a mean value of 134 mg/L. Regarding nitrates, $\text{NO}_3\text{-N}$ in the river water samples of KAC and JR ranged from 0.23 mg/L to 12.70 mg/L with a mean value equal to 3.5 mg/L which falls below the maximum limit for the Jordanian drinking water standards and WHO, which is 50 mg/L. The bicarbonate (HCO_3^-) was found to be the most abundant and varied in concentration from 114 mg/L in JV4 to 716 mg/L in JR3 with an average concentration of 297.1 mg/L. All the samples of JV were found to be within the safe limits of Jordanian Standards (JS) while the JR samples exceeded the JS of 100–500 mg/L. Regarding chloride, its concentration was found to be within the permissible limits of JS in all sites of KAC except in the JR where a high concentration within the range of 1,688.5 to 3,304 mg/L is found. The Cl^- was found to be higher than the prescribed limit (250 mg/L) for JR. In general, the chloride concentration is an indicator of pollution by sewage.

Regarding sodium, its concentration has a range between 42 mg/L at KAC to 2,510 mg/L at JR with an average value of 514.9 mg/L. According to the WHO guideline, the maximum admissible limit is 200 mg/L. All the surface water samples in the KAC were found within the maximum permissible limit while all the samples from JR exceeded the maximum permissible limit. Regarding magnesium, its concentration is within the permissible limit of WHO in KAC, while for JR the Mg^{2+} concentrations are above the permissible limits. The increase in Mg^{2+} concentration at JR may be due to sewage disposed to that sampling location from Zarqa River. Regarding the calcium concentration, Ca^{2+} was found between 39.2 and 565 mg/L with an average value of 167.4 mg/L. The increased value of calcium was found on the JR samples due to the mixing with Zarqa river surface water. Regarding the potassium concentration, K^+ is varying from 4 to 148 mg/L with an average value of 34 mg/L. Potassium content in the JR water samples found to be higher than the prescribed limit of JS and WHO which is 12 mg/L. Regarding fluoride, F^- in KAC and JR range from 0.25 to 1.19 mg/L, which is within the permissible limit given by WHO and JS (1.5 and 2 mg/L respectively). Lastly, the sulphate of the surface water samples varies from 51.7 to 2,261 mg/L. The average concentration of the SO_4^{2-} is 624.2 mg/L which exceeds the acceptable limit of 250 mg/L. All KAC samples are within the permissible limit of JS and WHO Standards while all the JR samples exceed the permissible limit which could be due to discharge from waste disposal, domestic waste and untreated sewage (Al-Mashagbah, 2015).

According to the Jordanian Standards (WAJ, 1990), the guidelines for drinking water quality (WHO, 2022) and the relative weights of each physico-chemical parameter, the monthly calculated Water Quality Index (WQI) in the different sampling sites assessed the suitability of KAC and JR water body for drinking purposes (Table 9). The classification of WQI values for human consumption is presented by Ramakrishnaiah et al. (2009) and Chellali et al. (2021).

Only one single site's water quality can be described as excellent and this is site's JV4 (KAC). The water quality of sites JV1, JV6 and JV7 (KAC) can be characterized as good water. The water quality of sites C2 and CX (KAC) is classified as poor water. In addition, site JR2 (JR) is classified as very poor water. However, all these sites can be used for domestic purposes after disinfection procedure. Lastly, the sites JR1 and JR3 (JR) have water unfit for human consumption.

It is evident that the quality of water in the Lower Jordan River has severely deteriorated. While the headwaters upstream are unaffected, the lower sections of the river consist primarily of untreated sewage and agricultural return flows, groundwater seepage, as well as brackish water from springs diverted into the river away from Tiberias Lake (Royal HaskoningDHV and MASAR, 2015). Additional information on the water quality of the Lower Jordan River is presented by Segal-Rozenhaimer et al. (2004) and Hillel et al. (2015).

Table 8. Water quality parameters for King Abdullah Canal and Jordan River. JV1, JV4, JV6, JV7, C2 and CX are samples from King Abdullah Canal and JR1, JR2 and JR3 are samples from Jordan River (Al-Mashagbah, 2015).

Parameter	Sampling points										mean	min	max
	JV1	JV4	JV6	JV7	C2	CX	JR1	JR2	JR3				
pH	8.30	8.32	8.19	8.09	8.53	8.49	7.85	7.82	7.89	8.2	7.53	8.79	
EC	992	1143	1036.4	1057	2029.4	2083.5	11427	5825.5	11290	4098	585	17450	
TSS	41.00	7.96	33.00	47.36	83.71	66.75	430.27	124.4	371.82	134.0	2.00	1518	
NO ₃ -N	1.10	0.23	0.63	0.63	7.36	7.29	6.92	2.13	5.41	3.5	0.23	12.70	
HCO ₃	286.0	126.7	206.0	205.6	291.1	293.0	437.27	384.1	444.45	297.1	114.	716.00	
Cl	123.0	257.7	178.3	190.1	360.5	376.7	3304	1688.5	3188.4	1074.2	63	5528	
Na	78.00	118.0	94.12	99.61	224.9	235.3	1543.1	712.9	1528.4	514.9	42.0	2510.0	
Mg	34.00	31.68	31.25	31.64	44.05	46.62	561.64	320.0	541.27	182.5	19.0	1181.0	
Ca	75.00	44.13	58.14	58.12	117.3	119.4	397.55	238.4	398.36	167.4	39.2	565.00	
K	7.00	7.19	6.88	7.18	25.16	26.04	96.42	35.55	94.13	34.0	4.00	148.00	
F	0.60	0.25	0.40	0.41	0.43	0.43	1.19	0.58	1.17	0.6	0.25	1.19	
SO ₄	116.00	51.70	77.40	79.00	217.00	214.00	2261.00	346.00	2256.00	624.2	51.70	2261.00	

** All parameters are in mg/L except EC in $\mu\text{S}/\text{cm}$ and pH in SU.

Table 9. WQI for KAC and JR (Al-Mashagbah, 2015).

Site code	Sampling point	WQI	Water quality
JV1	King Abdullah Canal	60.48	Good water
JV4	King Abdullah Canal	46.66	Excellent water
JV6	King Abdullah Canal	53.12	Good water
JV7	King Abdullah Canal	56.48	Good water
C2	King Abdullah Canal	104.28	Poor water
CX	King Abdullah Canal	101.83	Poor water
JR1	Jordan River	542.08	unsuitable for drinking
JR2	Jordan River	226.14	Very poor water
JR3	Jordan River	522.19	unsuitable for drinking

Water quality of Jordanian dams: The water chemistry parameters and indices for six dams (Al Kafraïn, Al Waala, KTD, Mujib, Sharhabil bin Hasna (Ziqlab) and Shuaib) located in Jordan (Figure 15) are presented in Table 10. The key water quality parameters (Electrical conductivity, chloride, sulphate, bicarbonate, sodium, calcium and magnesium) were derived from the analysis of various water samples from 2015 to 2021. The calculated indices were the sodium adsorption ratio (SAR), the soluble sodium percentage (SSP), the residual sodium carbonates (RSC), the permeability index (PI), the Kelley ratio (KR), the magnesium adsorption ratio (MAR) and the total hardness (TH). Lastly, irrigation water was categorized using the US Salinity Laboratory (USSL), Wilcox, Doneen, Piper and Gibbs diagrams.

The irrigation water quality guidelines for Jordan (MWI, 2014) are adopted from the FAO guidelines (Ayers and Westcot, 1985). According to the FAO guidelines (restriction on use), all the water samples of Al Kafraïn dam and KTD would have no restriction on use and Al Waala dam would have Slight to Moderate. Regarding Mujib dam, 50% of the water samples would have no restriction on use while the remaining 50% would have Slight to Moderate. Regarding Sharhabil and Shuaib dams, 96% of the water samples would have no restriction on use.

According to the classifications of irrigation water based on the USSL diagram (Richards, 1954), for Al Kafraïn, Sharhabil and Shuaib, 90.6, 72.7 and 92.7% of water samples, respectively, fall under the C3S1 category (high salinity, low sodium hazard). Moreover, 93.8, 61.8, and 27.3% of Al Waala, Mujib, and Sharhabil samples, respectively, are categorized as C2S1 (medium salinity, low sodium hazard). In the case of KTD, 75.3% of water samples fall under the C3S2 (high salinity, medium sodium hazard).

Most of the water samples have high salinity and low sodium risks. Long-term irrigation with such water can lead to salt accumulation in the soil, harming both soil health and crop production. Poor water quality can lead to health problems for local communities and disrupt aquatic ecosystems.

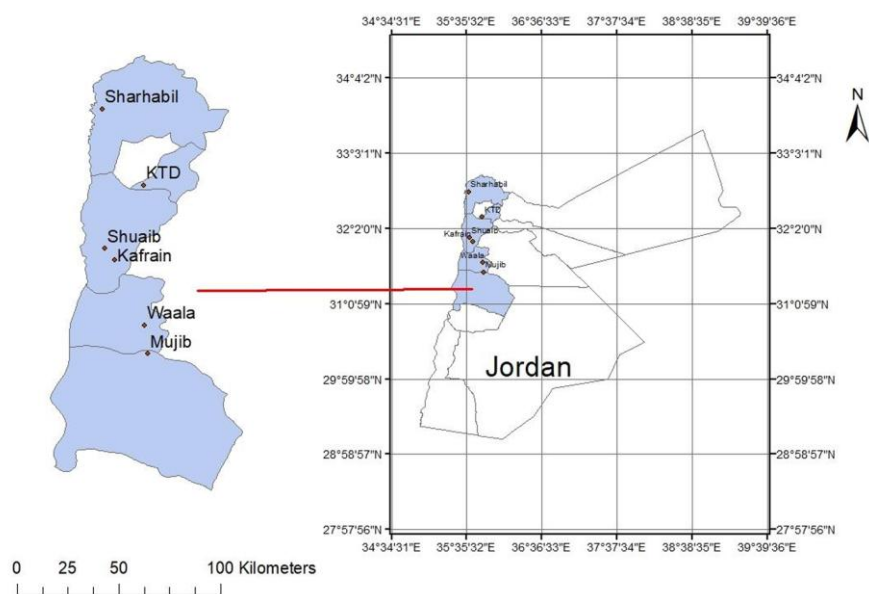


Figure 15. Location map of the Jordanian dams (Gharaibeh et al., 2024).

Table 10. Average \pm standard deviation of water chemistry parameters and indices for the Jordanian dams (Gharaibeh et al., 2024).

	Al Kafraïn	Al Waala	KTD	Mujib	Sharhabil	Shuaib
EC	0.95 \pm 0.15	0.39 \pm 0.1	1.87 \pm 0.19	0.76 \pm 0.32	0.81 \pm 0.09	1.1 \pm 0.24
Cl ⁻	147.75 \pm 38.59	33.76 \pm 15.47	309.56 \pm 43.34	83.75 \pm 52.59	79.64 \pm 21.14	146.37 \pm 45.27
SO ₄ ²⁻	124.98 \pm 86.02	17.13 \pm 20.94	216.22 \pm 57.7	106.85 \pm 77.87	62.83 \pm 81.64	113.8 \pm 99.23
HCO ₃ ⁻	140.04 \pm 51.66	137.33 \pm 44.8	271.75 \pm 40.25	165.6 \pm 46.05	272.61 \pm 51.97	227.64 \pm 52.9
Na ⁺	87.31 \pm 23.86	32.57 \pm 11.48	230.44 \pm 33.57	64.69 \pm 32.39	45.36 \pm 15.31	87.94 \pm 28.13
Ca ²⁺	44.24 \pm 17.75	32.14 \pm 9.96	90.6 \pm 11.6	55.34 \pm 23.11	53.05 \pm 15.6	70.8 \pm 15.15
Mg ²⁺	38.31 \pm 12.76	8.71 \pm 11.03	39.54 \pm 17.77	23.11 \pm 15.28	43.07 \pm 12.17	40.2 \pm 18.65
SAR	2.37 \pm 0.74	1.33 \pm 0.35	5.15 \pm 0.9	1.83 \pm 0.5	1.14 \pm 0.45	2.1 \pm 0.67
SSP	42.8 \pm 9.03	41.43 \pm 7.04	58.15 \pm 5.65	39.47 \pm 6.02	25.22 \pm 6.74	37.54 \pm 8.27
RSC	-2.97 \pm 0.99	-0.04 \pm 0.8	-3.43 \pm 1.93	-1.94 \pm 1.64	-1.7 \pm 1.01	-3.04 \pm 1.63
PI	57.84 \pm 8.38	80.84 \pm 13.45	67.73 \pm 6.94	61.7 \pm 9.82	50.38 \pm 6.94	54.71 \pm 8.97
KR	0.75 \pm 0.29	0.65 \pm 0.18	1.33 \pm 0.32	0.62 \pm 0.17	0.34 \pm 0.18	0.59 \pm 0.22
MAR	58.75 \pm 13.92	26.5 \pm 17.86	40.37 \pm 10.31	38.79 \pm 13.67	57.17 \pm 11.19	46.28 \pm 12.42
TH	268.42 \pm 56.59	116.22 \pm 51.04	389.39 \pm 76.88	233.58 \pm 96.94	310.08 \pm 54.63	342.65 \pm 92.38

** Abbreviations and units: EC, Electrical conductivity (dS/m); Cl⁻, SO₄²⁻, HCO₃⁻, Na⁺, Ca²⁺ and Mg²⁺ in mg/L; SAR, sodium adsorption ratio; SSP, the soluble sodium percentage; RSC, residual sodium carbonates; PI, permeability index; KR, Kelley ratio; MAR, magnesium adsorption ratio; TH, total hardness. TH is in mg/L, all the other index concentrations in meq/L.

In terms of nitrate concentrations (NO₃-N), the Al Kafraïn dam has nitrate levels of 4.38 \pm 3.56 mg/L, Al Waala dam 1.48 \pm 2.97 mg/L, KTD 10.16 \pm 3.14 mg/L, Mujib dam 0.80 \pm 0.62 mg/L, Sharhabil dam 1.12 \pm 0.47 mg/L and Shuaib dam 11.43 \pm 5.58 mg/L. As observed, KTD is one of the most nitrate-concentrated dams in Jordan due to its role in wastewater storage (from As Samra WWTP) and runoff collection (from Zarqa

river). In terms of ammonium concentrations ($\text{NH}_4\text{-N}$), the Al Kafraïn dam has nitrate levels of 0.90 ± 1.49 mg/L, Al Waala dam 0.45 ± 0.65 mg/L, KTD 0.43 ± 0.55 mg/L, Mujib dam 0.34 ± 0.22 mg/L, Sharhabil dam 0.54 ± 0.89 mg/L and Shuaib dam 1.10 ± 3.73 mg/L. In terms of phosphate concentrations ($\text{PO}_4\text{-P}$), the Al Kafraïn dam has nitrate levels of 0.16 ± 0.24 mg/L, Al Waala dam 0.14 ± 0.18 mg/L, KTD 1.96 ± 0.85 mg/L, Mujib dam 0.09 ± 0.15 mg/L, Sharhabil dam 0.08 ± 0.12 mg/L and Shuaib dam 0.58 ± 0.38 mg/L.

According to the Piper diagram (cation and anion composition), Al Kafraïn shows mixed and sodium-type cations, and mixed and chloride-type anions (mixed and NaCl-type), suggesting that the water is influenced by the dissolution of minerals containing sodium and chloride, such as halite. The presence of mixed cations indicates a combination of different mineral inputs, making the water chemistry relatively complex. Al Waala shows mixed cations and calcium type, as well as bicarbonates dominance (Ca- HCO_3 type). Al Waala water is likely to be influenced by the weathering of carbonate rocks, such as limestone and dolomite, that release calcium and bicarbonate ions into the water.

KTD shows sodium, mixed anion and chloride-type anions (Na-Cl type). This points to the influence of evaporite minerals like halite or the presence of saline water sources. The dominance of sodium and chloride ions suggests that the water is influenced by the dissolution of sodium chloride minerals. The high levels of salinity and sodicity may be the result of mixing treated wastewater with runoff as KTD receives freshwater from the Zarqa River and effluent from the As Samra WWTP.

Mujib and Shuaib show mixed cations and anions (mixed type), reflecting a diverse range of geological sources contributing to water chemistry. The mixed nature suggests that the water receives inputs from various mineral dissolution processes, including silicate and carbonate weathering, which introduce a variety of cations and anions. This complexity often points to heterogeneous geological formations in the catchment area.

Finally, water from Sharhabil Dam is dominated by magnesium and mixed cations, and bicarbonate and mixed anions (Ca- HCO_3 and mixed type). The presence of magnesium alongside calcium indicates that the water interacts with both carbonate and silicate minerals. The dominance of bicarbonates suggests significant weathering of carbonate rocks, but the mixed-cation type also points to contributions from other mineral sources.

According to Gibbs diagram (processes controlling water chemistry), the results indicate that water samples from all dams fall within the rock (weathering) dominance zone. This suggests that rock weathering or interactions with rocks are the major sources controlling the chemistry of water in all dams. The water samples from KTD exhibited an inclination towards the evaporation-dominant zone, suggesting an increase in sodium and chloride ions, leading to higher total dissolved solids because of water contamination. Therefore, surface water chemistry is influenced by geological conditions and chemical weathering of various rocks (Gharaibeh et al., 2024).

Water quality of groundwater in Jordan: The water quality parameters (pH, EC, water temperature, calcium, magnesium, sodium, potassium, chloride, sulphate, bicarbonate) of deep wells in the Jordanian part of JV including Mukheibeh, North Shouna, Manshiya, Waqqas, Abu Zigan, JICA, Rama and Hisban thermal wells (Figure 16) are presented in Table 11.

Wells from Yarmouk to Deir Alla areas have water with salinities (expressed in electrical conductivity (EC) units) of 701–1,932 $\mu\text{S}/\text{cm}$. The pH ranges from 6.78 to 7.45. The groundwater from Deir Alla and Abu Zighan areas have EC between 4,310 and 16,350 $\mu\text{S}/\text{cm}$. The pH values range from 6.23 to 6.93. Wells from Deir Alla to the Dead Sea area have water ranging from 4,170 to 8,680 $\mu\text{S}/\text{cm}$, with temperatures ranging from 31.5 to 35.3 $^{\circ}\text{C}$. In addition, the bicarbonates (HCO_3^-) content is high ranging from 13.5 to 20.7 meq/L (Salameh and Tarawneh, 2017).

According to the FAO guidelines by Ayers and Westcot (1985) regarding the restriction on use of water for irrigation purposes, the water of these areas (Yarmouk to Dead Sea) has some restriction on use because the EC is higher than 700 $\mu\text{S}/\text{cm}$. The water in Northern Jordan (except from North Shuna) has Slight to Moderate restriction on use while the water in Middle and Southern Jordan has Severe restriction on use. Irrigation with highly saline water can cause soil salinization and can affect growth, yield, nutrient availability and soil properties (Sheferia et al., 2021).

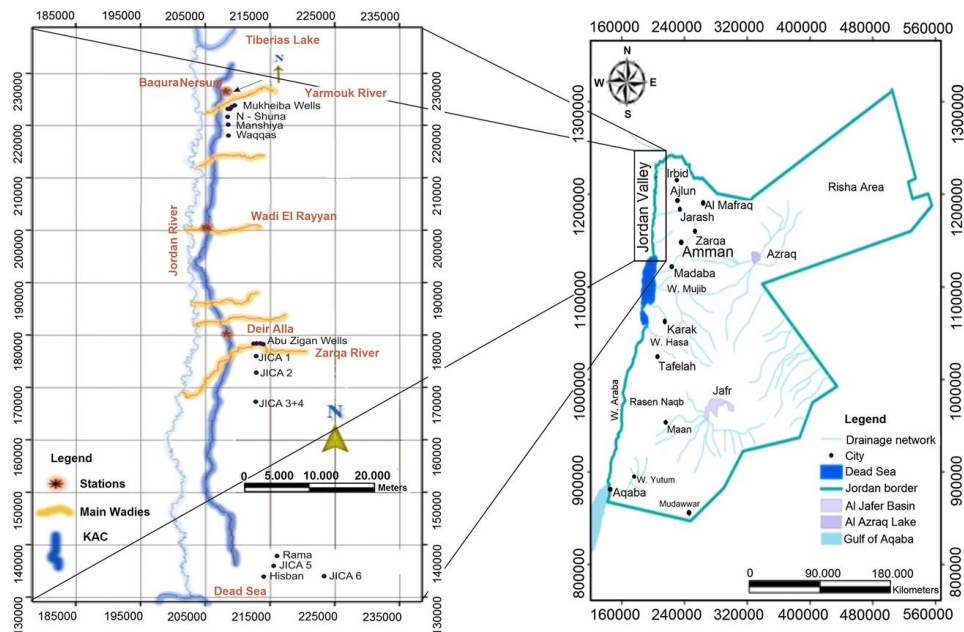


Figure 16. Location map of groundwater sampling sites in Jordan (Salameh and Tarawneh, 2017).

Table 11. Water quality parameters for deep wells in the Jordanian part of JV (Salameh and Tarawneh, 2017).

Area	Sampling site	EC	pH	Temp °C	Ca ²	Mg ²	Na ⁺	K ⁺	Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	
Area												
North	Mukheibeh 2	807	7.10	28.80	4.80	2.39	1.67	0.08	1.56	1.14	5.11	
	Mukheibeh 4	809	7.12	28.14	4.80	2.47	1.68	0.08	1.65	1.19	5.11	
	Mukheibeh 8	701	7.45	44.90	3.40	1.65	2.32	0.13	1.82	0.58	4.64	
	Mukheibeh 7	752	7.38	38.50	4.05	2.06	1.90	0.10	1.67	0.51	5.04	
	North Shuna	1932	6.95	28.60	5.05	3.79	10.00	0.86	6.88	0.01	13.92	
	Manshiya 1	744	6.78	48.40	3.75	2.88	1.46	0.05	1.23	0.97	5.29	
	Waqgas 2	766	6.97	40.90	3.35	2.55	2.19	0.10	1.55	0.54	5.25	
Middle	Abu Zigan 3	7820	6.93	28.3	27	10	51.25	na	48.86	27.07	18.11	
	Abu Zigan 2	6590	6.59	0.00	17.5	0.04	30.27	na	35.93	29.35	17.51	
	Abu Zigan 4	13,390	6.61	28.60	37.0	19.00	92.37	na	91.97	34.96	23.40	
	Abu Zigan 5	7020	6.35	29.10	35.0	12.00	na	na	36.65	36.75	17.71	
	Abu Zigan 8	4880	6.23	28.00	29.0	8.00	18.76	na	20.12	25.61	17.91	
	Abu Zigan 7	16,350	6.57	27.80	48.0	5.00	119.80	na	114.25	47.58	26.67	
	Abu Zigan 12	4310	6.43	27.20	14.14	8.08	na	na	22.29	13.23	11.27	
	Abu Zigan 13	8320	6.33	27.20	36.00	5.00	53.60	na	50.30	5.71	18.11	
	Abu Zigan 14	16,120	6.24	26.80	39.0	40.00	na	na	140.94	26.54	17.56	
	Abu Zigan 16	13,750	6.44	26.80	35.0	16.00	0.00	na	100.66	26.19	24.85	
	JICA 1	8550	6.38	36.3	37.15	10.4	51.4	4.2	50	34.3	17.16	
	JICA 2	14,760	6.47	31.9	46.69	16.6	104	6.5	116	36.34	26.62	
	JICA 3	8080	6.61	27.5	33.5	13	51.6	3	45.3	37.96	16.44	
	JICA 4	12,760	6.62	31.7	44.86	12.8	96.5	5.5	88.7	46.69	24.38	
	South	JICA 5	8680	6.12	35.3	22.94	11.98	57.75	4.5	64	11.17	20.72
		JICA 6	7970	6.16	31.5	21.72	10.25	52.1	4.5	56.4	11.87	19.16
Rama		4250	6.69	33.5	10.4	6.2	40.29	3.4	29.16	7.65	18.02	
Hisban thermal		4170	6.48	31.8	12.8	7	24.38	2.46	26.95	7.93	13.49	

**EC is in $\mu\text{S}/\text{cm}$, all others in meq/L. All wells have H₂S smell, NO₃ in most wells is not detected and in few, in Abu Zigan area, generally below 10 mg/L, na not analyzed.

Water quality of treated wastewater in Israel: As mentioned, the majority of wastewater generated through water consumption in the industrial and domestic sectors in Israel is collected and treated in centralized systems and then reused for irrigation of agricultural crops. Irrigation of treated wastewater in the JV area of interest originates from 3 wastewater treatment plants. Details about the quality (pH, BOD, COD, NH₄, TKN, TP, TSS, fats, oils and grease, Cl, Ca, Mg and Na) of wastewater inflows and treated wastewater outflow, along with general plant characteristics are presented in Table 12 (NPA, 2018).

Table 12. Water quality in treatment plants within the JV area of interest.

Name of Plant	Bitaniya/Lower Tiberia	Beit Shean	Jerusalem (east)/Nebi Mosa
Technology	Activated Sludge	Activated Sludge	Extended Aeration
Drainage Basin	Yavniel River	Bazak River	Ogg River

Quantity treated in 2018 (1000 CM/yr)	3,244	3,589	9,004
Quality parameters of wastewater inflow (and treated wastewater outflow)			
pH	7 (7.8)	7.33 (7.55)	-
BOD	761 (8.2)	593.76 (16.3)	340 (22)
COD	1,874 (48.3)	1,306.61 (101.4)	858 (45)
NH ₄	62 (4.5)	44.44 (31)	51.40
TKN	105 (8)	75.8 (25.6)	69.5 (69.3)
TP	22.7 (8.4)	13.24 (6.3)	9.40
TSS	863 (3.5)	534.51 (22.5)	444 (24.5)
Fats, oils and grease	183.0	519.9	87.0
Cl	361 (366.4)	364.45 (339.9)	157 (150.2)
Ca	-	131 (107.5)	-
Mg	-	47.7 (40.7)	-
Na	264 (201.7)	234.28 (186.5)	116 (105.8)

**The NPA regularly monitors 40-50 quality parameters. This table presents those that were monitored and recorded in 2018 in the 3 plants of the JV area. All parameters are in mg/L except for pH.

Water quality of natural water resources in Israel: Water quality in the 3 sub-basin aquifer system (Eastern Mountain, Northeastern Mountain and Lower Galilee) surrounding the JV area of interest is very heterogeneous. The groundwater extraction is generally of good quality, whereas the spring flow discharge is predominantly saline (Figure 17).

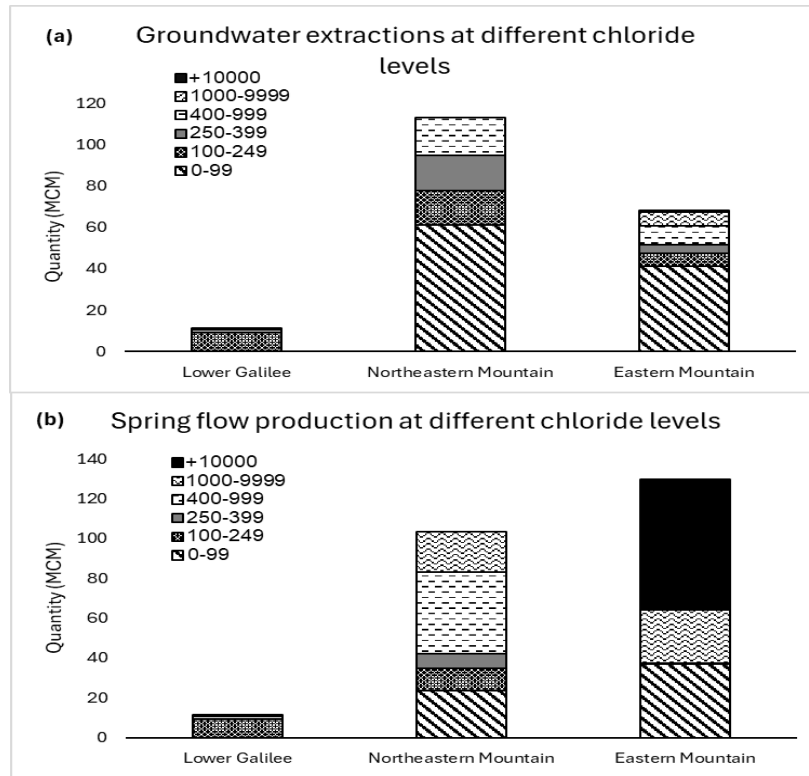


Figure 17. Production of water from natural resources in Israel at different chloride levels, (a) Groundwater extractions and (b) Spring flows.

Zooming into the JV area of interest, sampling of three representative groundwater wells in the Lower Galilee sub-basin in the JV area demonstrates a sharp increase in both chloride and nitrate levels over time (Figure 18). These salinization processes are primarily attributed to agricultural activities and unregulated wastewater discharge upstream. Further east, in the Valley of Springs area of the JV, relying on Northeastern sub-basin water, reported chloride level for a representative well in 2020 was 604 mg/L, and twice as much then the level measured in the 1970s. In another well, chloride levels are mostly stable at 70 mg/L. The water quality in the springs ranges from 306 to 1195 mg/L of chlorides, which represents an increase of 60 to 320 mg/L compared to levels measured in the 1950s. Nitrate levels in the JV area overlying the Northeastern Mountain aquifer range in between 15 and 30 mg/L (HS, 2023).

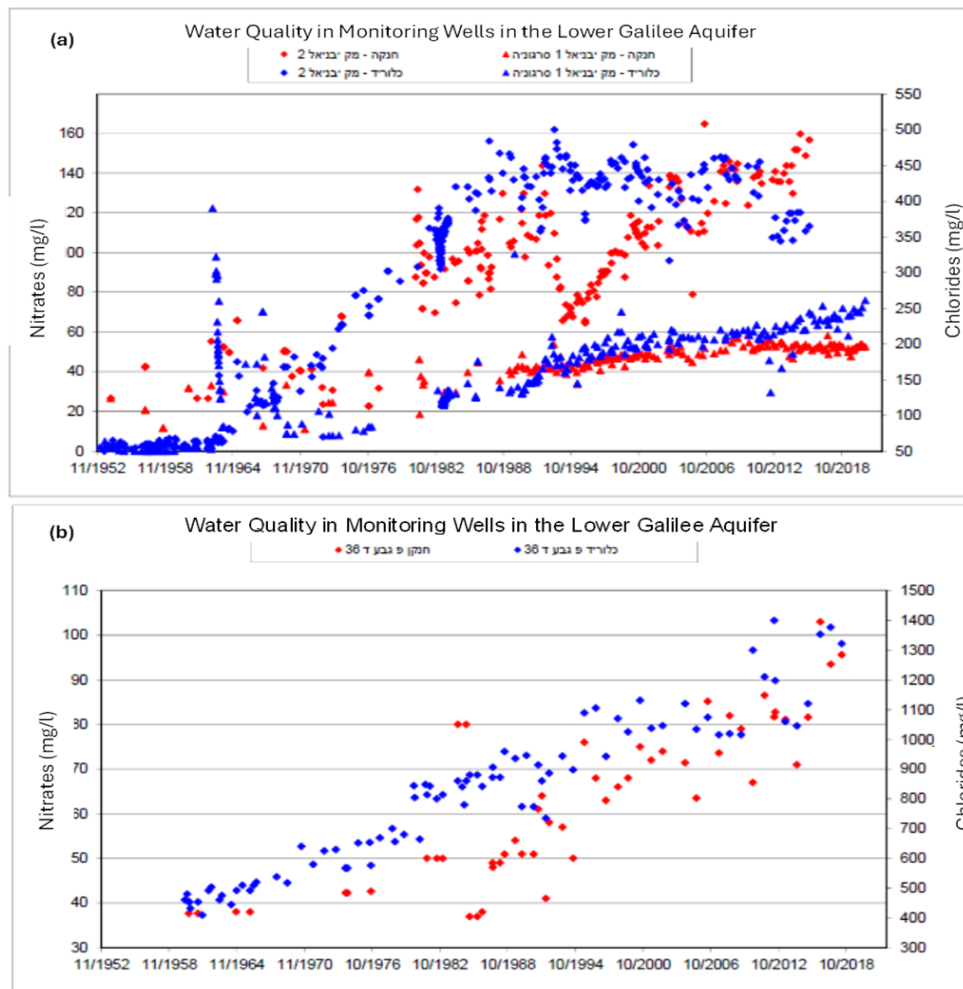


Figure 18. Chloride (blue) and Nitrate (red) levels in representative wells in the Lower Galilee aquifer, (a) Wells located on the northwest boundary of the JV area of interest and (b) Well located in the Valley Harod of the JV area of interest (HS, 2023).

Water quality of groundwater in Palestine: Although groundwater quality in the West Bank is generally acceptable, localized high concentrations of nitrates and chlorides have been identified. Elevated nitrate concentrations in the groundwater and spring water of the West Bank are of increasing concern. Approximately 20% and 30% of the samples in 2005 and 2009, respectively, contain nitrate concentrations above the Maximum Allowable Concentration of 50 mg/L (Figure 19) of Palestinian and WHO guidelines (PWA, 2013).

The areas with the most elevated nitrate concentrations are areas characterized by heavy agricultural activities. Other anthropogenic influences are from nitrogen fertilizers, pesticides, manure and animal farms. However, nitrate contamination in populated areas, where no agricultural activities exist, is attributed to leaking septic and sewer systems. Overall, the combination of poor wastewater facilities, uncontrolled intensive chemical fertilizers use for agriculture, wastewater flowing from Israeli settlement

and the aquifer vulnerability (karstic aquifers) are causing nitrate contamination levels to rise. In addition, untreated wastewater flowing from Israeli settlement into the West Bank contains industrial wastewater which negatively affect groundwater quality.

Data on groundwater quality in West Bank are limited to selected wells located in the Jordan Valley, Qalqiliya and Tulkarm. In Tulkarm and Qalqiliya, water testing shows that the nitrate concentration exceeds the WHO allowable limit (50 mg/L) in some wells, while the chloride concentration in these wells remains within the acceptable limits. Most of the wells in the Jordan Valley have high concentrations of chloride, exceeding the acceptable guideline set by the WHO (250 mg/L) while the nitrate concentration is quite low.

Brackish water exists in the West Bank in Jericho Governorate. Figure 20a, b, c is a contour map for the EC, the nitrate and chloride concentration for the Jericho Governorate respectively. Figure 20 shows that the chloride and EC increase while going east with chloride values above 1,000 mg/L and EC values above 5,000 mS/cm. Based on this figure, it is also clear that brackish water exists in Jericho Governorate especially in areas next to the Jordan River.

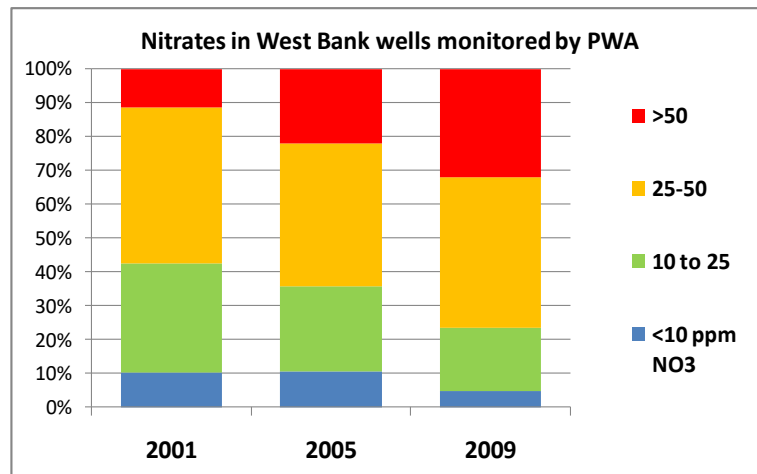


Figure 19. Percentage of wells with nitrates in excess for West Bank (PWA, 2013). The WHO allowable limit is 50 mg/L (Red color in the graph).

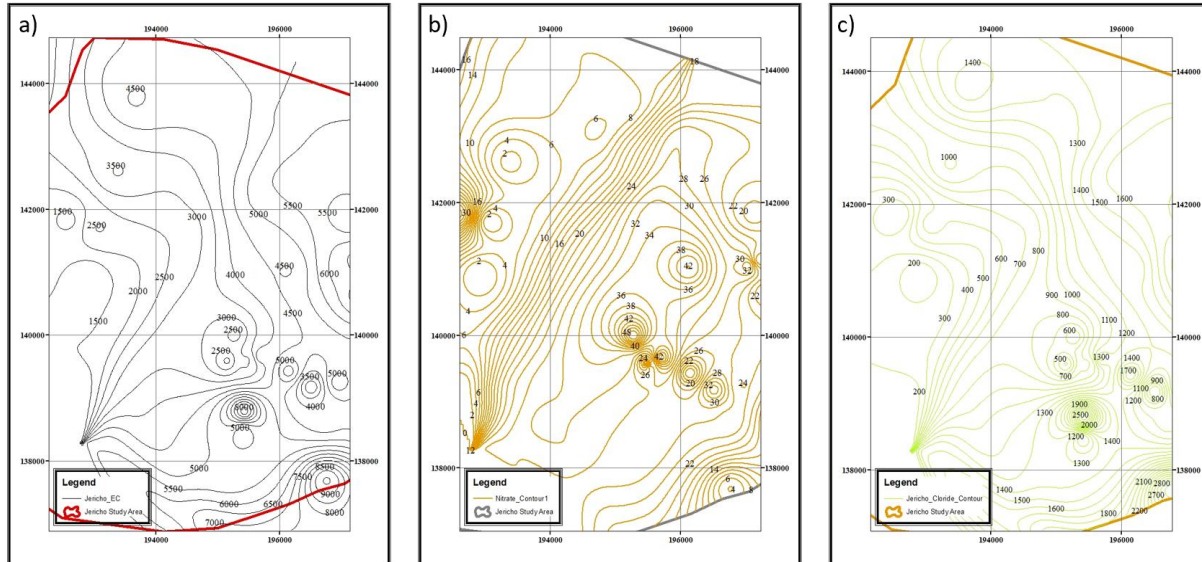


Figure 20. a) EC (mS/cm), b) Nitrate Concentration (mg/L) and c) Chloride Concentration (mg/L) in Jericho Governorate (PWA).

The geologic setting is also prone to high **erosion** rates and suspended **sediments** in surface waters. The steep slopes of the JV and the erodible sandstone formations of the deposits in combination with the lack of vegetation are highly erodible and result in high loads of suspended sediments in the surface water with all the associated impacts to the environment (Hötzl et al., 2009).

The abovementioned pressures can lead to negative impacts on ecosystems and biodiversity in the JV. In addition, the rich biodiversity of the JV faces a pressing threat from **invasive species**, which has become a significant ecological concern in the region. Invasive species, whether introduced accidentally or intentionally, possess the ability to disrupt the delicate balance of native ecosystems. The JV, with its unique flora and fauna, is particularly susceptible to the impacts of non-native species that can outcompete, prey on, or otherwise displace indigenous plants and animals. *Prosopis juliflora*, commonly known as mesquite, is one of the highly invasive plant species, is dominantly present in the Dead Sea region and continues to spread into the surrounding region across the Jordan Valley. It has the ability to tolerate drought and high temperatures. *Prosopis* invasion significantly reduces native woody species density, basal area, richness and diversity, water resources, and their poisonous thorns cause wounds to livestock and human beings (Tadros et al., 2020).

2.5 Conclusions

This report, in addition to assessing the ecosystem services, describes the present-day, baseline conditions of the WEF Nexus and represents the “Do-Nothing” scenario that will be compared with other scenarios that will aim at improving the WEF Nexus and address/reverse the impacts of desertification. EcoFuture will examine two scenarios; one that optimizes the Nexus at the national level (development separate,

nationally based strategic plans to address desertification) and the other, the “Blue-Sky” scenario where full cooperation is assumed between the 3 territories and the Jordan Valley is considered as a whole with full cross-border collaboration.

The JV is a critical region where the interplay of water, energy, food, and ecosystem dynamics presents both challenges and opportunities for sustainable development and climate change mitigation and adaptation. The valley’s unique geographical and climatic conditions have historically made it a focal point for agriculture, requiring intensive water management strategies to overcome its arid climate. Water scarcity in this region is acute, with sources such as the Jordan River and Yarmouk river and underground aquifers under increasing pressure from over-extraction and pollution, directly impacting agricultural productivity and food security. Energy is another critical component, heavily intertwined with water through the energy-intensive processes of water pumping, treatment, and distribution, as well as in agricultural operations and food processing. The food sector in the JV is highly dependent on the sustainable management of water and energy resources, with agriculture accounting for a significant portion of employment and food supply in the three territories, yet facing the challenges of limited water availability and the need for energy-efficient technologies. The ecosystem of the JV, characterized by its rich biodiversity and unique habitats, plays a crucial role in supporting agricultural activities. However, these ecosystems are under threat from overuse of natural resources, habitat destruction, and climate change impacts, necessitating integrated approaches to management. The Water-Energy-Food-Ecosystem (WEFE) nexus emerges as a vital framework in this context, emphasizing the interconnectedness of these sectors and the need for a holistic management approach to achieve socioeconomic welfare for the people of the valley.

Ecosystems in the JV provide regulating, cultural and heritage services and most importantly, provisioning services.

The status of the **regulating services** is the following:

- **Global climate regulation (carbon sequestration)** – The intensive cultivation of the land over millennia have deteriorated the quality of the soil and decreased the sequestered soil carbon to less than 1%. Current practices are not increasing soil carbon and thus are not contributing to climate regulation. To reverse this trend, active carbon addition to the soil is necessary.
- **Flood protection** – The Jordan Valley is particularly vulnerable to flooding during periods of heavy rainfall or sudden storms. The most flood-prone areas include: a) the Northern Jordan Valley near the Yarmouk River and Jordan River is susceptible to overflow and flooding of the surrounding agricultural areas, b) the Central Jordan Valley (Zarqa river and surrounding streams and channels can carry large amounts of water during storms, causing flash floods in the valley) and c) the Southern Jordan Valley (Areas around Wadi Araba and the Dead Sea region are also prone to flooding from nearby wadis).
- **Water regulation** – The water resources system (surface and ground waters) in the Jordan Valley is highly regulated and impacted by the ever-increasing demand for drinking water and irrigation. The impacts to water quantity and quality due to anthropogenic pressure have been evident and have been documented in this report.
- **Erosion prevention** – The geomorphological conditions of the Jordan Valley coupled with the increasing extreme events are causing soil erosion and suspended sediment transport to Jordan River and the Dead Sea.

The status of the **cultural and heritage services** is:

- **Aesthetic values** – The Jordan Valley has beautiful and diverse landscapes that make the region unique and visually appealing. The region is characterized by mountain ranges, river valleys, and gorges. The elevation difference from the highland areas to the valley creates stunning views, especially in the southern part of the Valley. Wetlands along the Jordan River (along the protected demilitarized zone) are rich in vegetation, especially in the spring and provide home to migratory birds. Finally, hiking trails such as the Jordan Trail allows the visitors to appreciate the beauty of the region.
- **Cultural values** – The Jordan Valley boasts a rich cultural heritage, underscoring its profound historical, religious, and cultural significance. As a longstanding center of human civilization, the area offers plenty of tourist attractions unique to its terrain. Embedded within the Jordan Valley is a deep-rooted cultural legacy, comprising historical, religious, and archaeological treasures integral to the region's identity and narrative. Many cultural sites in Jordan Valley are inextricably linked to the three monotheistic religions namely Judaism, Christianity and Islam which exist for millennia.
- **Spiritual/heritage values** – The presence of several UNESCO World Heritage sites in Jordan comprises cultural and mixed sites emblematic of the country's rich heritage. Some noteworthy historical sites include the 1) Jordan river Baptism Site (Al-Maghtas), 2) Pella (Tabaqat Fahil), 3) Yarmouk River Valley, 4) Jericho, 5) Tell Deir 'Alla, 6) Tomb of Abut 'Ubaydah, 7) Hydroelectric Power Station at Bakoura/Naharyim, 8) As-Sinnabra and 9) Beit Alpha (Synagogue and archeological park).

The status of the **provisioning services** is the following:

- **Water** – drinking and irrigation water from the springs and aquifers. In the water sector serious issues have been identified that need to be addressed. Surface water level decline has been observed in the Jordan River and the Dead Sea. The annual flow in the Lower Jordan River used to be 1,250 MCM while nowadays it fluctuates between 40 and 100 MCM. The Dead Sea has seen a rapid decline in its water levels, dropping over one meter per year. Moreover, groundwater decline has been observed in Jordan, Israel and Palestine due to over abstraction. Another issue is the deterioration of water quality due to over exploitation, pollution from agricultural runoff and wastewater discharge. The water of Jordan River is characterized as very poor to unsuitable for drinking water due to its high EC and concentrations of chlorides, magnesium, sodium, calcium, potassium and sulphate. The water of Jordanian dams has high levels of salinity and it is controlled by weathering which results in high concentrations of chloride, sodium, calcium and carbonate. Lastly, the groundwater in Jordan, Israel and Palestine demonstrates high salinity and, increased chloride and nitrate levels.
- **Food** – In the food sector serious issues have been identified that need to be addressed. The agricultural land has been degraded due to continuous cultivation for millennia which has as a result extremely low soil organic carbon. The impact of this situation is depicted in the estimated crop yields. This is a common problem for the three territories of the JV necessitating measures for soil restoration using agro-ecological practices and active carbon additions to soils that will improve soil quality, fertility and health. In addition, the progressively increasing soil salinity threatens the sustainability of irrigated agriculture in the

central and southern regions. This increase is attributed to unsustainable agricultural practices and inputs, quality of irrigation water, lack of advanced irrigation technologies and efficient drainage systems, and improper land management. Lastly, the recycling of biomass does not cover the P and K fertilization needs in Israel and Palestine. The fertilizer demand in Israel and Palestine can be satisfied by the recycling of livestock excreta/manure through livestock housing.

Table 13 presents a visual representation of the ecosystem services status in the Jordan Valley. The status of most of the regulating services has been decreasing or remains the same as is the provisioning services. On the other hand, the cultural and heritage services have been increasing.

Jordan Valley has been intensively cultivated for more than five millennia. The impacts of climate change have already been seen in the region with decreasing precipitation between 11 to 34% and increasing average annual temperature by 1.9 °C over the past 40 years. The WEF Nexus condition and the ecosystem services have been dramatically deteriorating.

Table 13. Status of the Ecosystem Services in the JV.

ES Category	Ecosystem Service	Increasing	The same	Decreasing
Regulating	Global climate regulation			☑
	Flood protection			☑
	Water regulation			☑
	Erosion prevention		☑	
Cultural and heritage	Aesthetic values	☑		
	Cultural values	☑		
	Spiritual/heritage values	☑		
Provisioning	Water			☑
	Food		☑	

3. Ecosystem services assessment using the SWAT model

In this chapter, we present the assessment of sediment and nitrate concentrations in the Jordan River using the hydrologic SWAT (Soil Water Assessment Tool) model. After calibrating the model to capture the patterns of the Jordan River flow (Deliverable 3.1), we use the same set-up to simulate nitrate and suspended sediment concentrations. Additionally, two Nature-Based Solutions (NBS) were examined and presented: the implementation of terracing to reduce soil erosion and consequently sediment transport, and the reduction of manure application to decrease nitrate concentrations in surface runoff.

3.1 Geochemical modelling of Jordan Valley

The SWAT model was used for the hydrologic modeling of the study area. Detailed inputs, processes, and results are reported in Deliverable 3.1. Here, we present the hydrologic simulation for the Jordan River at the Baptism Site (Figure 21), near its outlet into the Dead Sea. Continuous long-term time series data were not available for the study area. Therefore, data used for calibration and validation were sourced from

published studies reporting sediment and nitrate concentrations in the study area, specifically Segal-Rozenhaimer et al. (2004) and Hillel et al. (2015).

More specifically, Hillel et al. (2015), offers a continuous time series of more recent daily NO₃ observations, among others, at the Baptism Site covering the period 2010-2012 (Hillel et al., 2020a). The authors installed a hydrometric station including an automatic water sampler (Andress and Hauser Liquiport 2000), and an independent EC-sensor (Condumax CLS12). In total, 428 water samples representing the time period 2010/03/26- 2012/07/09 were collected, filtered (0.22 µm PVDF) and analyzed for anions (Cl, Br, NO₃, SO₄) applying IC Dionex DX-320 and for cations (Na, K, Mg, Ca) applying IC Dionex DX-500, both with conductometric detection. The time series of NO₃ concentration is shown in Figure 22. The same authors provide measurements of turbidity at the same sampling point (Hillel et al., 2020b), using a turbidity sensor (TurbiMax WCUS41). The sediment concentration series (note the logarithmic y axis) is shown in Figure 23. The mean suspended sediment concentration at the Jordan Baptism site is 2,200 mg/L.

Segal-Rozenhaimer et al. (2004) provide concentrations of NO₃ for samples taken from various tributaries or the main flow, once a month (specific day of the month is not clarified) for a six- to seven-month period (2001-2002). The coordinates of many of the locations are not specified, therefore we only use three sampling points (one in the Yarmouk tributary and two in the main flow) which have names that can be tracked, approximating their exact location. The NO₃ concentration values from this publication are mainly used for validation of the model (Figure 24).

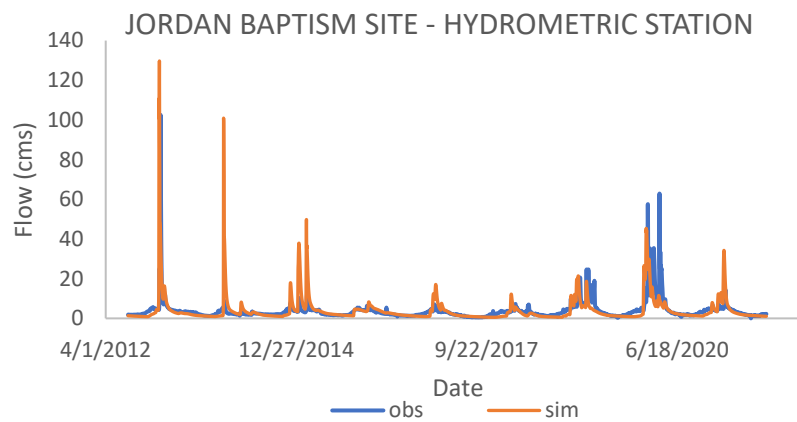


Figure 21. Comparison of observed and simulated daily flow data at the Jordan Baptism Site hydrometric station.

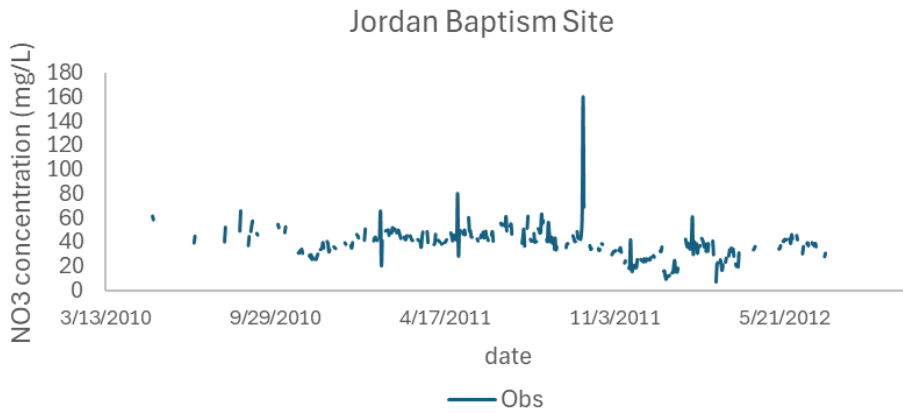


Figure 22. Nitrate concentration at Jordan Baptism Site (Hillel et al., 2020a).

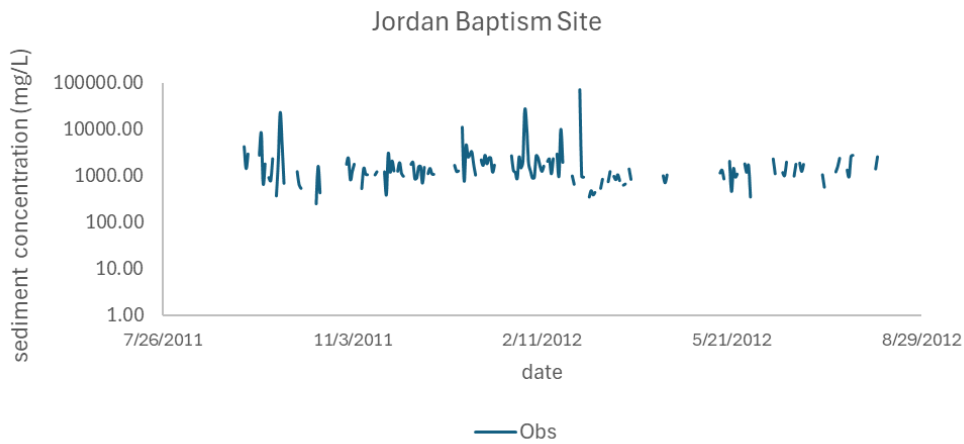


Figure 23. Suspended sediment concentration at Jordan Baptism Site (Hillel et al., 2020b).

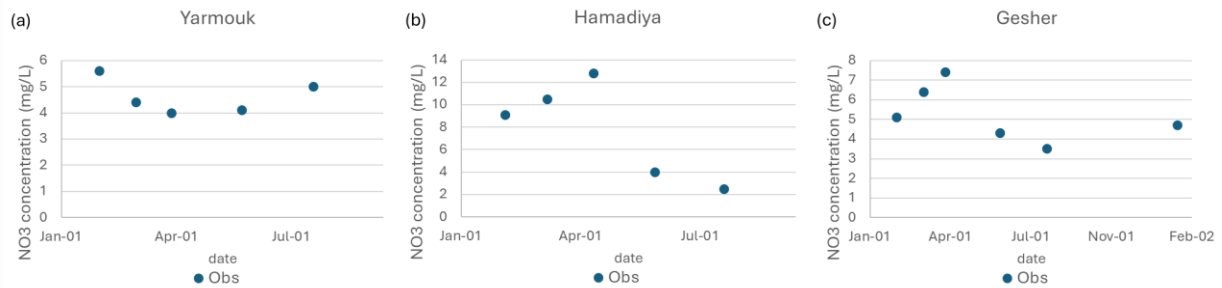


Figure 24. Nitrate concentration at sites used as validation (Segal-Rozenhaimer et al., 2004).

3.1.1 Methodology of Model Calibration

The objective of the model calibration was to achieve a close agreement between simulated and observed nitrate and sediment concentrations.

For nitrate simulation, nitrogen (N) loads from livestock were estimated by multiplying the animal population (Table 14) by standardized nitrogen excretion rates (kg/head/year), as reported by OECD (2007). The estimated potential nitrate loads from livestock manure are presented in Table 15. To introduce nitrate quantities through manure and fertilizer, the total amount was aligned with the values presented in Table 15 for each area. After iterative testing, it was logically assumed that continuous manure application from animals would not occur in sub-basins with steep slopes (>10%). Consequently, manure was allocated exclusively to sub-basins with slopes less than 10%. Agricultural nitrogen demand was calculated by multiplying the cultivated area of each crop type by a standard nitrogen application rate (kg/ha), based on fertilizer requirement guidelines. The sum of the nitrogen needs across all crop categories yielded the total annual fertilizer nitrogen demand, also reported in Table 15.

Each management operation within the model begins with crop planting and growth. For sub-basins with agricultural activity and/or animal presence, continuous fertilization is implemented to reflect ongoing manure input. Auto-irrigation is applied dynamically based on crop water requirements, and operations conclude with harvest and crop termination.

Two types of scheduling were used for management practices:

- Heat unit scheduling was applied in agricultural sub-basins without animal populations.
- Date-based scheduling was applied in sub-basins with animal presence.

Fertilization schedules for livestock were fine-tuned to ensure that the total nitrate input from excreta matched the regional values shown in Table 15. For cultivated areas, fertilizer was applied once per 10 days, calibrated to ensure that the total nitrogen input aligned with the estimated demand per region.

Observed high sediment in the field concentrations necessitated adjustments to increase simulated sediment yield. Calibration focused on key parameters within the SWAT (Soil and Water Assessment Tool) model that influence sediment dynamics. The most relevant parameters included:

- USLE_P – Support Practice Factor
- USLE_C – Cover and Management Factor
- USLE_K – Soil Erodibility Factor
- SPCON – Linear parameter for sediment re-entrainment in channel routing
- SPEXP – Exponent parameter for sediment re-entrainment
- PRF – Peak rate adjustment factor for sediment routing in the main channel

- CH_EROD – Channel erodibility factor
- CH_COV1 – Channel cover factor
- CH_COV2 – Channel erodibility factor

Among these, the parameters with the greatest influence on sediment concentration were PRF, SPCON, and SPEXP.

Table 14. Animal population in the three territories of JV.

Animal population	Jordan	Israel	Palestine
Dairy cattle	17,770	21,594	4,072
Poultry	10,381,320	5,270,419	708,300
Sheep and Goats	1,131,930	20,274	154,659
Horses	No data	No data	1,092

Table 15. Estimated potential nitrate loads from livestock excreta and agriculture.

Region	Jordan	Israel	Palestine
Total nitrate load from livestock	23,778	4,894	3,123
Total nitrate load from agriculture	3,629	1,709	2,090

3.1.2 Results

The simulation effectively follows the patterns of the observed nitrate concentrations at the Jordan Baptism Site (Figure 25), demonstrating the robustness of the hydrological model and the validity of the input data. Although some discrepancies are evident at peak concentrations, likely due to inconsistencies in precipitation input the general trend is well captured. The average observed nitrate concentration is 39.5 mg/L, while the average simulated value is 39.3 mg/L over the same period. The Nash-Sutcliffe Efficiency (NSE) is 0.76, indicating a very good (Moriasi et al., 2007) agreement between observed and simulated results.

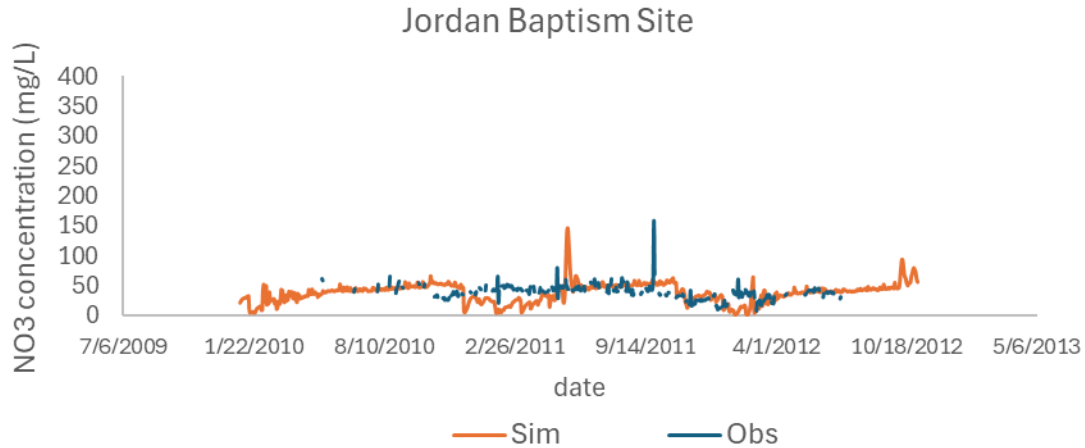


Figure 25. Observed and simulated nitrate concentration at the Jordan Baptism Site.

To assess model performance upstream, we used data from Segal-Rozenhaimer et al. (2004) (Figure 26). Since these data points represent random days within each month (exact dates not specified), perfect alignment with simulations is not expected. Nevertheless, the model successfully reproduces both the general patterns and the mean concentrations for each tributary, including Yarmouk, Hamadiya, and Gesher. The close alignment between observed and simulated concentrations across all sub-sites supports the spatial validity of the model.

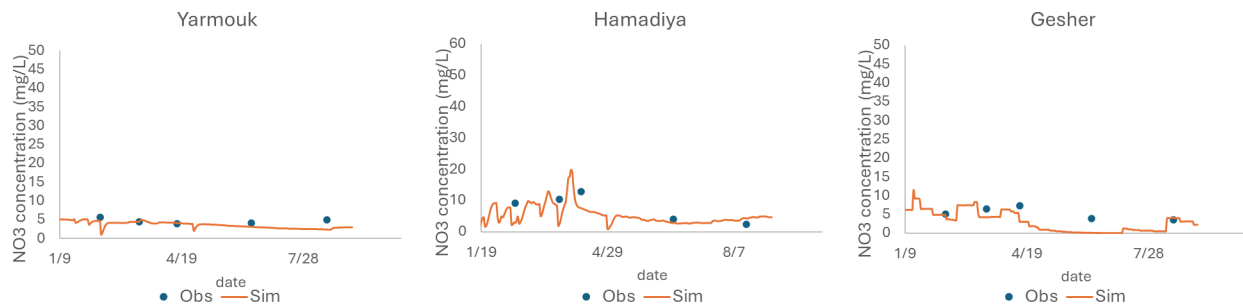


Figure 26. Observed and simulated nitrate concentration at sites used as validation (Segal-Rozenhaimer et al., 2004).

The total inorganic nitrogen fertilizer input is 56.92 kg/ha per year, complemented by an additional 44.73 kg/ha from organic nitrogen sources. However, crop nitrate uptake is only 25.69 kg/ha, less than half of the nitrogen applied. This indicates inefficient nitrogen utilization, with a significant portion likely being lost through leaching or volatilization or retained in organic form. These findings underscore the need for better nitrogen management strategies to enhance plant uptake efficiency and reduce environmental losses.

The simulation of sediment concentrations at the Jordan Baptism Site (Figure 27) also shows good agreement with observed patterns, although some sharp peaks in the observed data are not fully captured by the model. This is likely due to the difference in temporal resolution: while the model simulates daily

average values, the observations are instantaneous measurements, often taken during high-flow events. Despite this, the model captures the major events and seasonal variability well.

The daily average observed sediment concentration is 2,200 mg/L, compared to an average simulated value of 2,540 mg/L, suggesting a slight overestimation. The NSE index for sediment simulation is 0.4, which is considered satisfactory for sediment transport modeling, given the high variability and complexity involved.

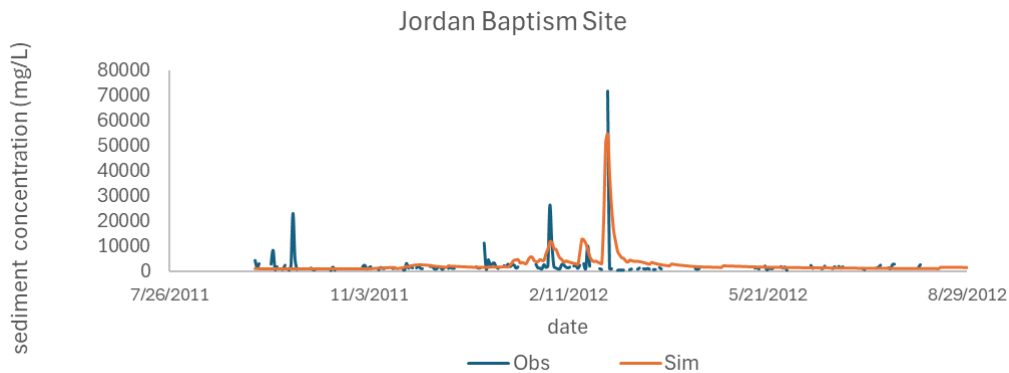


Figure 27. Observed and simulated sediment concentration at the Jordan Baptism Site.

The spatial distribution of sediment yield (Figure 28) highlights areas of elevated erosion risk, particularly in steeply sloped sub-basins (slopes >10%), such as regions within the Yarmouk and parts of Palestine. Here, daily sediment yields range from 29 to 218 Mg/ha, indicating severe soil loss. According to the SWAT sediment budget, the average upland sediment yield is 28.5 Mg/ha, well above the 10 Mg/ha threshold typically considered high. One particularly vulnerable Hydrologic Response Unit (HRU)—sub-basin 38, classified as barren land—shows a maximum sediment yield of 218.97 Mg/ha, pointing to intense localized erosion likely driven by slope, poor vegetation cover, and erodible soils. On the other hand, instream sediment change is -26.84 Mg/ha, indicating net deposition in the stream channels. This could lead to reduced channel capacity, habitat alteration, and floodplain sediment accumulation, suggesting the need for targeted mitigation strategies. Table 16 presents the parameter values used for calibration across the entire basin.

Table 16. Selected parameter values for calibration

Symbol	Meaning	SWAT Range	Values selected for subbasins
USLE_P	Support Practice Factor (e.g., contouring, strip cropping)	0 – 1 (lower values reduce erosion)	1
USLE_K	Soil Erodibility Factor	0 – 0.65	0.5
SPCON	Linear parameter for sediment re-entrainment in channel	0.0001 – 0.01	0.01
SPEXP	Exponent parameter for sediment re-entrainment in channel	1 – 2.5	2.5
PRF	Peak rate adjustment factor for sediment routing	0 – 2	1.2
CH_ERODMO	Channel erodibility factor	0 – 1	0
CH_COV1	Channel cover factor for sediment attenuation (e.g., grass cover)	0 – 1 (lower values indicate higher protection)	0.6
CH_COV2	Channel cover factor for bank erosion	0 – 1 (same principle as CH_COV1)	1
CDN	Denitrification exponential rate coefficient	0 – 3	0
SDNCO	Denitrification threshold water content	0 - 1	0
N_UPDIS	Nitrate uptake distribution parameter	0 – 100	50
NPERCO	Nitrate percolation coefficient	0 – 1	0.9
SHALLST_N	Initial shallow groundwater storage of nitrate (mgN/L)	0 – 1000	80
HLIFE_NGW	Half-life of nitrate in shallow aquifer (days)	1 – 200	200

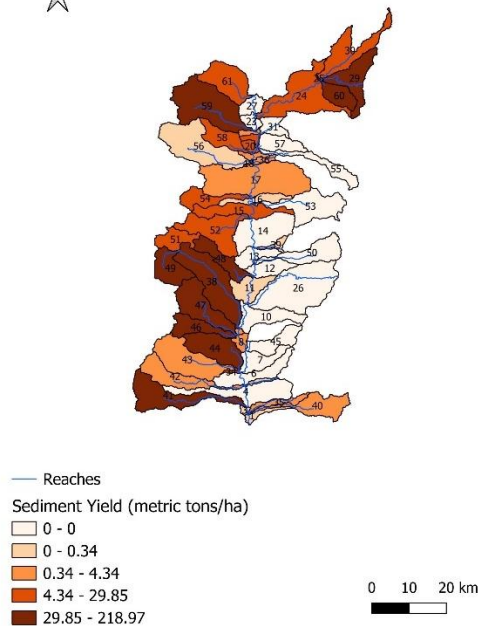


Figure 28. Spatial distribution of the mean daily sediment yield (metric tons/ha) for each sub-basin of the Jordan River Catchment (estimated over the period 2002-2021).

3.2 Modeling of Nature-Based and Hybrid Solutions

The Jordan Valley faces significant environmental challenges, particularly soil erosion and nitrate pollution, largely due to agricultural practices (Salameh et al., 2024; Farhan et al., 2015; Al Kuisi et al., 2008). To address these issues, several Nature-Based Solutions (NBS) and hybrid solutions were implemented and assessed in the region. Specifically for soil erosion, two scenarios were applied: the first involved the use of terracing to reduce erosion on sloped agricultural lands, and the second focused on reducing bank erosion along water channels. In parallel, another scenario aimed at decreasing the application of livestock manure to mitigate nitrate contamination in soils and adjacent water bodies. These measures collectively support more sustainable land management and enhance environmental health in the area.

Terracing was incorporated into the SWAT model by adjusting the USLE (Universal Soil Loss Equation) practice factor. This factor depends on variables such as the slope of the terraced land, the average slope length (TERR_SL), which is influenced by soil morphology, and the curve number (TERR_CN), which varies depending on slope class (Neitsch et al., 2011). These modifications were applied to the dominant Hydrologic Response Units (HRUs) within subbasins where mean daily sediment yield reaches up to 0.34 tons per hectare.

According to literature and in situ observations, Jordan Valley suffers from bank erosion. To address this issue within the SWAT model, we adjusted two key parameters: the channel erodibility factor (CH_COV1) and the channel cover factor (CH_COV2). The channel erodibility factor was set to 0, indicating a completely non-erodible channel (Neitsch et al., 2011). Similarly, the channel cover factor was set to 0 (Neitsch et al., 2011), representing full protection of the channel by vegetation or other stabilizing material throughout the basin, thereby effectively minimizing the potential for channel erosion.

To address nitrate (NO_3^-) pollution, a scenario simulation was implemented by fertilizing the agricultural land with livestock manure and reducing the equivalent amount from the livestock grazing area. The manure application rate was reduced by 25% in the grazing area, a level sufficient to meet crop nutrient demands. Subsequently, scenarios involving 50% and 100% reductions of the manure in the grazing area were also tested. These higher reductions reflect the potential outcomes of improved livestock management practices, such as confined or stable animal rearing which ensures manure collection with potential to process and sell it as fertilizer. The objective was to evaluate the resulting impact on nitrate concentrations (NO_3^- in mg/L) in surface water. Results were analyzed near the basin outlet, close to the Jordan River Baptism Site, where observed nitrate concentration data are available.

3.2.1 Results of NBS and Hybrid Scenario Implementation

To understand how SWAT simulates the implementation of terraces, we conducted a sensitivity analysis focusing on three key model parameters: the Curve Number of the terraced HRUs (TERR_CN), the average slope length (TERR_SL), and the support practice factor (TERR_P). The Curve Number (TERR_CN) represents the runoff potential of a hydrologic response unit (HRU) with terraces. According to the literature, TERR_CN values should not significantly deviate from the base CN values of each sub-basin, as terraces typically affect runoff timing and soil loss processes more than runoff

volume (Ben Khelifa et al., 2016; Neitsch et al., 2011). Therefore, we selected a conservative adjustment approach by reducing the CN values by 5 and 10 units relative to the original values.

The average slope length (TERR_SL) represents the length of slope between terraces and plays a key role in determining sediment transport capacity. Considering the prevailing soil morphology in the study area, we tested TERR_SL values ranging from 2 to 20 meters, reflecting both short and extended terrace spacing scenarios (Ayele et al., 2022).

The support practice factor (TERR_P) originates from the Universal Soil Loss Equation (USLE) and simulates the effectiveness of erosion control practices such as terracing. TERR_P is a dimensionless coefficient ranging from 0 to 1, where lower values indicate more effective erosion control. The results are presented for three sub-basins—one from each region (Jordan, Israel, and Palestine)—each of which faces significant erosion problems.

The scenario with the optimal parameter combination includes the parameters that resulted in the greatest reduction of sediment and are representative for the area. More specifically, TERR_SL was set to 5 m, TERR_P to 0.10, and the Curve Number (CN) was reduced by 10 units.

The analysis of sediment load (SED_OUT) in Jordan reveals a significant reduction in soil erosion through various land management scenarios (Figure 29). In the baseline scenario, the average annual sediment load (Table 17) is 71.48 tons/ha. Gradually reducing the slope length (TERR_SL) from 20 to 2 meters leads to a steady decrease in sediment load, reaching 55.10 tons/ha at TERR_SL = 2. Likewise, decreasing the support practice factor (TERR_P) from 0.4 to 0.1 reduces sediment load from 60.56 to 54.58 tons/ha. More substantial reductions are achieved by adjusting the Curve Number (CN): CN -5 lowers sediment load to 41.31 tons/ha, while CN -10 achieves a further decrease to 26.96 tons/ha. The optimal parameter combination scenario results in the greatest reduction, with sediment load dropping to 22.92 tons/ha. The Figure 30, clearly illustrates this trend, showing consistently lower sediment yield values under terracing scenarios—particularly during extreme rainfall years—compared to the baseline.

Percentage Reduction of SED_OUT for Each Scenario (vs. Baseline) – Jordan

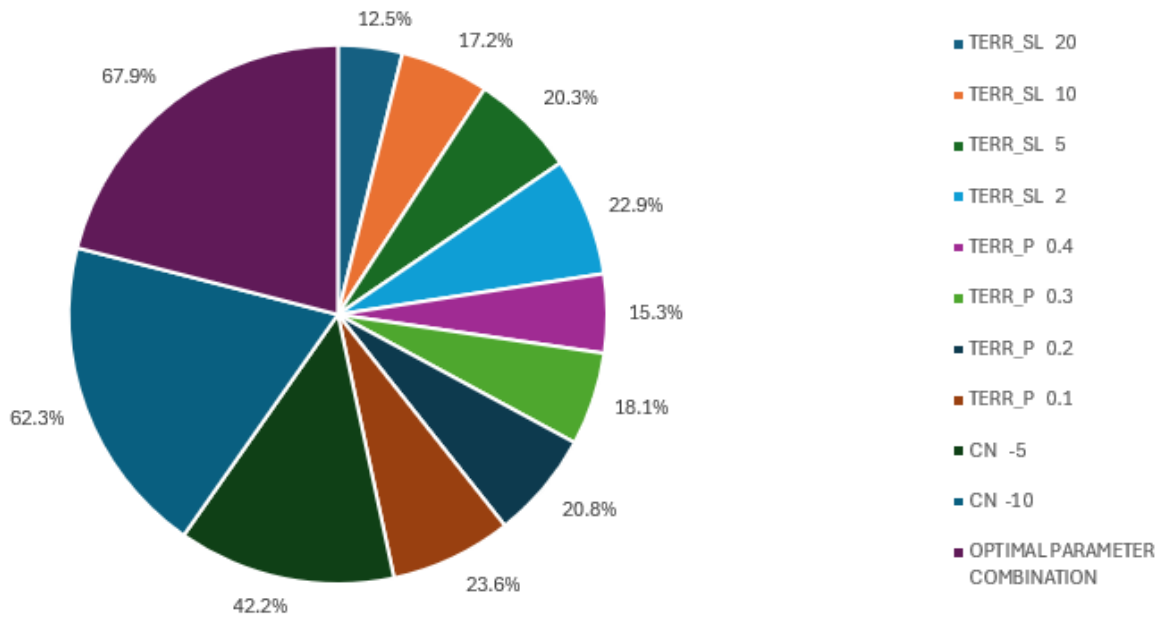


Figure 29. Percentage Reduction of Sediment Output in Jordan

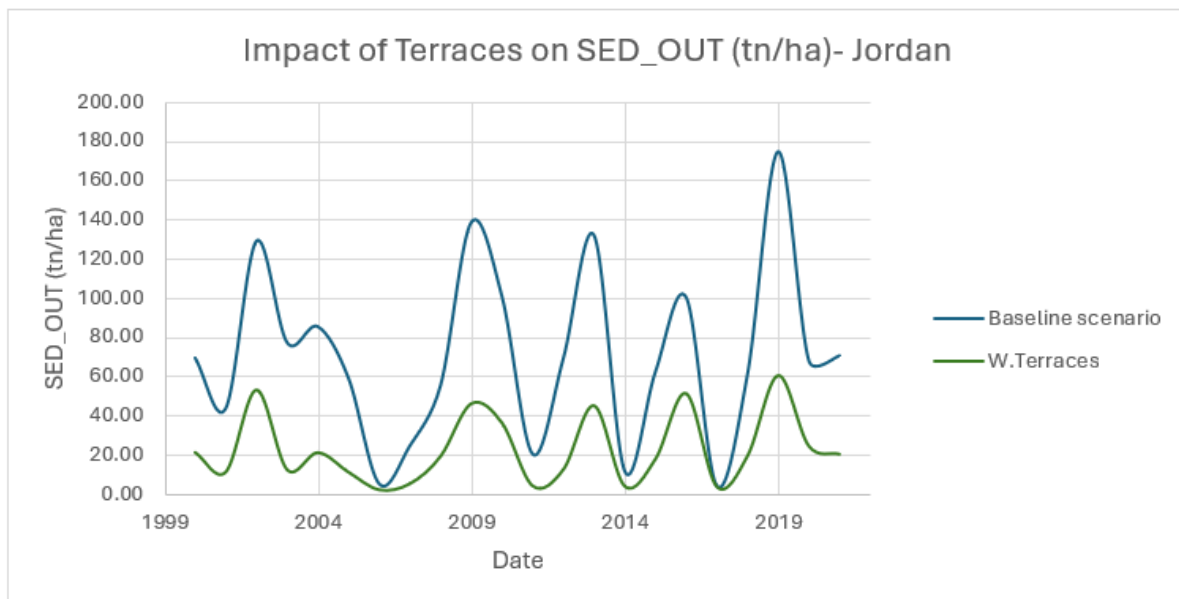


Figure 30. Sediment Output Variation under Terracing Scenario in Jordan

Table 17. Sediment Output for Each Scenario in Jordan

Scenario	BASELINE SCENARIO	TERR_SL 20	TERR_SL 10	TERR_SL 5	TERR_SL 2	TERR_P 0.4	TERR_P 0.3	TERR_P 0.2	TERR_P 0.1	CN -5	CN -10	OPTIMAL PARAMETER COMBINATION
Mean Annual SED_OUT (tn/ha)	71.48	62.56	59.18	56.94	55.10	60.56	58.57	56.58	54.58	41.31	26.96	22.92

The analysis of sediment load (SED_OUT) in Israel demonstrates that implementing different land management scenarios significantly reduces soil erosion (Figure 31). In the baseline scenario (Table 18), the average annual sediment load is 34.99 tons/ha. A gradual reduction is observed as the slope length (TERR_SL) decreases from 20 to 2 meters, reaching 24.65 tons/ha at TERR_SL = 2. Similarly, reducing the support practice factor (TERR_P) from 0.4 to 0.1 results in a notable decrease, with the lowest value being 24.16 tons/ha. Even greater reductions are achieved by decreasing the Curve Number (CN) by 5 and 10 units, leading to sediment loads of 12.06 tons/ha and 7.47 tons/ha, respectively. The optimal parameter combination scenario achieves the most significant reduction, lowering the sediment yield to just 5.31 tons/ha. This trend (Figure 32) is clearly illustrated in the line graph, where the application of terraces under the optimal scenario leads to a substantial decline in sediment yield compared to the baseline, especially during peak rainfall events.

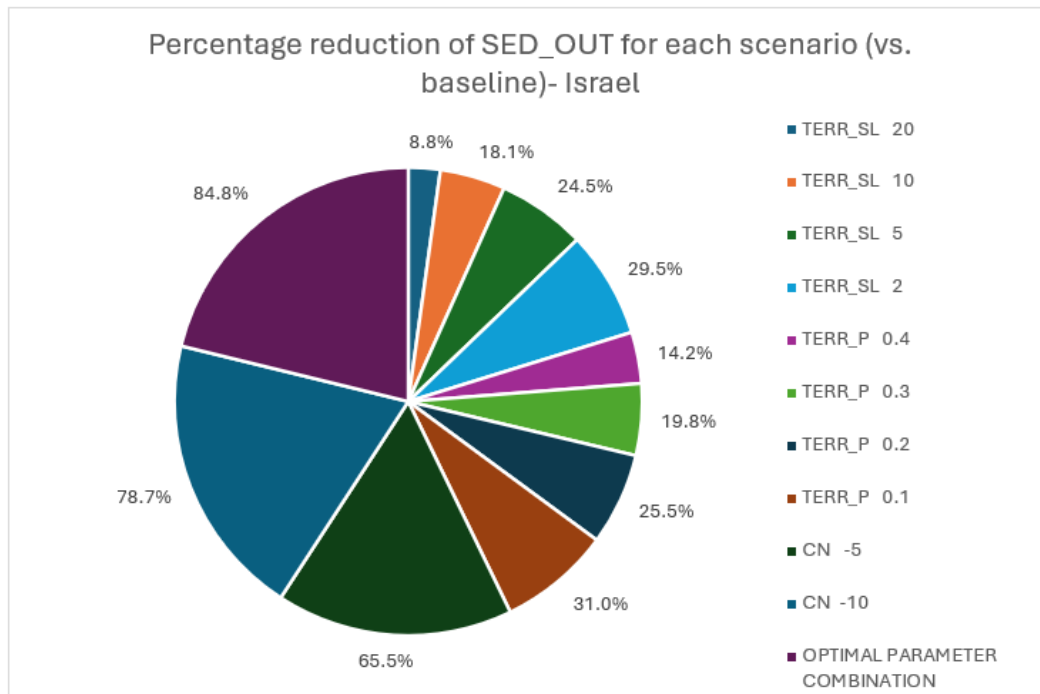


Figure 31. Percentage Reduction of Sediment Output in Israel

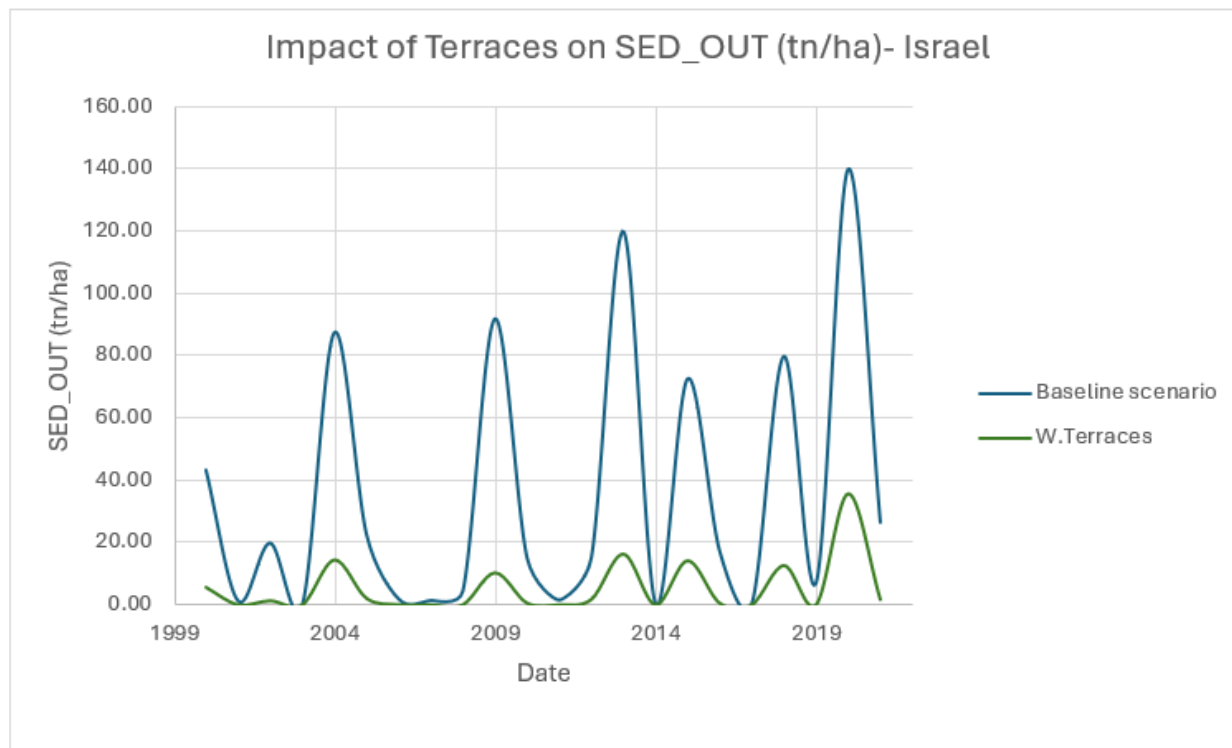


Figure 32. Sediment Output Variation under Terracing Scenario in Israel

Table 18. Sediment Output for Each Scenario in Israel

Scenario	BASELINE SCENARIO	TERR_SL 20	TERR_SL 10	TERR_SL 5	TERR_SL 2	TERR_P 0.4	TERR_P 0.3	TERR_P 0.2	TERR_P 0.1	CN -5	CN -10	OPTIMAL PARAMETER COMBINATION
Mean SED_OUT (tn/ha)	34.99	31.91	28.65	26.41	24.65	30.02	28.05	26.06	24.16	12.06	7.47	5.31

The analysis of sediment load (SED_OUT) in Palestine shows that the application of different land management scenarios significantly reduces soil erosion (Figure 33). In the baseline scenario (Table 19), the average annual sediment load reaches 100.10 tons/ha, the highest among all cases. Gradually reducing the slope length (TERR_SL) from 20 to 2 meters leads to a consistent decrease in sediment yield, reaching 87.06 tons/ha at TERR_SL = 2. Similarly, decreasing the support practice factor (TERR_P) from 0.4 to 0.1 reduces SED_OUT from 91.99 to 86.56 tons/ha. More substantial reductions are observed when the Curve Number (CN) is decreased, with CN -5 resulting in 67.16 tons/ha and CN -10 in 49.60 tons/ha. The optimal parameter combination yields the lowest sediment output, at 46.23 tons/ha, representing the most effective scenario. The line graph (Figure 34) confirms this trend, showing a clear and consistent reduction in sediment yield over time when terraces are applied, especially during peak rainfall periods.

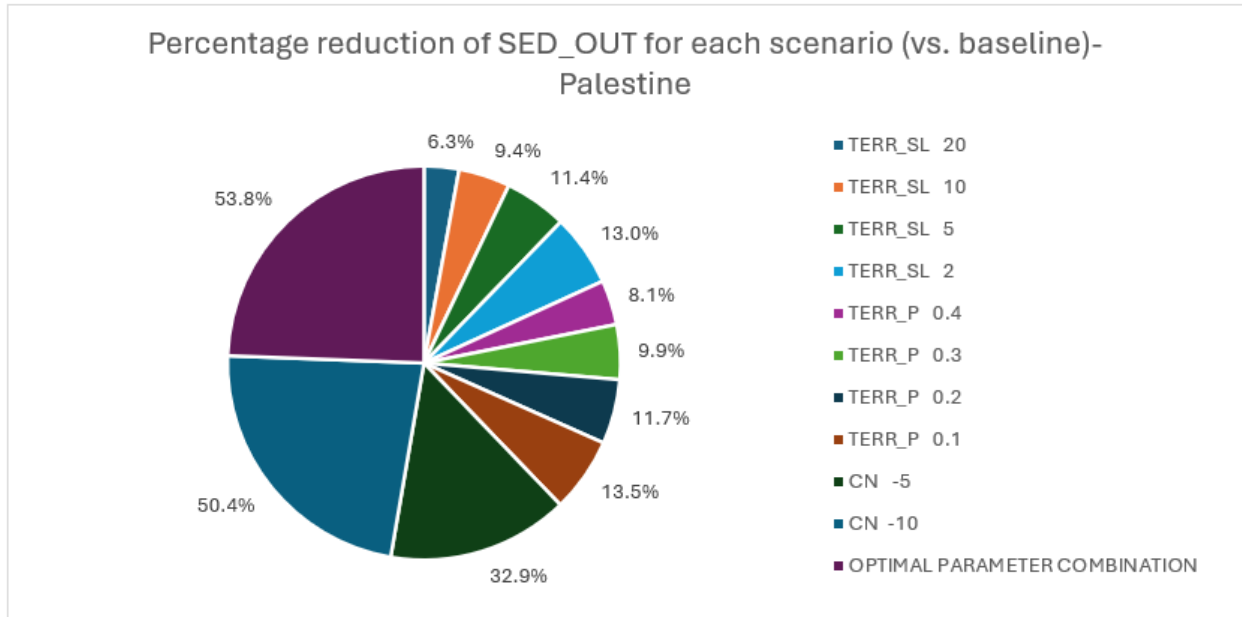


Figure 33. Percentage Reduction of Sediment Output in Palestine

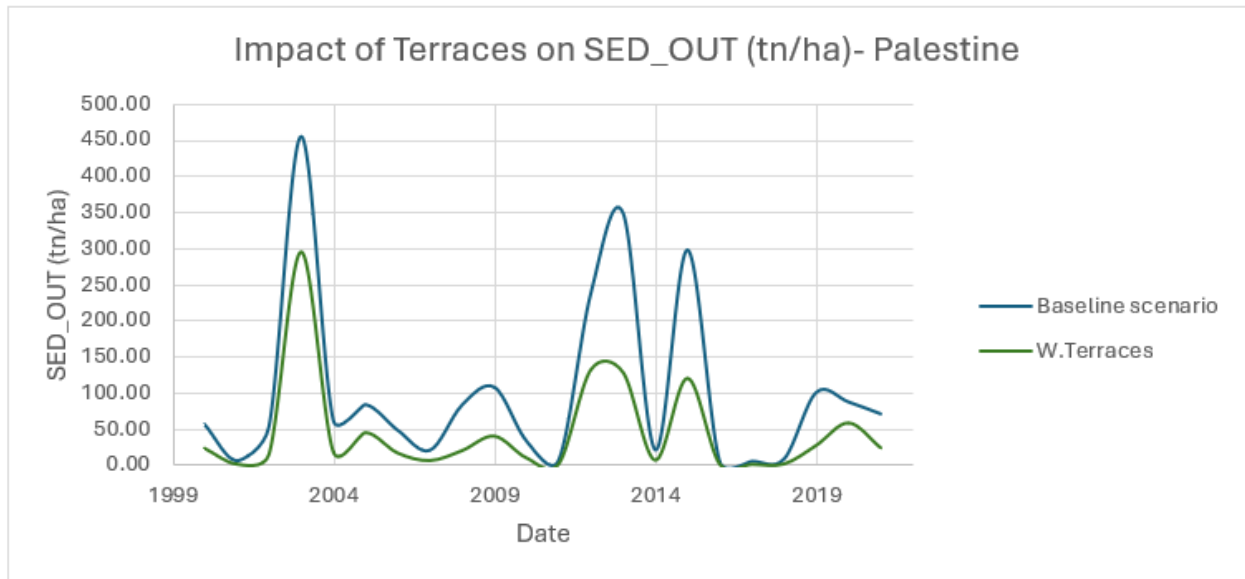


Figure 34. Sediment Output Variation under Terracing Scenario in Palestine

Table 19. Sediment Output for Each Scenario in Palestine

Scenario	BASELINE SCENARIO	TERR_SL 20	TERR_SL 10	TERR_SL 5	TERR_SL 2	TERR_P 0.4	TERR_P 0.3	TERR_P 0.2	TERR_P 0.1	CN - 5	CN - 10	OPTIMAL PARAMETER COMBINATION
Mean annual SED_OUT (tn/ha)	100.10	93.76	90.73	88.72	87.06	91.99	90.19	88.40	86.56	67.16	49.60	46.23

The analysis of sediment output (SED_OUT) at the Jordan Baptism Site reveals minimal effectiveness of individual land management scenarios in reducing soil erosion (Figure 35). In the baseline scenario, the average annual sediment output is 26.70 tons/ha (Table 20), which remains nearly unchanged across most tested interventions. Adjusting the slope length (TERR_SL) from 20 to 2 meters and modifying the support practice factor (TERR_P) from 0.4 to 0.1 each result in a negligible reduction of just 0.09 tons/ha, yielding a consistent SED_OUT value of 26.61 tons/ha. Slight reductions are observed under CN -5, with a SED_OUT of 26.59 tons/ha, while CN -10 and the optimal parameter combination scenarios unexpectedly increase sediment output to 27.15 tons/ha—1.7% higher than the baseline. These findings suggest that the individual parameter changes have limited impact, and even the optimal combination does not effectively reduce sediment yield in this context.

Percentage Reduction of SED_OUT for Each Scenario (vs. Baseline) – at the Jordan Baptism Site

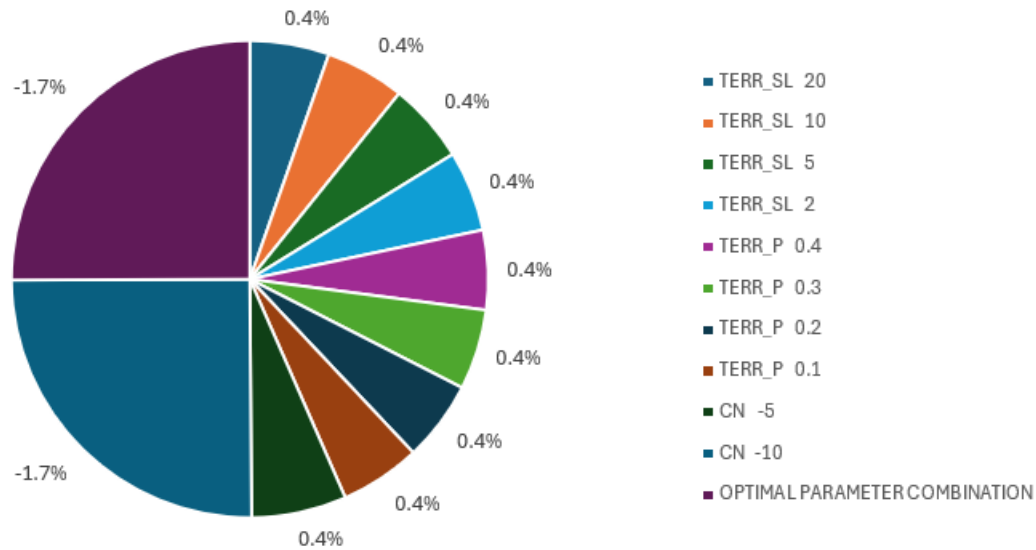


Figure 35. Percentage Reduction of Sediment Output at the Jordan Baptism Site

Table 20. Sediment Output for Each Scenario at the Jordan Baptism Site

Scenario	BASELINE SCENARIO	TERR_SL 20	TERR_SL 10	TERR_SL 5	TERR_SL 2	TERR_P 0.4	TERR_P 0.3	TERR_P 0.2	TERR_P 0.1	CN - 5	CN - 10	OPTIMAL PARAMETER COMBINATION
Mean annual SED_OUT (tn/ha)	26.70	26.61	26.61	26.61	26.61	26.61	26.61	26.61	26.61	26.59	27.15	27.15

The analysis of the impact of bank erosion reduction on sediment output (SED_OUT) at the Jordan Baptism Site demonstrates a remarkable decrease in sediment load (Figure 36). As shown in the graph, the baseline scenario exhibits significant fluctuations in annual sediment output, with peaks reaching up to 14 tons/ha during periods of intense rainfall. In contrast, the implementation of a bank erosion reduction scenario drastically lowers sediment output, maintaining near-zero levels throughout the entire study period. According to the table, the average annual SED_OUT drops from 3.16 tons/ha in the baseline scenario to just 0.04 tons/ha, representing an impressive 98.73% reduction in sediment load (Table 21). These results highlight the reduction of bank erosion as an extremely effective strategy for controlling sediment output in the area.

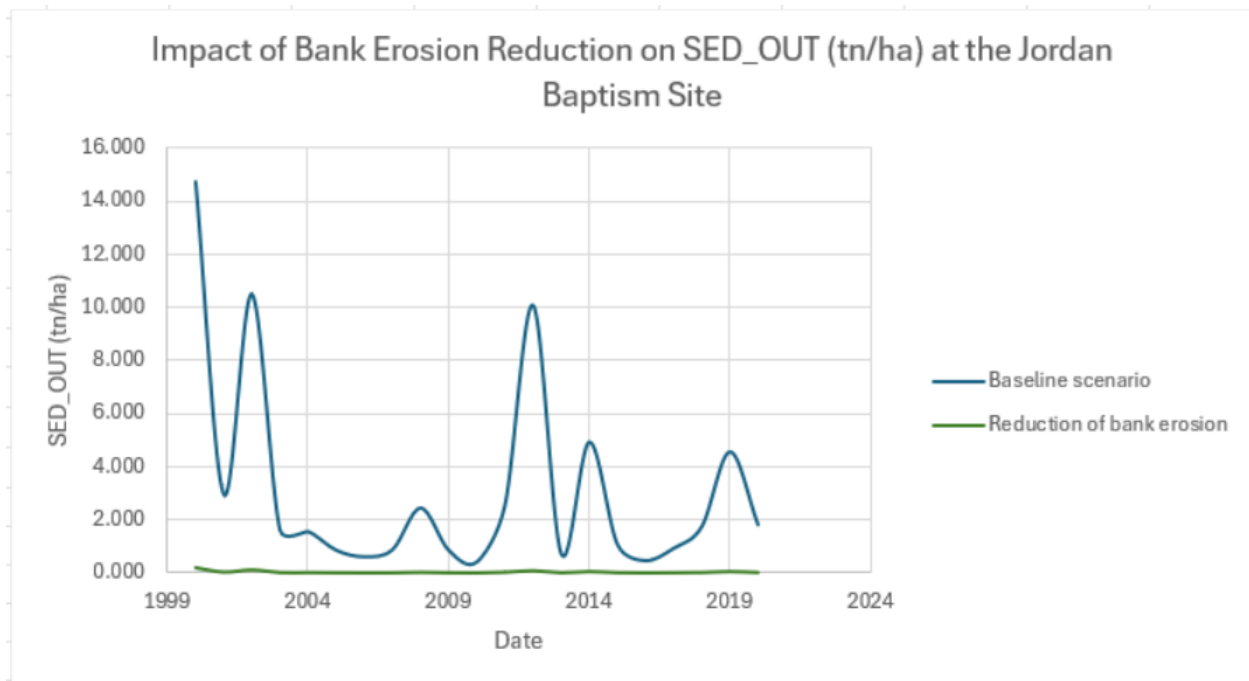


Figure 36. Sediment Output Variation under Reduction Bank Erosion Scenario at the Jordan Baptism Site

Table 21. Sediment Output under Reduction Bank Erosion Scenario at the Jordan Baptism Site

Scenario	Average annual SED_OUT (tn/ha)	Percentage reduction of sediment load
Baseline scenario	3.16	-
Reduction of bank erosion	0.04	98.73%

Figure 37 and Table 22 illustrate the impact of manure reduction on nitrate (NO_3^-) concentrations over time. The Figure presents NO_3^- concentrations (mg/L) from 1999 to 2023 under four different scenarios: the baseline scenario with no manure reduction, and scenarios with 25%, 50%, and 100% reductions in manure application. Significant fluctuations in nitrate concentrations are observed throughout the study period, with notable peaks around the years 2004 and 2008. While the overall trend remains similar across all scenarios, a gradual decrease in nitrate concentrations is evident as the level of manure reduction increases. The accompanying table summarizes the average annual NO_3^- concentrations and the corresponding percentage reduction relative to the baseline scenario. The baseline scenario yields an average nitrate concentration of 195.30 mg/L. A 25% reduction in manure results in a concentration of 189.22 mg/L (a 3% decrease), a 50% reduction leads to 183.21 mg/L (a 6% decrease), and a complete elimination (100% reduction) results in 170.66 mg/L, corresponding to a 13% reduction. These findings indicate that reducing manure application contributes to lower nitrate concentrations. However, even under the scenario of complete manure elimination, the overall reduction remains moderate. This suggests that existing nitrate contamination in the system takes a very long time to flush out.

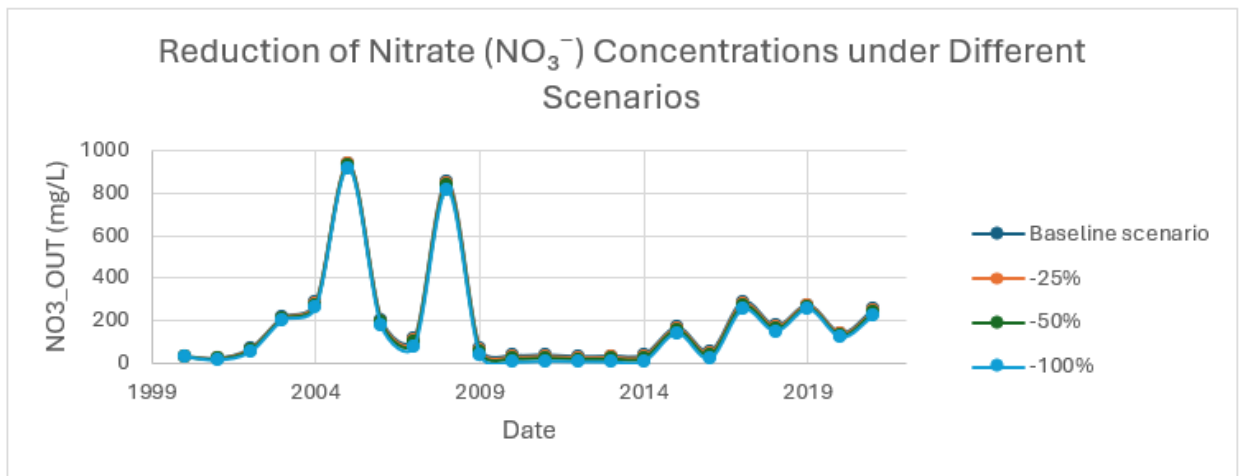


Figure 37. Variation of NO₃ Reduction Under Different Scenarios

Table 22. NO₃ Output Under Manure Reduction Scenario

Scenario	Average annual NO ₃ _OUT (mg/L)	Percentage reduction of nitrate concentration
Baseline scenario	195.30	--
-25%	189.22	3%
-50%	183.21	6%
-100%	170.66	13%

4. Ecosystem services assessment with the 1D-ICZ model

4.1 Site description

The Jordanian pilot site is located in Deir Alla region. Deir Alla region is an old plateau in the middle of the Jordan valley with an altitude of around 310 meters b.s.l and has a total area of around 240 km² (60% of Jordan Valley area).

The Deir Alla site has a total area of around 0.35 ha. The soil is deep with a depth ranging from 2.7 to more than 3 meters. The annual precipitation is around 225 mm. The site contains six plastic houses of around 420 m² each in which tomatoes are being cultivated. It also contains a water desalination plant (capacity: 10 m³/hr), an irrigation pond and three water harvesting tanks. The irrigation pond is used to supply the desalination unit with water and provides irrigation water for the two comparison plastic houses (1 & 2). Floating PV panels installed over the irrigation pond provide enough power to all used equipment including the desalination plant and at the same time decrease the a) evaporation water losses from the pond and b) algae growth at the water surface inside the irrigation pond. The location also has two adjacent plastic multi-spans with one of them provided with a water harvesting system and a water storage tank. A new tank with a higher storage capacity was installed and stores enough rainwater to provide two plastic houses (3 & 4) with irrigation water. Another water storage tank is placed close to the desalination unit to supply another two plastic houses (5 & 6) with irrigation water as well as providing additional water in case precipitation is not enough (Figure 38).

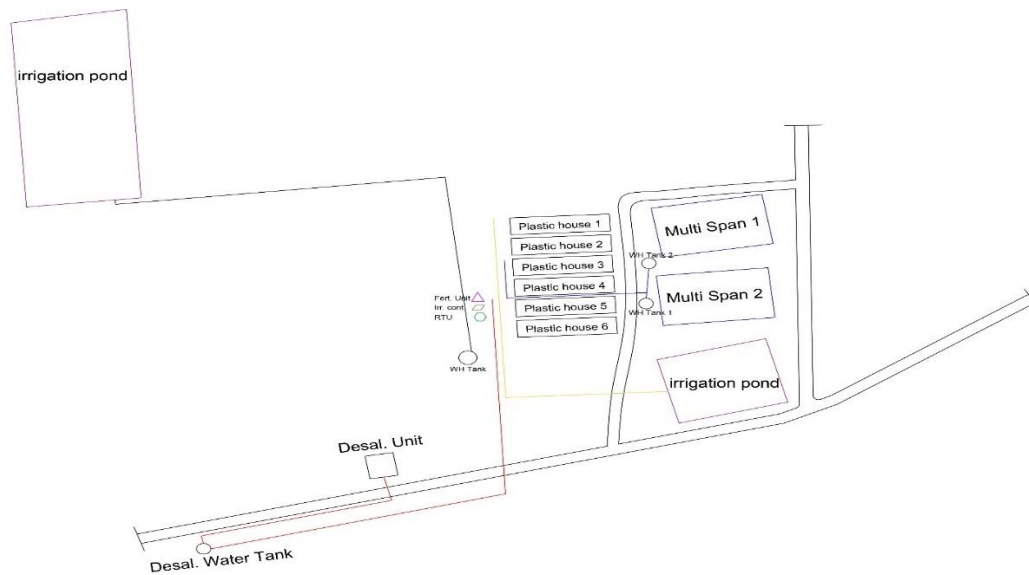


Figure 38. Jordanian pilot site at Deir Alla.

More specifically, the activities in each plastic house are described below:

Plastic houses 1 & 2 (CON)

- Irrigation depending on traditional farmer experience in the area using mixed water from KTD.
- Addition of fertilizers and pesticides according to requirement.
- Monitoring of soil salinity (EC) and soil pH and, recording of a) volume of irrigation water used, b) amount of fertilizers and pesticides used and, c) yield obtained.

Plastic houses 3 & 4 (WH)

- Use of efficient irrigation system (drip irrigation system using two no-drain lines for each planted row equipped with pressure compensating and low flow rate drippers) and irrigation based on soil moisture measurements (automated irrigation using soil moisture sensors installed at 3 soil depth intervals).
- Use of improved irrigation water quality with harvested rainwater from the two existing multi-spans for direct irrigation.
- Use of compost (80%) and manure (20%) to improve soil quality (8.96 tC/ha).
- Addition of fertilizers and pesticides according to requirement.
- Monitoring of a) soil salinity (EC), b) soil pH, c) soil moisture at three soil depth intervals and, recording of a) volume of irrigation water used, b) amount of fertilizers and pesticides used and, c) yield obtained.

Plastic houses 5 & 6 (RO)

- Use of efficient irrigation system (drip irrigation system using two no-drain lines for each planted row equipped with pressure compensating and low flow rate drippers) and irrigation based on

soil moisture measurements (automated irrigation using soil moisture sensors installed at 3 soil depth intervals).

- Use of improved irrigation water quality with desalinated water (capacitive de-ionization) using the existing desalination unit very close to the site area.
- Use of compost (80%) and manure (20%) to improve soil quality (8.96 tC/ha).
- Addition of fertilizers and pesticides according to requirement.
- Monitoring of a) soil salinity (EC), b) soil pH, c) soil moisture at three soil depth intervals and, recording of a) volume of irrigation water used, b) amount of fertilizers and pesticides used and, c) yield obtained.

The tomatoes were planted on the 20th of October 2024, with no tillage applied and the tomatoes were harvested on the 24th of April 2025. Organic fertilizers were applied once before planting in the WH and RO plastic houses but not in the control houses. Regarding the irrigation system: each planting row has two drip lines with 2 drippers per plant. Each dripper has a flow rate of 2.5 L/hour. There are 107 plants per line, and with six lines per plastic house, the total number of plants per plastic house is 642.

4.2 Model description

The one-dimensional integrated critical zone (1D-ICZ) model (Figure 39) is a mechanistic mathematical model capable of simulating and quantifying key soil functions including food and biomass production, water flow and storage, carbon/nutrient sequestration and biodiversity (Giannakis et al., 2017; Kotronakis et al., 2017). The model couples soil formation (aggregation and disaggregation) and structure with soil hydrology, cycling of nutrients, plant productivity and weathering (Nikolaidis et al., 2014; Kotronakis et al., 2017). The 1D-ICZ model consists of four sub-modules: HYDRUS-1D, CAST, PROSUM and SAFE Weathering. HYDRUS-1D sub-module simulates water flow, heat and solute transport and the chemical weathering sub-module simulates the dissolution kinetics of minerals. PROSUM sub-module simulates the plant dynamics, i.e., biomass production, water and nutrient uptake and litter production of C and N (Nikolaidis et al., 2014; Giannakis et al., 2017; Kotronakis et al., 2017). The Carbon, Aggregation and Structure Turnover (CAST) sub-module is the core model that uses the RothC carbon pools and thus simulates the macro-aggregate formation (around POM) and disruption to form micro-aggregates and silt-clay sized micro-aggregates (Stamati et al., 2013; Giannakis et al., 2017). The CAST model has been used globally (Damma Glacier in Switzerland, Heilongjiang Mollisols in China, Koiliaris and Milia in Greece, Clear Creek in United States, Slavkov Forest in Czech Republic and Marchfeld in Austria) in order to simulate the soil structure, C/N/P dynamics and especially C sequestration (Panakoulia et al., 2017).

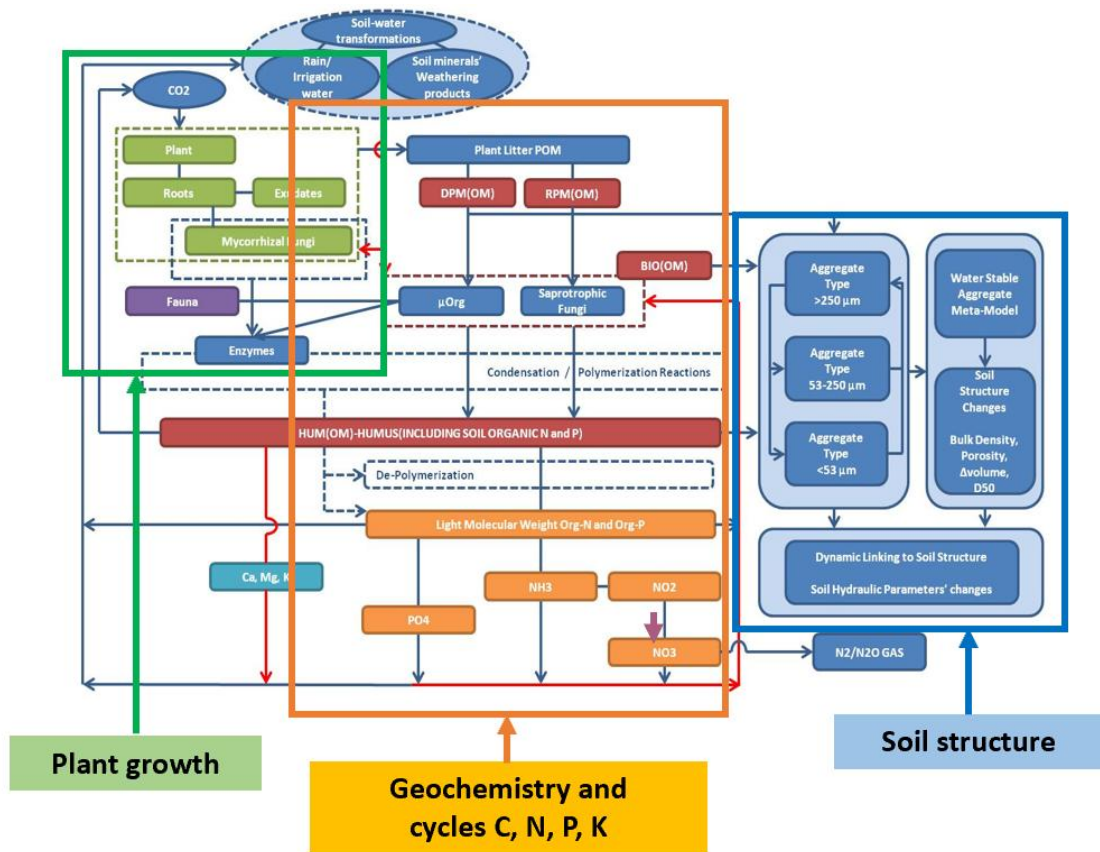


Figure 39. Schematic representation of 1D-ICZ model (Giannakis et al., 2017).

4.3 Model initialization and calibration methodology

The 1D-ICZ model was initialized and calibrated from October 2024 to April 2025 (7 months) in order to simulate two of the main ecosystem services: biomass production and soil organic carbon (SOC) of the a) CON (control) plastic houses, b) WH (water harvesting) plastic houses and c) RO (reverse osmosis) plastic houses. Monthly time series of temperature, irrigation, fertilization, evapotranspiration, photosynthetic active radiation (PAR) and solute concentrations were used as provided by NARC to initialize the model.

The PROSUM sub-module uses monthly time series of temperature and PAR and takes into consideration harvest, tillage events and the type of plant (deciduous, evergreen, herbaceous, mycorrhizal, non-mycorrhizal). In this case, no tillage was applied, harvest occurred in April 2025 and tomato is a herbaceous mycorrhizal plant. The gross primary production (GPP) on the field was calculated by using data about the weight of a) produced tomatoes and b) plant with roots. These weights were converted into gC/m^2 as the TOC content of a tomato is 400-560 gC/kg , the TOC content of a tomato's root is 420-450 gC/kg and the area of each plastic house is 420 m^2 . The 1D-ICZ model simulated the GPP of the control, WH and RO plastic houses by manually adjusting the parameter related to light limitation of productivity ($\text{PAR}_{\text{exponent}}$) and the maximum productivity at a standard CO_2 concentration (MaxC_{fix}).

Composite soil samples were collected from a depth of 20 cm below the soil surface inside each plastic house, targeting areas close to the seedlings to accurately represent the root zone. Soil sampling was

carried out before planting to assess the initial soil condition. Although planting began in October, the sampling took place in early November to ensure proper site stabilization. A follow-up soil sampling was conducted in April 2025 from the same locations and at the same depth (20 cm), after completing the experiment. The soil samples underwent Water Stable Aggregate (WSA) Fractionation analysis (Elliott, 1986; Lichter et al., 2008) to determine the distribution of WSA and SOC in each plastic house. The C stock distribution data of November 2024 were used as initial conditions and the data of April 2025 were used as set aside values to calibrate the CAST sub-module. The manual adjustment of the rate constants associated with the fragmentation and the decomposition of plant litter pools and aggregate types AC3, AC2 and AC1 calibrated the soil dynamics.

Moreover, the HYDRUS-1D sub-module was used to simulate the soil moisture of the WH and RO plastic houses from November 2024 to April 2025 (daily time step). The HYDRUS-1D sub-module is driven by meteorological data (temperature and evapotranspiration time series), irrigation data, soil hydraulic parameters (van Genuchten-Mualem parameters) and geometry information (soil depth, layers and materials). Regarding the calibration, the initial water content (θ) and the van Genuchten-Mualem parameters θ_r , θ_s , a , n and K_s were calibrated so that the soil moisture measurements in a depth of 20 cm to be as close as possible to the simulated data.

4.4 Results

Figure 40 shows the simulated and observed GPP for the control, WH and RO plastic houses during the 7 months of tomato cultivation. The 1D-ICZ model successfully simulated the production in each management. For the control plastic houses, the measured GPP was 3,336.82 gC/m² while the modeled GPP was estimated at 3,335.21 gC/m² (error: 0.05%). For the WH plastic houses, the measured GPP was 4,171.43 gC/m² while the modeled GPP was estimated at 4,170.68 gC/m² (error: 0.02%). For the RO plastic houses, the measured GPP was 4,527.09 gC/m² while the modeled GPP was estimated at 4,528.48 gC/m² (error: 0.03%). The plastic houses that use reverse osmosis have the highest GPP while the control plastic houses have the lowest GPP.

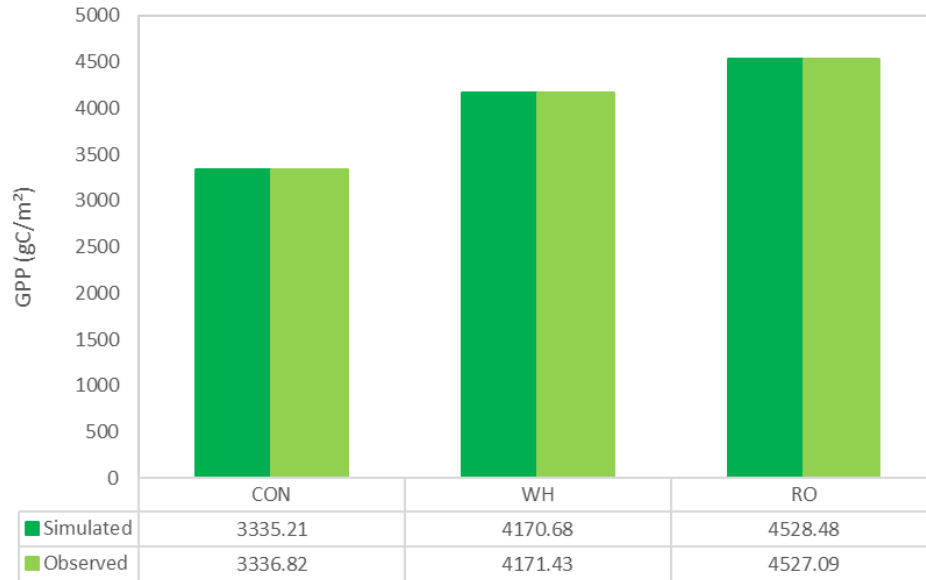


Figure 40. Simulated and observed GPP (gC/m^2) for the control, WH and RO plastic houses from October 2024 to April 2025.

Figures 41 to 43 present the SOC and the organic carbon (OC) contained in macro-aggregates (AC3), micro-aggregates (AC2) and silt-clay sized micro-aggregates (AC1) for the control, WH and RO plastic houses respectively.

For the control plastic houses, the SOC remained stable with an average value of 21.09 tC/ha. The OC contained in a) macro-aggregates was 4.32 tC/ha, the OC contained in micro-aggregates was 13.80 tC/ha and the OC contained in silt-clay sized micro-aggregates was 2.97 tC/ha. Regarding WSA, the macro-aggregates (AC3) account for the 20.35% of the WSA mass, micro-aggregates (AC2) account for the 62.87% of the WSA mass and silt-clay sized micro-aggregates account for the 16.78% of the WSA mass.

For the WH plastic houses, the SOC decreased from 44.64 to 34.31 tC/ha. The OC contained in a) macro-aggregates decreased from 24.44 to 13.14 tC/ha, the OC contained in micro-aggregates remained stable with an average value of 15.33 tC/ha and the OC contained in silt-clay sized micro-aggregates increased from 4.88 to 5.85 tC/ha. Regarding WSA, the macro-aggregates (AC3) account for the 27.07% of the WSA mass, micro-aggregates (AC2) account for the 53.78% of the WSA mass and silt-clay sized micro-aggregates account for the 19.14% of the WSA mass.

For the RO plastic houses, the SOC decreased from 27.92 to 23.37 tC/ha. The OC contained in a) macro-aggregates decreased from 10.79 to 5.30 tC/ha, the OC contained in micro-aggregates remained stable with an average value of 13.03 tC/ha and the OC contained in silt-clay sized micro-aggregates increased from 4.10 to 5.05 tC/ha. Regarding WSA, the macro-aggregates (AC3) account for the 28.77% of the WSA mass, micro-aggregates (AC2) account for the 51.33% of the WSA mass and silt-clay sized micro-aggregates account for the 19.91% of the WSA mass.

Regarding the particulate organic matter (POM), in the control plastic houses 9% of the SOC is in the POM fraction, while in the WH plastic houses the POM accounts for 40% of SOC and in the RO plastic houses for the 20% of SOC.

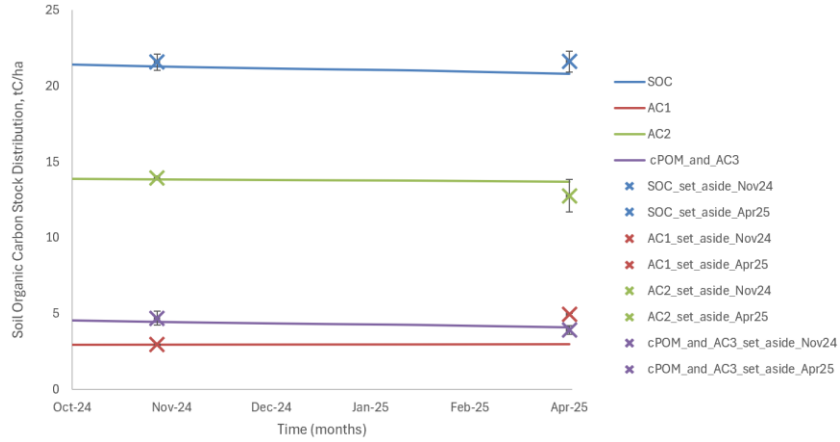


Figure 41. SOC Distribution for the control plastic houses (tC/ha).

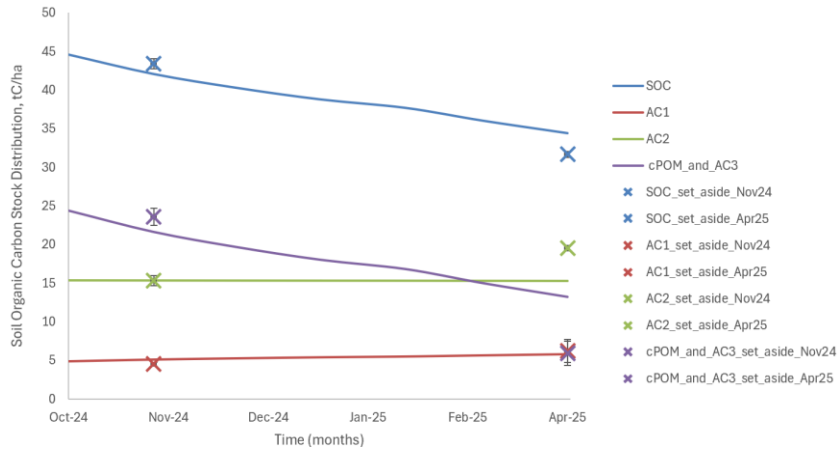


Figure 42. SOC Distribution for the WH plastic houses (tC/ha).

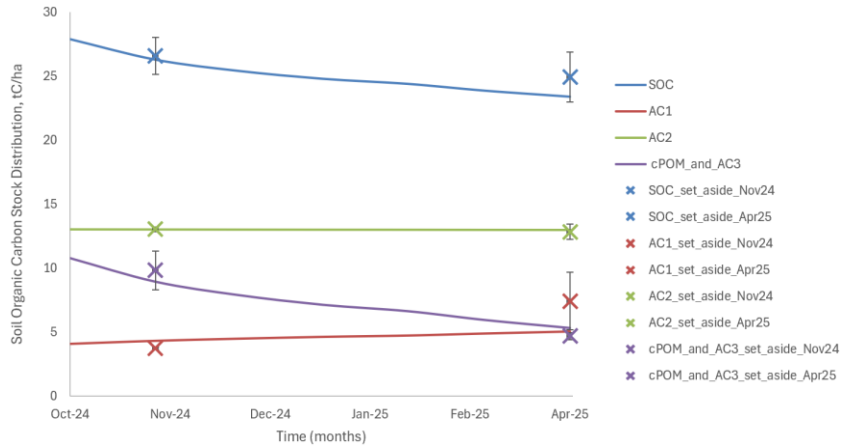


Figure 43. SOC Distribution for the RO plastic houses (tC/ha).

Figures 44 and 45 present the simulated and observed soil moisture from November 2024 to April 2025 (181 days) for the WH and RO plastic houses. For the WH plastic houses, the soil moisture of the WHV1 fluctuates from 17.4 to 52.8% while the soil moisture of WHV2 fluctuates from 18.8 to 55.0%. For the RO plastic houses, the soil moisture of the ROV1 fluctuates from 26.0 to 59.6% while the soil moisture of ROV2 fluctuates from 18.9 to 49.0%. The average measured soil moisture for the WH plastic houses was 36.18% while for the RO plastic houses was 39.45%. The average simulated soil moisture for the WH was 44.55% while for the RO plastic houses was 44.60%.

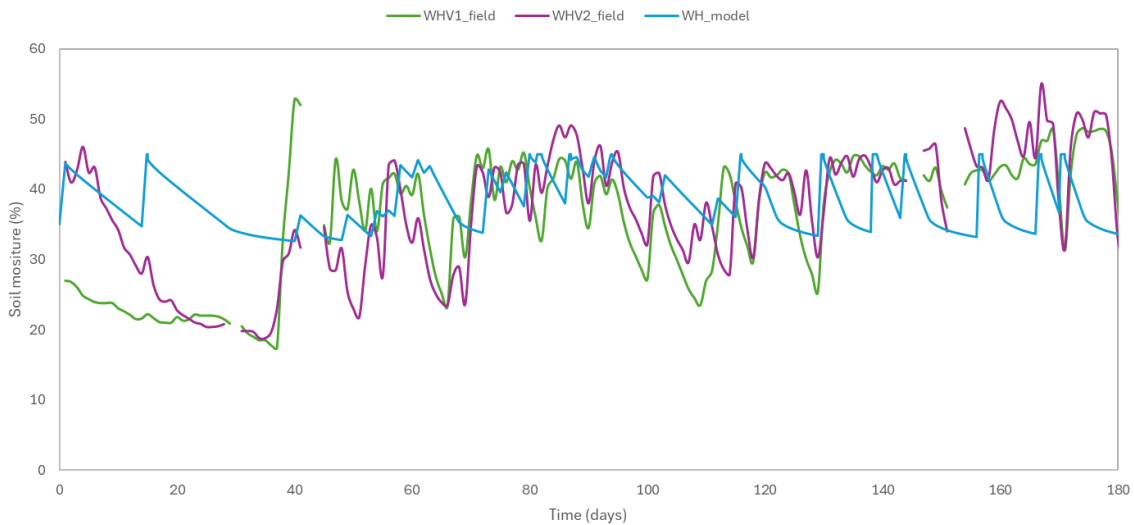


Figure 44. Simulated and observed soil moisture (%) for the WH plastic houses.

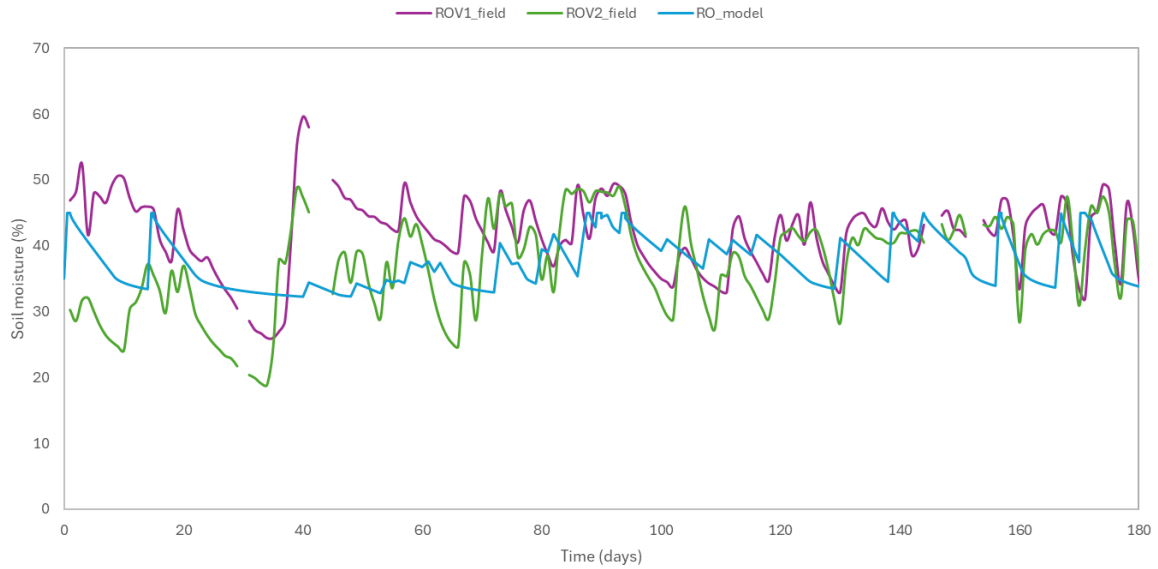


Figure 45. Simulated and observed soil moisture (%) for the RO plastic houses.

Table 23 provides a comparison of parameters between the control, WH and RO plastic houses regarding the biomass production, soil structure and dynamics (Water Stable Aggregates, soil carbon and nitrogen stocks) and soil moisture. The majority of the WSA mass is contained in micro-aggregates accounting for 63% in the control plastic houses, 54% in the WH plastic houses and 51% in the RO plastic houses. Regarding the quantification of ecosystem services, for the control plastic houses, the GPP was estimated at 33.35 tC/ha, the soil carbon stock at 21.09 tC/ha and the soil nitrogen stock at 3.00 tN/ha. Similarly, for the WH plastic houses, the GPP was estimated at 41.71 tC/ha, the soil carbon stock at 39.04 tC/ha and the soil nitrogen stock at 4.42 tN/ha. For the RO plastic houses, the GPP was estimated at 45.28 tC/ha, the soil carbon stock at 25.12 tC/ha and the soil nitrogen stock at 3.57 tN/ha. The above- and below ground carbon of the WH and RO plastic houses is higher than the control's due to the carbon addition in both WH and RO plastic houses.

Table 23. Comparison of parameters for the control, WH and RO plastic houses.

	CON	WH	RO
Macro-aggregates >250μm (%)	20.35	27.07	28.77
Micro-aggregates 53-250μm (%)	62.87	53.78	51.33
Silt-clay sized micro-aggregates <53μm (%)	16.78	19.14	19.91
Silt-clay (%)	77.80	83.95	86.25
Above ground C (tC/ha)	33.35	41.71	45.28

Below ground C (tC/ha)	21.09	39.04	25.12
POM (tC/ha)	6.15	33.84	12.56
Below ground N (tN/ha)	3.00	4.42	3.57
POM (tN/ha)	1.43	2.37	1.75
C/N (below ground)	7.03	8.83	7.04
Soil moisture (%)	-	44.55	44.60

5. Conclusions

The JV demonstrates deeply interconnected challenges across the water, energy, food, and ecosystem sectors. The baseline "Do-Nothing" scenario reveals major inefficiencies, particularly in nutrient use and sediment control. These issues highlight the urgent need for coordinated cross-sectoral management to address growing resource pressures and climate vulnerabilities.

The Karst-SWAT hydrological model successfully simulated nitrate and sediment dynamics, supporting its credibility for ecosystem service assessment. However, the analysis revealed that nitrogen use efficiency remains low, with significant nutrient losses occurring through leaching and denitrification. Sediment yields were particularly high in sloped sub-basins, well above critical erosion thresholds, underscoring the need for urgent intervention.

Simulated land management scenarios achieved significant sediment reductions across the region, with reductions up to 84.8% in Israel and 67.9% in Jordan. However, at the Jordan Baptism Site, conventional surface-based erosion controls failed due to dominant bank erosion. Targeted adjustments simulating full bank vegetation cover resulted in a remarkable 98.7% reduction in sediment yield, demonstrating the necessity of tailored riparian interventions in erosion-prone zones.

Scenarios exploring reduced manure application showed only limited declines in nitrate concentrations, with the most aggressive reduction strategy (100% manure elimination) achieving a 13% decrease. These findings indicate that existing nitrate contamination in the system takes a very long time to flush out.

The 1D-ICZ model provided accurate simulations of tomato production under different plastic house configurations, using the results of the first-year experiment of Jordanian pilot in Deir Ala. Reverse osmosis (RO) and water harvesting (WH) systems demonstrated superior performance in terms of productivity and soil nitrogen retention compared to control scenarios. WH systems also preserved higher levels of soil organic carbon, while both setups maintained adequate soil moisture and structural stability, indicating strong potential for sustainable agricultural intensification in arid environments.

The modeling and simulation efforts conducted under this task provide valuable evidence for comparing future development scenarios, including nationally optimized strategies and a fully cooperative "Blue-Sky" approach. The demonstrated benefits of NBS and hybrid solutions, improved nutrient management, and erosion control, especially for bank erosion, emphasize their role in enhancing ecosystem services and long-term resilience. These insights are essential for guiding cross-border planning and reversing desertification across Jordan, Palestine, and Israel under the EcoFuture framework.

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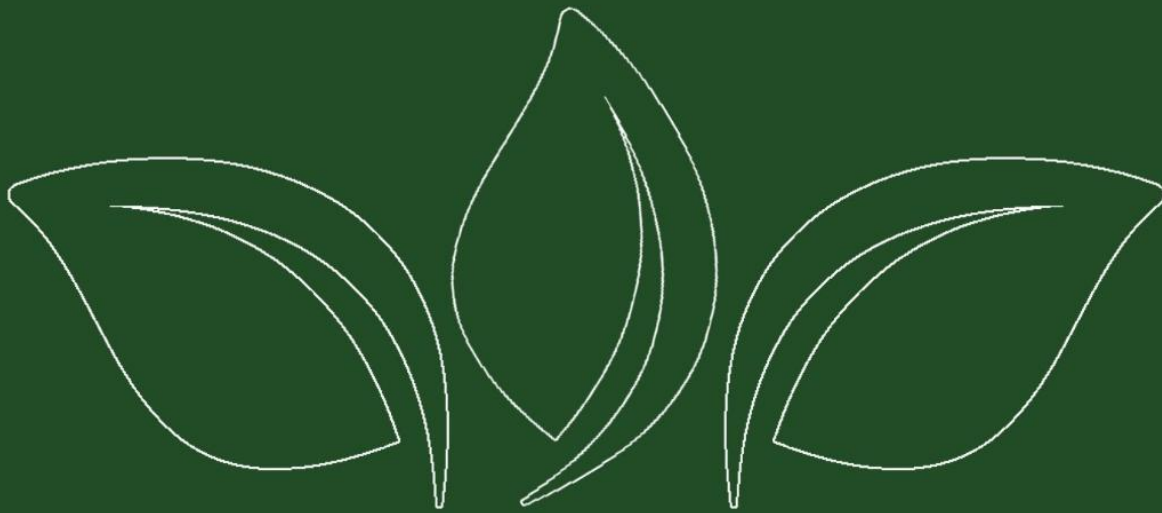
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