Greenhouses in the Lower Jordan valley, Jordan ©Xanke

Management Strategies for the Reuse of Treated Wastewater in the Lower Jordan Valley

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KEY FINDINGS

A large part of the treated wastewater can be reused for agricultural irrigation.

Managed aquifer recharge (MAR) using treated wastewater is a promising solution to regenerate depleted groundwater levels in the alluvial aquifer, mitigate droughts and freshen brackish groundwater to make them usable again for irrigation.

Discharging treated wastewater into the Jordan River would help to partially rehabilitate the Jordan River floodplains and slow down the water level decline of the Dead Sea.

MOTIVATION

The study identifies different variants for reusing treated wastewater (TWW) in the Lower Jordan Valley (LJV) in the conjunctive use with freshwater and brackish groundwater and develops different reuse alternatives to strengthen irrigation and ecosystem rehabilitation. The general water distribution and reuse concept are based on estimated wastewater volumes and their expected availability for 2050 [Regional Wastewater Infrastructure Development Strategies for Jordan and Palestine, p. 40], focusing on meeting future irrigation requirements and expanding agricultural land, assessing the potential for managed aquifer recharge (MAR) and evaluating existing approaches for the rehabilitation of the Jordan river (Gafny et al. 2010) and mitigating the water level decline of the Dead Sea (ICL 2020). All three reuse variants serve to create balanced reuse alternatives for the treated wastewater and groundwater from a technical and economic point of view, also considering ecological aspects. The reuse alternatives are developed and evaluated based on the combination of different criteria to provide decision support towards implementing an integrated reuse strategy to strengthen irrigation development and ecosystem rehabilitation [Multi-Criteria Assessment of Water Resources Planning Options, p. 80].

METHODOLOGY

The reuse alternatives show different combinations of three reuse variants, which are:

- Irrigation with prior mixing with freshwater or brackish groundwater.
- Managed aquifer recharge (MAR) into brackish groundwater zones
- Rehabilitation of the floodplains of the Jordan River

On the Jordanian side of the Jordan Valley, all reuse variants were investigated. On the Palestinian side, the analysis concentrated on MAR only. The reuse alternatives in Jordan are developed based on the volumes of TWW forecasted for 2050 of 445.1 Mio. m^3/a with centralized treatment solutions and 374.9 Mio. m^3/a with decentralized treatment solutions, averaging at 410 Mio. m^3/a.

The irrigation water requirement (IWR) was calculated based on the specific crop water requirement (CWR) for the average production of fruit, vegetables, and crop patterns from 2008 to 2017. The calculations consider an average irrigation efficiency of 70% (Al-Omari et al. 2015), an expansion of agriculture by 12% to the maximum usable area, and a 10% increase in IWR by 2050 due to climate change (Karablieh and Salman 2013).

The potential for **managed aquifer recharge** is assessed on a large scale. An assessment of the available storage space is made based on the hydrogeological conceptual model and results from the numerical groundwater models of the

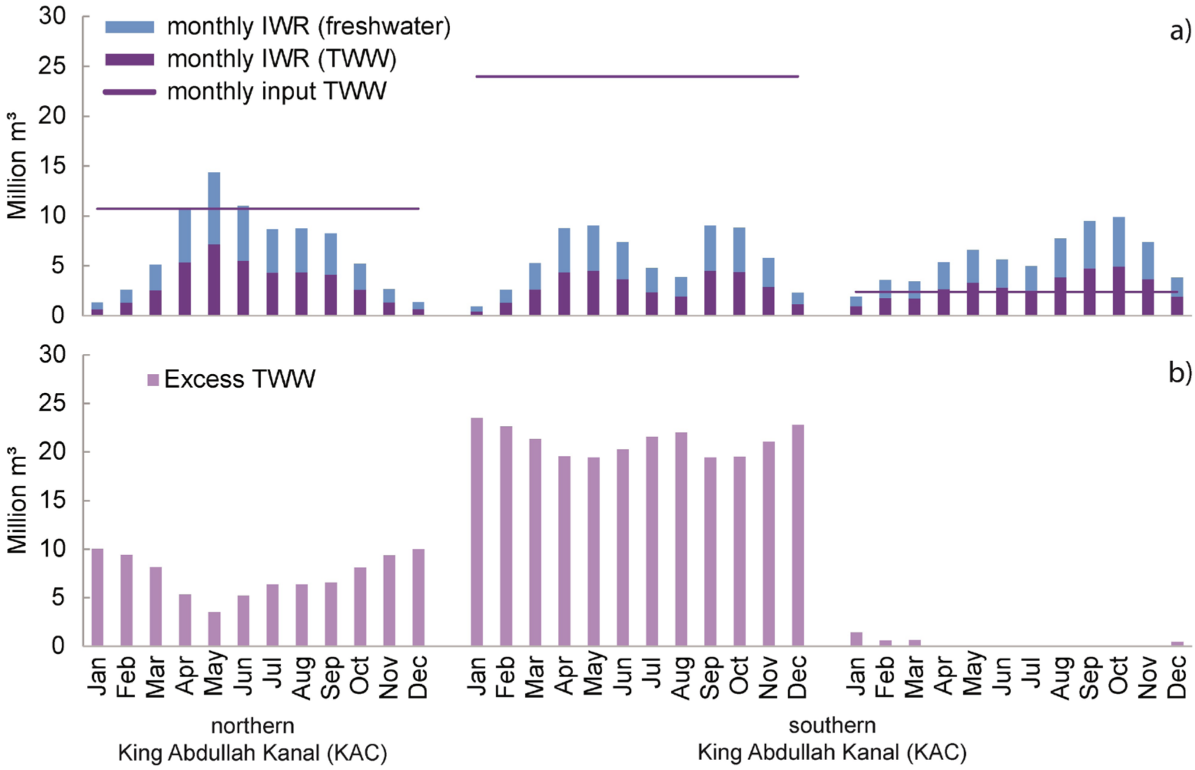

Figure 1 a) Monthly irrigation demand (IWR) in 2050 for the northern, central, and southern Lower Jordan Valley (Jordan), with the respective monthly inputs of treated wastewater from centralized solutions, and b) the monthly surplus of treated wastewater if the water is used for irrigation. The deficit of treated wastewater in the southern valley (March-November) must be covered with freshwater or treated wastewater from the central valley.

alluvial aquifer in the LJV [Groundwater Models of the Lower Jordan Valley Aquifer, p. 54]. On the Jordanian side, locations of potentially available storage volume in the subsurface are assessed, depending on the thickness of the unsaturated zone, effective porosity and the groundwater salinity, to avoid degradation of freshwater areas by infiltrated TWW. The conditions are transferred into a MAR potential with zones ranging from „none" to „high" potential. Furthermore, conceptual infiltration calculations by Xanke et al. (2019) are used to estimate the number and size of MAR plants to achieve a specific recharge volume.

The Palestinian side of the valley was divided into three zones (Jeftlek, Uja, and Jericho), to estimate the storage capacity per zone and the recovery rate for four injection/recovery scenarios illustrated as follows: SC1: Inject water informally to the demand areas, SC2 (based on SC1): abstract water (Recovery), SC3: Generate a hydraulic barrier to the east of the demand areas/Dead Sea, and SC4 (based on SC3): abstract water (Recovery). The storage capacity was computed considering the following constraints (1) no flow from the alluvial deposits to the mountain aquifer, and (2) no flooding allowed at the surface.

Jordan River floodplain rehabilitation is considered through the discharge of TWW using the river rehabilitation scenarios developed by Gafny et al. (2010). They developed five scenarios ranging from „Take No Action" to the „Full Restoration" scenario with intermediate steps of "Partial Restoration", "River Rehabilitation" and "Flow Enhancement". As one of the three reuse variants, the release of TWW into the floodplains of the Jordan River is evaluated from a quantitative perspective. Furthermore, the potential effect on the rehabilitation of ecosystems, river salinization, and declining Dead Sea water level is discussed. The latter is assessed with a water loss of up to 700 Mio. m³/a resulting in an average decline of more than 1 m in recent decades (ICL 2020).

RESULTS

Land use analysis revealed that ca. 12% of the area in the Jordanian section of the alluvial aquifer is unused grassland that could be converted into arable land. In this case, an average IWR of 261.3 Mio. m³/a could be reached by 2050. The volumes of TWW targeted for 2050 are sufficient to meet the IWR, except for some months of the year in the southern section (Figure 1a). The example for centralized solutions shows that IWR could be covered by using a 50:50 mixture of TWW and freshwater for irrigation with an excess of 314.5 Mio. m³/a, which is then available for managed aquifer recharge or the rehabilitation of the Jordan River and the Dead Sea.

Evaluation of the MAR map in Jordan (Figure 2c) shows four major sections in the alluvium of different MAR potential that differ in groundwater salinity, depth to groundwater, and aquifer porosity. Overall, most of the alluvial aquifer is

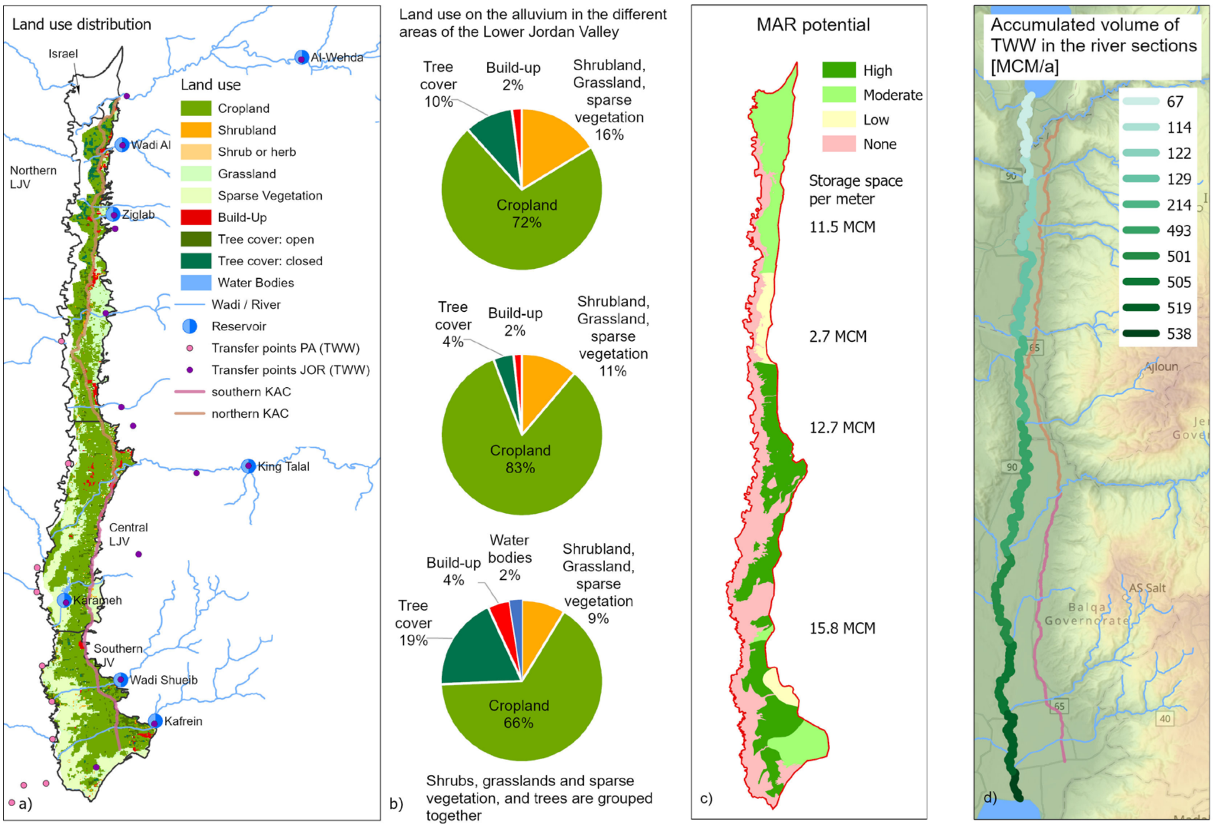

Figure 2 a) Land use in the Lower Jordan Valley (Jordan) with transfer points of treated wastewater from Jordan (JOR) and the Palestinian territories (PA), b) land use distribution, c) the derived potential map for managed aquifer recharge (MAR), d) accumulated volume of discharge in the different river sections if all of the treated wastewater is used for river rehabilitation (no base flow considered).

suitable for MAR using TWW, while zones of low permeability (red) are unsuitable. An increase in groundwater levels in the alluvial deposits by one meter would result in a storage volume increase of ca. 43 Mio. m^3 (Figure 2c). Using the approach presented by Xanke et al. (2019) showed that about 36 MAR plants with a size of 200 x 200 meters (40,000 m^2) would be required to infiltrate 43 Mio. m^3 per year. Surface infiltration is considered the most appropriate solution for the LJV. Experience for infiltration technology by infiltration ponds already exists (from Shafdan WWTP, close to Tel Aviv).

According to the numerical groundwater flow model of the Palestinian section of the Jordan valley alluvial aquifer, there is storage volume available for infiltration of treated wastewater to be recovered for irrigation of agricultural lands. Modelling results showed capacities for Jericho, Uja, and Jeftlek of 30, 8, and 15 Mio. m^3/a year , respectively. Should water be injected evenly across the respective demand areas (SC1), the maximum recommended water injection would be 30 Mio. m^3/a, with a recovery rate of 90% for the Jericho zone, while for SC3, maximum capacity would exceed 30 Mio. m^3/a, but only with a 70% recovery rate. Moreover, discharge to the Jordan River will increase by around 3 Mio. m^3/a for scenario SC3, which is twice as large as in scenario SC1.

Considering the rehabilitation of the Jordan River floodplains on the Jordanian side of the river, smaller volumes are transferred to the northern section and larger volumes to the central and southern sections (Figure 2d). The achievement level of the rehabilitation scenario (Gafny et al. 2010) would thus be up to about 34% in the northern part and

ALTERNATIVES WITH PRIORITIZATION	IRRIGATION	MAR	JORDAN RIVER	SUM TWW
Take no action	0	0	0	0
Irrigation before MAR and Jordan River	131	43	236	410
Irrigation before Jordan River and MAR	131	0	279	410

Table 1 Alternatives for treated effluent reuse on the Jordanian side of the LJV with the highest priority on irrigation and different priorities for MAR and Jordan River rehabilitation and the corresponding quantities of wastewater in [Mio. m^3/a].

fully reach it in the southern part with a significant dilution of the current salinity content in the Jordan River, which can reach about 11,000 ppm in the south (Gafny et al. 2010). Furthermore, a significant slowdown of the water-level decline in the Dead Sea (average loss of ~700 Mio. m^3/a) could be achieved, when all TWW is released into the Jordan River, and still be mitigated after subtracting irrigation use.

Table 1 summarizes the allocation of TWW for two reuse alternatives in Jordan considering the average amount of TWW of both treatment solutions, centralized and decentralized.

CONCLUSIONS

This study provides an overall analysis of reuse alternatives for treated wastewater in the Lower Jordan Valley as a key strategy for decision makers. Further detailed analysis would be required in a qualitative compatibility of each crop type with treated wastewater, an implementation of a test MAR pilot plant, as well as a meaningful water balance of the Jordan River with continuous monitoring of the water level and physicochemical parameters.

IRRIGATION WATER REQUIREMENT

For irrigation purposes, the IWR is determined, which is the sum of the individual Crop Water Requirement (CWR) according to:

$$\mathrm{CWR}_i = \sum_{t=0}^{T} (\mathrm{kc}_{i,t} \cdot \mathrm{ET}_o - P_{eff})$$

where *kc* is the crop coefficient of crop *i* during the growth stage *t*, and *T* is the final growth stage. ET_0 is the reference evapotranspiration (ASCE Penman-Monteith), and P_{eff} is the effective precipitation (taken as 80% of the total precipitation). In a specific system, the irrigation water requirement is the sum of the individual crop water requirements CRW_i, multiplied by the area under cultivation for the respective crops S_i.

$$IWR = \sum_{i=i}^{n} (CWR_i \cdot S_i)$$

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