SMART

12 years of multilateral IWRM research cooperation in the Lower Jordan Valley

Sustainable Management of Available Water Resources with Innovative Technologies

Key Products – Policy Briefs

Torsten Lange, Bernd Rusteberg, Martin Sauter (eds.)

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IWRM

SMART

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Cover picture: Oasis town of Jericho (https://commons.wikimedia.org/w/index.php?curid=12703612)

Contents

Dr. Christian Alecke, BMBF

Dr. Christian Alecke

Population growth, climate change and growing drinking water scarcity make the sustainable management of global water resources one of the biggest challenges of the 21st century. Within this setting, the Lower Jordan River constitutes not only one of the most severe examples of water stress today but is arguably also under the largest threat of future worsening of the situation.

The response to these challenges requires innovative technology as well as a society response with improved management of the limited resources in an integrated manner to secure peace, wellbeing and dignity for everyone.

Germany is aware of these challenges and has been a longstanding partner in supporting the riparians of the Lower Jordan River. A key role is the cooperation in high quality research on innovative water technologies and sustainable water management concepts. Water research projects funded by the Federal Ministry of Research and Education (BMBF) aim to inform decision makers, to establish efficient infrastructure, to raise awareness and last not least to build capacity at academic, school, vocational and institutional level. From the beginning, this included the concept of Integrated Water Resources Management (IWRM) which evolved from a conceptual idea to an established standard and a core element of the United Nations Sustainable Development Goals (SDG 6.5).

The IWRM-SMART-project presented here is part of the BMBF funding measure IWRM which pursued the concept of integrated water resources management in 17 large cooperation projects worldwide. IWRM-SMART is not only the largest of these projects but also the project with the longest history. Since its inception in 2006, we look back on 12 years of funding IWRM research at the Jordan River today. Considering the fact that BMBF supported also the GIJP-projects with German, Palestinian, Israeli and Jordanian partners since 1998, we can even celebrate 20 years of BMBF engagement for multilateral water projects in the region.

The set of SMART policy briefs in this brochure summarizes main outcomes of this remarkable process and I hope that it will be of use to a broader audience. An example for the significance and widespread recognition is the award of the most renowned environmental prize in Europe (the German Environmental Award 2018) for the research team working on decentralized wastewater management within SMART and the corresponding NICE-Office in Jordan.

What can we learn from SMART? One key to the success of SMART seems to be the cooperation and co-design at all levels. On the one hand, it is the close cooperation between academic researchers with the decision makers on national, regional and local level, which ensures the applicability and practical relevance of the outcomes. On the other hand, SMART achieved a constant and trusted cooperation between German, Israeli, Palestinian and Jordanian partners, which led to trustful knowledge exchange on a technical level as well as contributed to the area of water diplomacy.

I congratulate all the SMART partners who invested much of their energy during the last decade. I hope that the seeds spread by this research will receive further attention so that they can grow for the benefit of everyone living at the Lower Jordan River.

Christian Alecke

Preface of the SMART Partners of the Region

Successful and unique transboundary collaboration in the water sector.

On behalf of the local SMART and associated partners we would like to express our gratitude to the German Federal Ministry of Education and Research (BMBF) for funding the SMART (Sustainable Management of Available Water Resources Using Innovative Technologies) projects during the last 12 years, together with the GIJP-Projects, we can look back to 20 years of successful collaboration in the Lower Jordan Valley. The continued support resulted in a strong momentum in the water sector development of the Lower Jordan Valley region which suffers from increasing and severe water scarcity.

The implementation of the Integrated Water Resources Management (IWRM) concept by the SMART projects has been promoted by a wide spectrum of scientific methods, expert tools and innovative technological solutions for sustainable water development towards resilient water resources systems. This includes the development of water resources planning and management plans and guidelines and early warning systems for safe domestic water supply, wastewater treatment and reuse, environmental and water resources protection as well as irrigation development, considering all available sources of water. The suggested development water plans and strategies will enhance the high agricultural and economic potential of the region and contribute to improved living conditions of the local population. The SMART projects demonstrated impressively how close and trustful long-term transdisciplinary collaboration between national stakeholders, decision makers, researchers and companies, even under difficult climatic and political conditions, can significantly contribute to sustainable transboundary water resources development.

We wish to thank the SMART team, especially the initiator of SMART, Professor Heinz Hötzl, for this successful work during the last 12 years, based on mutual trust and durable friendship among the project participants.

The results speak for themselves. The project achievements constitute the basis for further strengthening the regional IWRM implementation process and future multilateral research cooperation, focusing on the regional challenge to cover the steadily increasing water deficits in Jordan and the Palestinian Territories based on water transfer and SWAP solutions.

The partners do believe that regional cooperation is not only the optimal way to meet the increasing demand but will act as a catalyst for the stability in the region.

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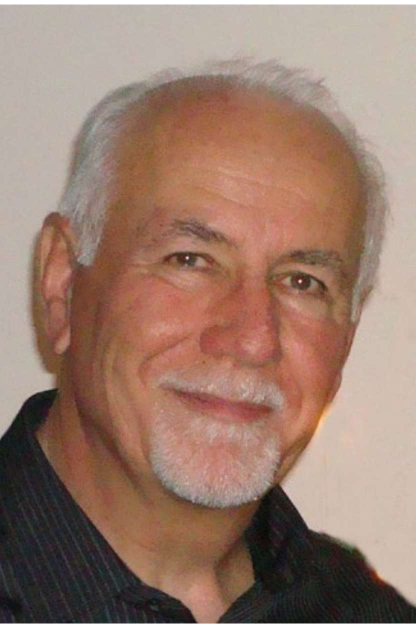
Prof. Dr. Heinz Hötzl



Prof. Dr. Heinz Hötzl

With the 2000 Millennium Declaration, the United Nations not only drew attention to the lack of drinking water supply to large parts of the world population and the resulting health problems, but also called on the member nations to provide comprehensive support in solving this great challenge.

As a contribution by Germany, the Federal Ministry for Research and Technology (BMBF) initiated the innovation platform „Research for Sustainable Development (FONA)", in which the joint project „Integrated Water Resources Management (IWRM)" was launched in 2004. The overall objective was to develop solutions for sustainable water management through interdisciplinary management approaches and implement them in selected model regions. Building on a previous multilateral project on water resources In the Jordan Valley (GIJP project 1997-2004), the international SMART consortium from Germany, Israel, Jordan and the Palestinian Territories successfully participated in the bidding process of the BMBF. One of the most important projects in the BMBF IWRM program was the promotion of the SMART (Sustainable Management of Available Water Resources with Innovative Technologies) project in three phases between 2006 and 2018 with the focus on developing and implementing a comprehensive and sustainable IWRM concept for the catchment area of the Lower Jordan River with its extreme scarcity of water and its problematic political borderline location. Efforts were made to improve water availability and sustainable management through innovative technologies to create transferable approaches to integrated water resources management for semi-arid regions.

The development of the IWRM concept to the implementation of individual solutions required a step-by-step approach and took place in three phases – SMART I (2006-2010), SMART II (2010-2013) and SMART-Move (2014-2018). In focus of the first phase was the inventrory of all available water resources including previously unused brackish and saltwater resources as well as wastewater in addition to surface water and groundwater. This required the compilation of available data as well as detailed hydrological surveys in selected sub-basins. In the second phase, especially the new technological approaches were pursued. The main focus of this work was the application of new techniques in the field of decentralized treatment and reuse of wastewater, controlled groundwater recharge and brackish water desalination in the form of test, demonstration and pilot plants. The third phase with the SMART-Move project was the actual implementation phase of the overall project, which aimed at both the transfer of innovative technologies and management tools to the water management practice. In addition, large-scale cross-sectoral studies were carried out in order to develop interdisciplinary decision-making aids for the required governance.

The great success and widespread acceptance of the proposed solutions – some of which were directly incorporated in national water planning – is based on the consideration of the diverse requirements of a sustainable water management, not only in terms of the availability of the various resources, but also in terms of socio-economic and ecological needs. Decisive for the special success of the project as a whole was the close and trusting cooperation of all involved groups starting from the state stakeholders in the partner countries with the specialized ministries and the competent water and environmental authorities, the companies and consultants as well as the participating scientists from universities and research institutions from the four participating countries.

The fruitful cooperation between all participating project partners with the innovative management concept was able to contribute to a constructive understanding of the different water interests of the participating riparian states despite the tense political situation in the region.

Heinz Hötzl

Consortium

Germany

- ATB Water GmbH (ATB)
- BAUER Resources GmbH (BAUER)
- Brandenburg University of Technology (BUT)
- Development and Assessment Institute in Waste Water Technology at RWTH Aachen (PIA)
- Disy Informationssysteme GmbH (DISY)
- DVGW - Research Center at Engler-Bunte-Institut (EBI)
- DVWG - Water Technology Center, Karlsruhe (TZW)
- Georg-August-University Göttingen (UGOE)
- HUBER SE (HUBER)
- Kreditanstalt für Wiederaufbau (KfW)
- Ruprecht-Karls-University Heidelberg (HU)
- Helmholtz Centre for Environmental Research (UFZ)
- Karlsruhe Institute of Technology (KIT)
- Rusteberg Water Consulting UG (RWC)
- SEBA Hydrometrie GmbH & Co. KG (SEBA)
- Stulz-Planaqua GmbH (SPA)
- Training and Demonstration Centre for Decentralized Sewage Treatment (BDZ)

Israel

- Ben-Gurion University of the Negev (BGU)
- Environmental & Water Resources Engineering (EWRE)
- Hebrew University Jerusalem (HUJ)
- Mekorot Water Company Ltd. (MEK)
- Tel Aviv University (TAU)
- Water Commissioner, Tel Aviv (WCI)

Jordan

- Arab Technologist for Economical and Environmental Consultation (ATEEC)
- Al-Balqa Applied University (BAU)
- ECO-Consult, Amman (ECO)
- Jordan University (JUA)
- Jordan Valley Authority (JVA)
- Ministry of Water and Irrigation (MWI)
- National Implementation Committee for Effective Decentralized Wastewater Management in Jordan (NICE)
- Wakileh & Contracting (NAW)
- Water Authority of Jordan (WAJ)

Palestinian Territories

- Al-Quds University (QUDS)
- Hydro-Engineering Consultancy (HEC)
- Ministry of Agriculture (MoA)
- Palestinian Hydrology Group (PHG)
- Palestinian Water Authority (PWA)

Introduction

Background

With different local foci the project region of the Lower Jordan Valley (LJV) extends from south of Lake Tiberias to the northern coast of the Dead Sea and includes the upstream wadi catchments in the mountainous areas of the West and East Bank, respectively (Figure 1). The LJV is shared by the three neighboring partner countries of Israel, Jordan and the Palestinian Territories. It is one of the numerous regions in the world that is characterized by extreme natural water shortage due to its semi-arid to arid climatic conditions, limited water availability, extreme hydrological variability, and dynamically increasing water demand driven by a continuous and substantial population growth. Widespread groundwater deterioration due to wastewater infiltration and increasing salinities, as well as the reduced flow rates of the Lower Jordan River caused by the regulated outflow from Lake Tiberias are additional anthropogenically induced stress factors for the water resources system. The most significant impact on groundwater quality is a result of an insufficient and ineffective infrastructure for wastewater collection, treatment and disposal of the residuals. Also, unexpected external pressures such as regional linear or cyclical changes of the climate pattern along the western and eastern mountain ranges or the Syrian war affect the fragile water situation in the project region. The Syrian war and the consequential influx of refugees, for example, has tremendously increased the already severe pressure on the water and infrastructural demand in Jordan due to the required extra supply for more than one million registered and unregistered Syrian refugees. This led to a considerable over-pumpage of the groundwater resources, in turn requiring the deepening and drilling of new wells. Groundwater vulnerability and pollution further increased to a major problem for water suppliers due to excess load on sewer networks and wastewater plants and the uncontrolled expansion of domestic and industrial areas. Similar problems in Palestinian Territories caused by groundwater over-exploitation and pollution are superimposed by the very difficult political and territorial, as well as economic and social situation under which sustainable water planning is seriously hampered. Lake Tiberias, the most important regional surface water reservoir is another example for the challenges associated with regional water resources management. With Israel abstracting significant volumes of water from the lake for distribution through the Israeli National Water Carrier since 1964, persistently low lake water levels developed during major dry periods during the last two decades. While changing climatic conditions were believed to be the major factor for the decreasing water inflow to the lake and higher salinities, recent research indicates more complex causes including increasing groundwater abstraction in the groundwater basin since the 1950s. In late 2018 the Israeli government approved an emergency plan to transfer desalinated Mediterranean Sea water to Lake Tiberias starting in 2019 to stabilize its water level and use it as a storage reservoir for the excess production of desalinated water during the winter season. The large scale commercial sea water desalination since 1999 fully reshaped the national water resources management strategy in Israel.

Coordination Meeting of the GIJP Group, March 2005, Jordan
(© Heinz Hötzl)

Due to generally weak national economic performances the younger generation in the project region faces multiple challenges especially with regard to their professional education and career perspectives. Only a comprehensive strategic orientation of the water sector together with more regional and international cooperation will improve the concrete living conditions and ensures predictable development potentials for agriculture, industry, tourism, and the service sector. This includes institutional development, professional and technical training and school education programs that need to keep pace with the technological and methodological innovations in the water sector and the regulatory requirements for the national IWRM implementation processes.

Existing limited water swap contracts need to be extended via a political process to negotiate and arrange alternative, regional, and transboundary IWRM strategies. The necessity is being increasingly realized in the three neighboring partner countries.

Objectives

The central goal of the SMART research and implementation project is the integrated transfer of innovative technologies and management instruments to the water management practice of cooperation partners in Israel, Jordan and the Palestinian Territories. Particular emphasis is placed on the testing and improvement of the robustness of water resource systems with respect to the observed high hydrological variability with often extreme events such as droughts and floods.

Generalized concepts for IWRM implementation were developed on the basis of catchment clusters on both sides of the Lower Jordan River, which take into account the social, economic and environmental policy strategies of the individual states. These water plans will provide better protection against the negative impact of extreme events (floods, droughts), and contribute to an improved water supply reliability, water availability, efficiency of water use, and resource protection. A wide spectrum of individual water management measures and technologies such as surface water storage, artificial aquifer recharge, decentralized wastewater treatment, brackish water treatment, well systems, technical standards, guidelines and policies, institutional development, knowledge transfer and capacity building are expanded into overall strategies.

The level of catchment clusters is large enough to validate the IWRM implementation concept and to make optimal use of the spectrum of water management measures and small enough to be tackled within the frame of a research-oriented project. Eastern and western cluster cover the bandwidth of hydrological-hydrogeological, land use and management characteristics as a prerequisite for a later generalization and transfer of the concepts and methodologies to other regions.

Project organization

The SMART research expended over three project phases and involved all necessary local partners to make it a success story: decision makers, stakeholders, as well as academic and industry partners. Its workflow relies on the three innovative scientific and technological based main pillars, which are cross-sectionally linked and supported by an institutional Implementation concept on the one hand and a Knowledge Transfer and Capacity Development concept on the other hand (Figure 2).

The first pillar (A) Monitoring and local Raw Water Management assesses the long-term availability and quality of the exploitable conventional and non-conventional water resources employing partly telemetric automated precipitation, runoff and spring monitoring, scenario deduction and automated Early Warning Systems

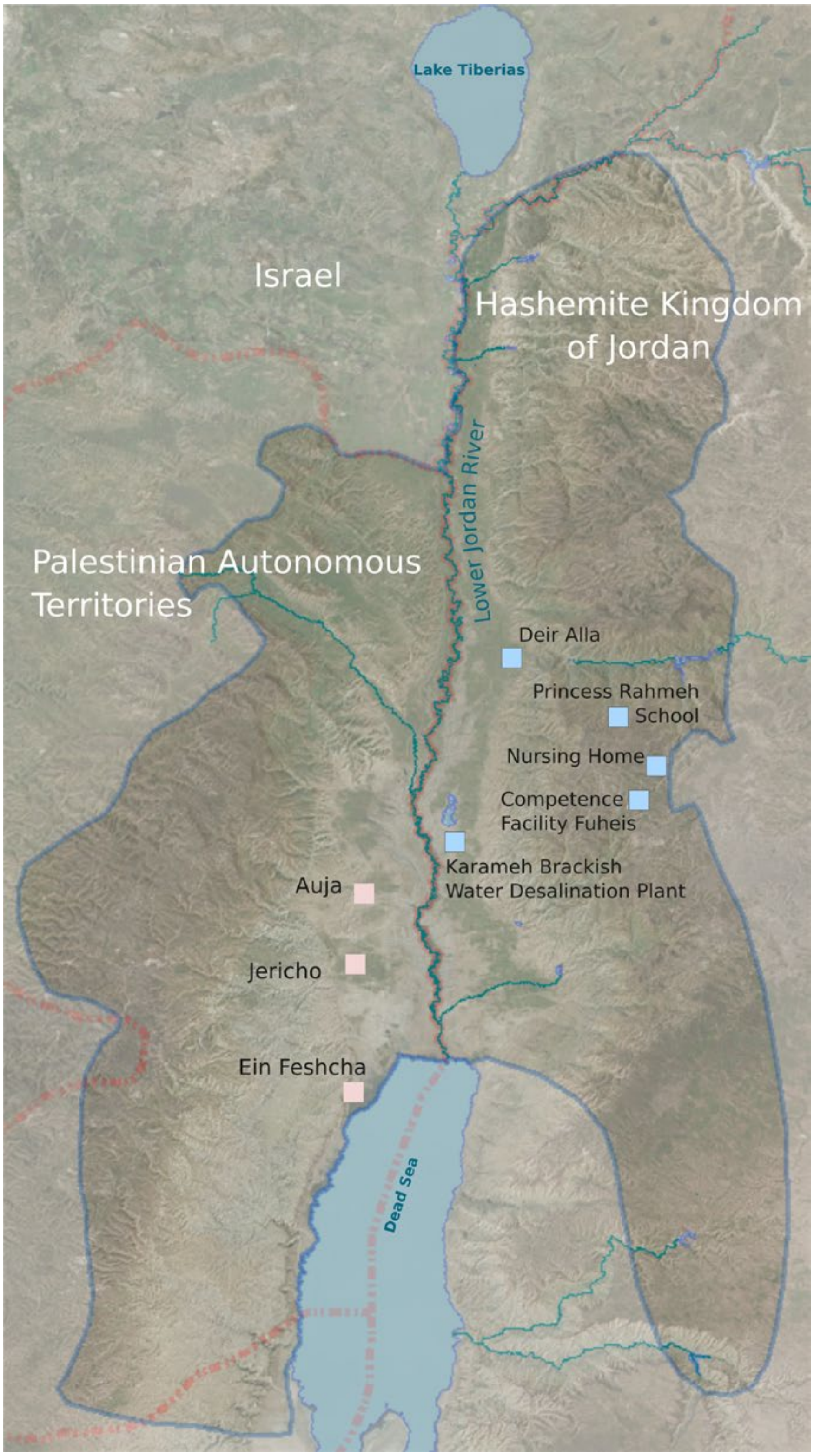


Figure 1: Overview map of the SMART-MOVE project region in the Lower Jordan Valley with a selection of focus sites.


View over the Jordan Valley (© Heinz Hötzl)

based on water quality parameters as well as conceptual and numerical groundwater modeling. The second pillar (B) Implementation of innovative Water Technologies addresses the innovative water technologies that are suitable and adjusted to the local requirements to implement all technologically-based components of the comprehensive IWRM concept, such as artificial aquifer recharge, decentralized wastewater treatment, brackish water desalination, as well as norms and guidelines. While component (C) Integrated Planning Tools for IWRM Implementation originally focused on catchment cluster scale and with appropriate generalization on a national level a complementary approach was introduced with the sub-project SALAM. The latter takes up the imperative for regional strategies for transboundary water management based on the provision of large-scale sea-water desalination, i.e. beyond the available resources. This aims at providing additional options and boundary conditions for water resources planning, because all quantitative data indicate that the natural water resources in the LJV are insufficient to cover the increasing water deficits due to a fast-increasing water demand, driven by high population growth rates and groundwater deterioration.

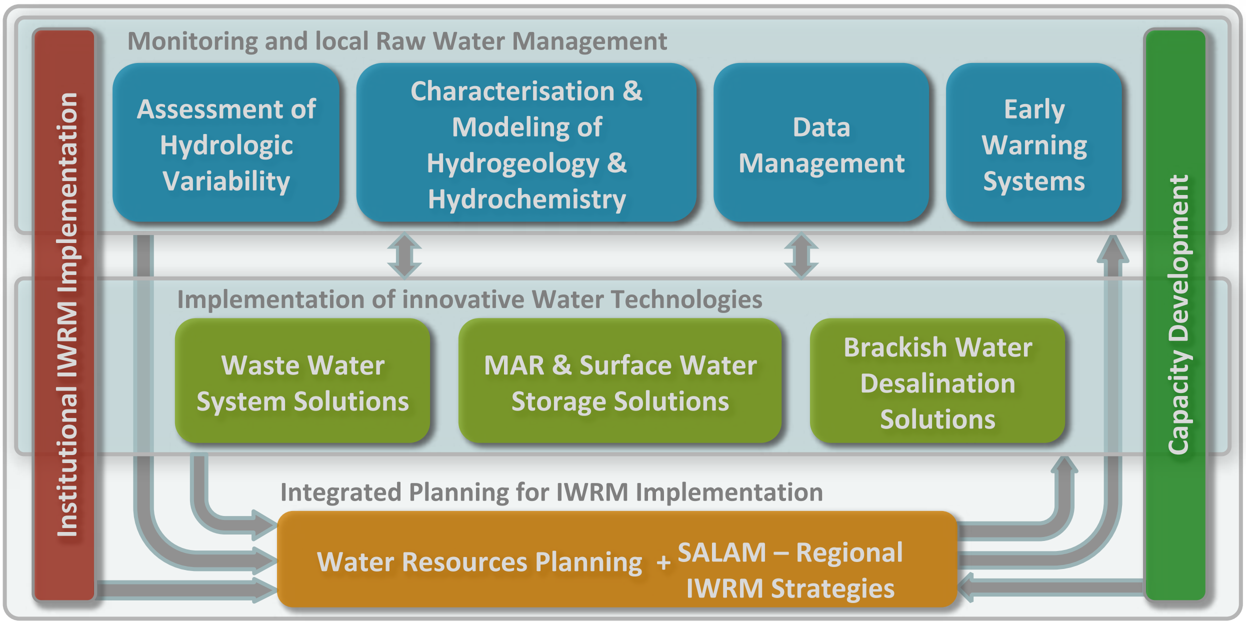
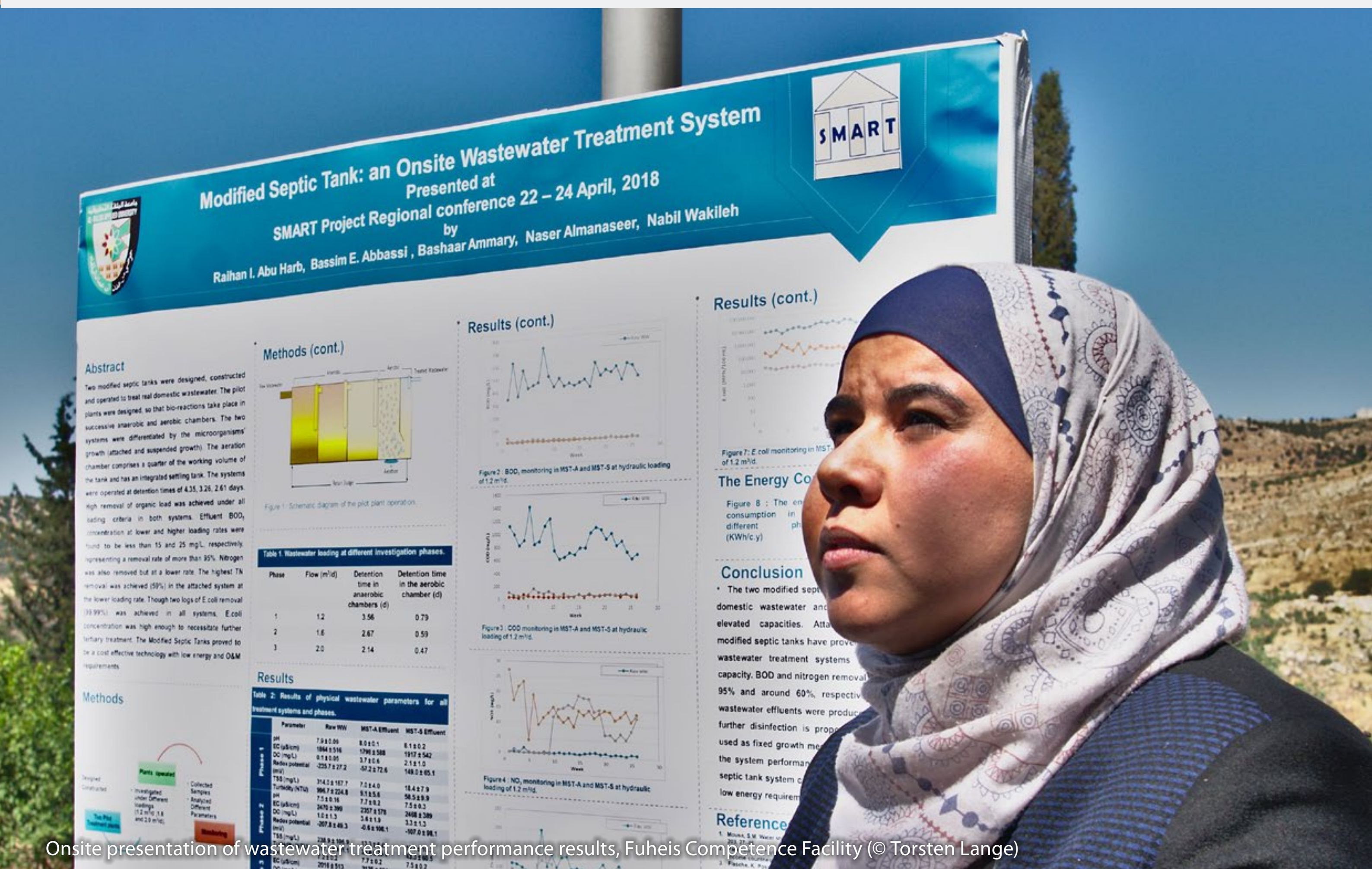


Figure 2: Schematic of the SMART IWRM Research Concept.

Beach terraces of the declining Dead Sea water level on the Jordanian side (© Heinz Hötzl)



Onsite presentation of wastewater treatment performance results, Fuheis Competence Facility (© Torsten Lange)

SMART work group from UFZ/BDZ receives German Environmental Award 2018 (© Deutsche Bundesstiftung Umwelt)


SMART-MOVE Transfer Meeting, 2018 (© André Künzelmann)

Onsite visit at Fuheis Competence Facility (© André Künzelmann)

NICE Steering Committee Meeting, 2018 (© André Künzelmann)


Yarmuk River (© Julian Xanke)

MONITORING AND LOCAL RAW WATER MANAGEMENT
Hydrological data acquisition, variability scenarios, and modeling for water resources planning – Jericho-Auja
Groundwater Model of the Shallow Aquifer of Jericho-Auja
The Marsaba-Feshcha groundwater basin and Ein Feshcha spring group: vulnerabilities, risks, water resources potential
Early Warning System for spring water contamination in Wadi Shueib
Vulnerability and risk mapping to strengthen the link between waste water treatment and groundwater protection in the hot spot area Wadi Shueib
Drinking water protection for a large-scale managed aquifer recharge site in a semi-arid karst region, Jordan
Identification of contamination pathways in a karst aquifer at Hidan well field by tracer testing
Transboundary Hydrogeological Model of the Lower Jordan Valley

IMPLEMENTATION OF INNOVATIVE WATER TECHNOLOGIES
Managed aquifer recharge planning for the Jericho-Auja area
Managed aquifer recharge (MAR) along the eastern Lower Jordan Valley - General Potential and Deir Alla Test Site
Managed aquifer recharge (MAR) into a karst groundwater system at Wadi Wala, Jordan
A Handbook on Brackish Water Usage in Water-Scarce Regions – The Jordan Valley
Treatment performance and suitability of EU-Certified DWWT-technologies treating strong wastewater representative for Jordan
Real-Scale Implementation of Decentralized Wastewater Treatment and Reuse Systems
Competence Facility for Decentralized Wastewater Management
National Implementation Committee for Effective Integrated Wastewater Management in Jordan – NICE
Water Fun – hands, minds and hearts on Water for Life!

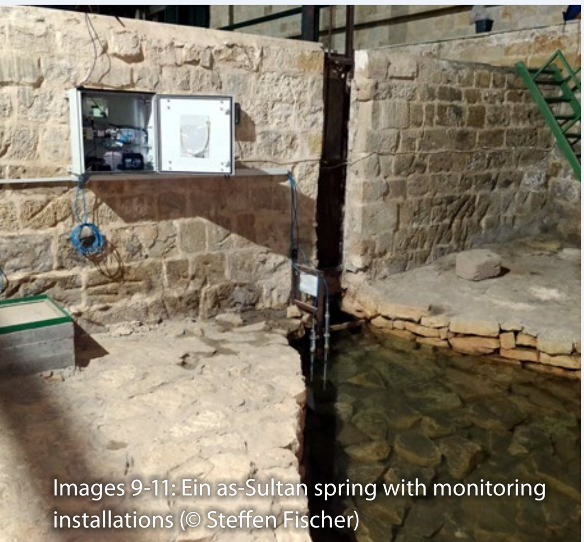
INTEGRATED PLANNING FOR IWRM IMPLEMENTATION
IWRM Concept and WEAP-Application, Cluster West
Socioeconomic and Political context of Integrated Water Resources Management in the Lower Jordan Valley
Economic assessment of alternative water plans in Jordan
Water management scenarios for Wadi Shueib using WEAP and MODFLOW models
GIS-based decision support: Assessment of Local Lowest-Cost Wastewater Management Solution (ALLOWS)
The SALAM Initiative: Concepts and Approaches for the Resolution of the Water Deficit Problem in the Middle East at Regional Scale

Images 1-5
Wadi Auja/Wadi Qilt (© Steffen Fischer)

© Steffen Fischer

Baqqouria spring, Wadi Shueib (© Felix Grimmeisen)

© Anna Ender



Images 9-11: Ein as-Sultan spring with monitoring installations (© Steffen Fischer)

Monitoring and Local Raw Water Management

> Hydro(geo)logical data acquisition under (semi-) arid conditions

> Assessment of the climatic and hydrological variability and scenario development

> Hydro(geo)logical modeling towards sustainable groundwater management

> Assessment of groundwater potential, vulnerability and related exploitation risks

> Implementation of early warning systems for spring water contamination

> Groundwater risk assessment as basis for sustainable urban planning

> Wastewater management and groundwater protection

> Groundwater vulnerability mapping to protect drinking water supply

> Contamination pathways in karst aquifers under MAR conditions

> Transboundary groundwater modeling

Hydrological data acquisition, variability scenarios, and modeling for water resources planning – Jericho-Auja

Sebastian Schmidt[1], Torsten Lange[1], Martin Sauter[1]

KEY FINDINGS

The quantity and quality of water resources in the study region is characterized by high variability on both, short-term and long-term temporal scales.

To assess long term hydrological variability, data from the past 104 years were analyzed.

High-resolution monitoring data gathered during SMART enabled the setup and calibration of various hydrological models required for water resources prediction.

Natural water resources were assessed for various hydrological 20-year scenarios, with a focus on (extreme) drought situations.

Introduction and Objectives

The area of Jericho-Auja and the related wadi catchments and groundwater recharge areas in the highlands of Jerusalem-Ramallah was a focus area regarding the assessment of water resources during all phases of the SMART-project. Like the project region in general, the specific study area is characterized by a short-term as well as long-term hydrological variability with respect to the quantity and quality of available water resources.

Quantitative hydrological data are a prerequisite for water management on a local scale (e.g. for water suppliers depending on karst springs) as well as the planning of water supply systems and their resilience against variable/extreme hydrological conditions (especially extended drought periods). Groundwater resources are difficult to predict because of their storage behavior of the aquifers. Surface water resources are mainly provided by flash floods, i.e. high intensity flows of short duration difficult to gauge and difficult to utilize. Groundwater quality concerns are mainly due to the rapid transport of pollutants (e.g. from wastewater infiltration) in the karst aquifers as well as long-term effects of pollution, e.g. rising nitrate concentrations.

Methodology

To evaluate the hydrological variability on a short-term basis and to initiate monitoring sites for long-term water resources assessment, a large number of hydrological monitoring sites were established during the project (e.g. Ries et al. 2015, Schmidt et al. 2017 & 2018). These included: automatic precipitation measurement stations, meteorological stations, gauging stations for flash flood runoff, soil moisture monitoring, groundwater head monitoring and spring discharge and water quality monitoring.

To evaluate drought and pluvial periods and cycles, available long-term hydrological data were assembled. Hereby, Jerusalem exhibits a long-term record of precipitation monitoring and climate data. For the analysis, data of the hydrological

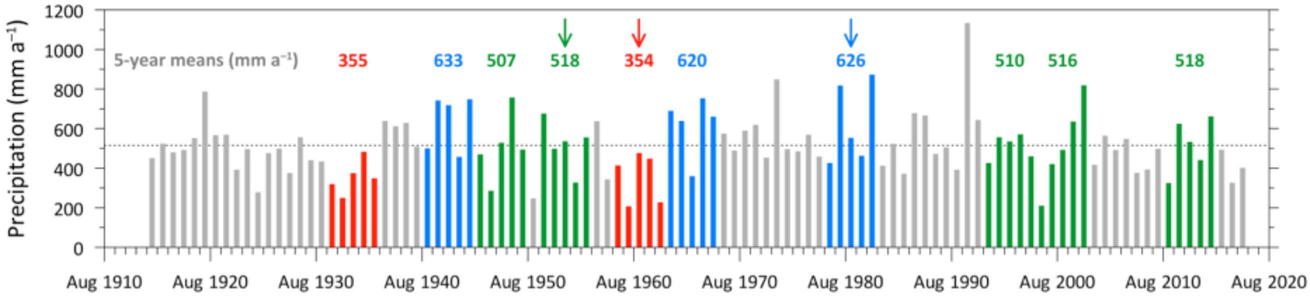


Figure 1: Representative 5-year drought, medium and wet periods selected from the long-term precipitation record (rain gauge at Jerusalem). The selected periods employed for the construction of the 20-year scenario combinations are indicated by arrows.

years 1915–2018 were compiled and analyzed. They served for the selection of hydrological scenarios and subsequently for the calculation of water resources by hydrological models.

Surface runoff of the three main wadis in the study area for the scenarios was predicted by empirical relationships developed by Ries et al. (2017) based on comprehensive runoff monitoring. Groundwater recharge and spring discharge were modeled and analyzed by reservoir models, which were individually developed for the four main springs and spring groups in the area (e.g. Schmidt et al. 2014).

Results

The monitoring stations, especially those with remote data transmission, provide the data for local raw water management and early warning systems, especially regarding spring water supplies. Transport time lags in the aquifers (e.g. fecal contamination introduced/mobilized by intensive precipitation events) can be quite variable and can range from less than one hour to about one week.

The scenario data enable the planning of water resources supplies and to enhance the resilience of water supply systems

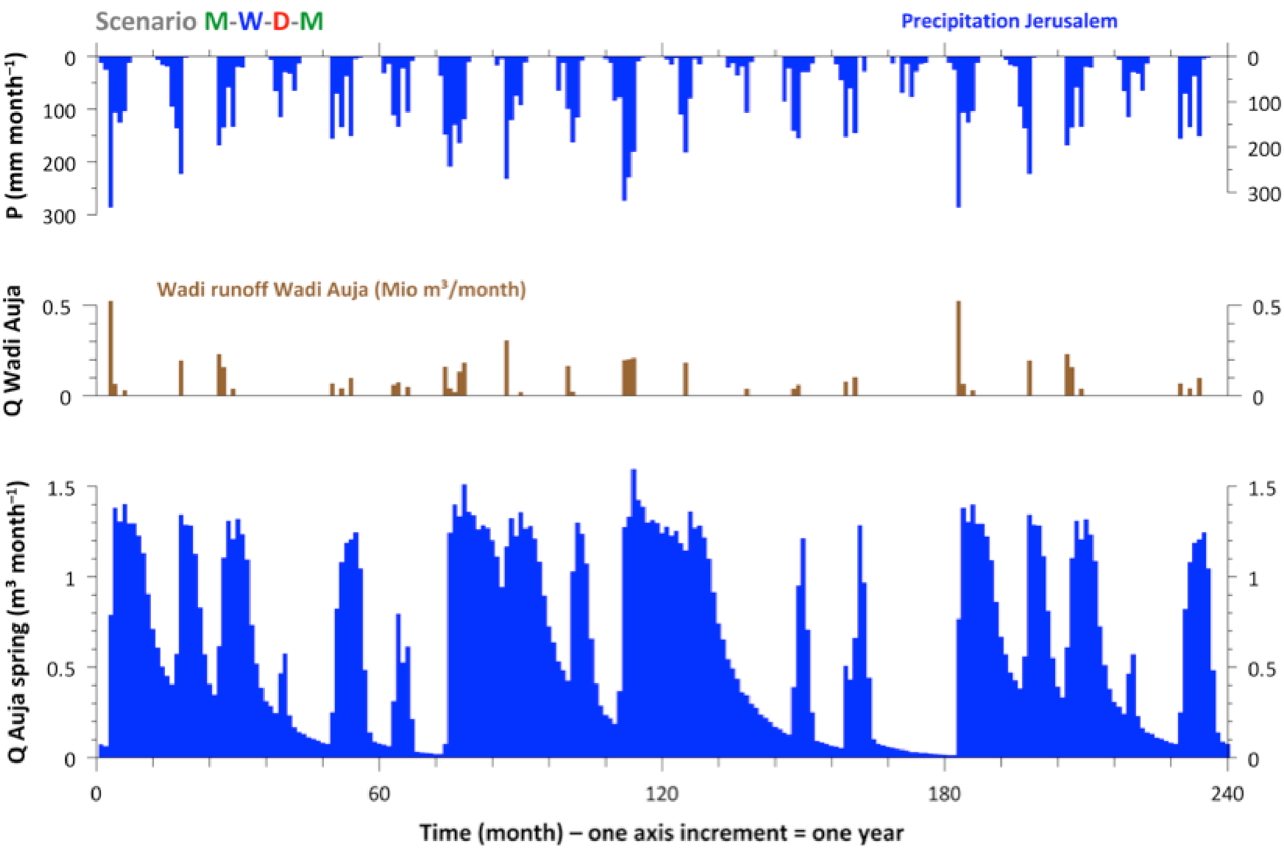


Figure 2: Calculated hydrological time series for the 20-year scenario combination Mean-Wet-Drought-Mean for Wadi Auja. Wadi flow (calculated for a surface catchment area of 55 km²) is of minor importance compared to spring discharge from Auja spring. Due to the high interannual variability even periods of overall mean to wet hydrological conditions can exhibit drought years and even multi-year drought periods (e.g. months 36–75 in the above figure).

against variable and especially low supplies. Figure 2 exhibits an example for the calculated scenario data for the northernmost watershed in the cluster, Wadi Auja. The example reflects long-term mean hydrological conditions with a high variation in natural water resources. Furthermore, two extended drought scenarios were developed. For example, those long-term drought periods (10–12 years) exhibit recharge rates that amount to only 24 % and 34% of the long-term average groundwater recharge.

Further Research Needs

Further research should be focused on the detailed spatial and temporal distribution of the precipitation by e.g. CML – techniques (commercial microwave link; Smiatek et al. 2017) and the delineation of the catchment areas in order to be able to associate the spring discharge response with catchment input time series. That way, we believe that the findings and the methodology can be generalized and transferred to other regions. The issue of catchment delineation is ubiquitously associated with carbonate aquifers and always a challenge. With the above information discharge variation can be predicted more reliably.

Capacity Development

The installation of the monitoring stations and the field work for maintenance, data readout and field measurements were accomplished in cooperation between the German partners (UGOE, SEBA) and the partners in the region. The local partner institutions also included local water suppliers (mostly on municipality level), which utilize the respective water resources for drinking and irrigation water supply. During the joint field visits, training was performed on the job, i.e. directly related to the individual monitoring installations. Furthermore, small individual workshops were conducted at the individual water suppliers and institutions. For the in-depth training of operation and maintenance of monitoring equipment, remote data-transfer and early warning systems for spring water contamination (see the corresponding chapter), a comprehensive 4-day workshop was conducted in Amman, Jordan in cooperation with project partners from KIT (main organizer) and SEBA.

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Monitoring installation at Ein as-Sultan (© Fabian Ries)

Installed weather monitoring station (© Sebastian Schmidt).

Project publications

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View along the western boundary of the Jericho-Auja Shallow Aquifer groundwater model (© Steffen Fischer)

Groundwater Model of the Shallow Aquifer of Jericho-Auja

Muath Abu Sadah[1/3], Amer Marei[1], Torsten Lange[2], Sebastian Schmidt[2], Florian Walter[2/4], Bernd Rusteberg[4], Martin Sauter[2]

Introduction and objectives

The groundwater model of the alluvial Shallow Aquifer of Jericho-Auja is an essential element of the tool chain to support the development and implementation of alternative water planning strategies in the context of an integrated IWRM approach for the Qilt-Nueimah-Auja Catchment Cluster on the western side of the Lower Jordan Valley (LJV). In combination with dedicated water resources planning tools such as WEAP or multi-objective optimization approaches the impact of action plans, water development scenarios, or strategies can be evaluated under different conditions in terms of environmental, social and economic sustainability, cost-efficiency, and resilience.

Methodology

All available hydrogeological and hydrological data like the structural and stratigraphic setting, the aquifer material, pumpage from the alluvial aquifer, aquifer recharge (rainfall, mountain runoff, agricultural return flow, leakage from agricultural and domestic water networks and cesspits), lateral inflow from the limestone formations of the Mountain aquifer, water level distributions, and more were used to construct and parameterize the numerical groundwater flow model. The mountain runoff itself is derived from calibrated rainfall-runoff models. Groundwater model calibration was performed based monthly time series data for the time period 2000 to 2014.

KEY FINDINGS

A transient numerical flow model of the Shallow Aquifer of the Jericho-Auja area was developed and calibrated for the period 2000 to 2014 on a monthly basis to support the development of MAR planning options and the optimization of alternative water strategies for IWRM implementation.

The budget assessment indicates average annual replenishment rates of ca. 9 Mm^3 for the period of 2000-2014 with ca. 6 Mm^3 through lateral inflow from the Cretaceous limestone formations of the Mountain Aquifer and ca. 3 Mm^3 of surface water recharge. Interestingly, the simulations show some flexibility of the groundwater system due to compensatory lateral inflow from the carbonate Eastern Mountain Aquifer in response to increasing well abstraction.

However, significant model uncertainties exist and are related to:

- pumping rates from agricultural wells,
- lateral flow rates from the deep limestone formations of the Mountain Aquifer along the western model boundary,
- limited spatial and temporal distribution of water level observations,
- the complex sedimentary setting of the alluvial aquifer.

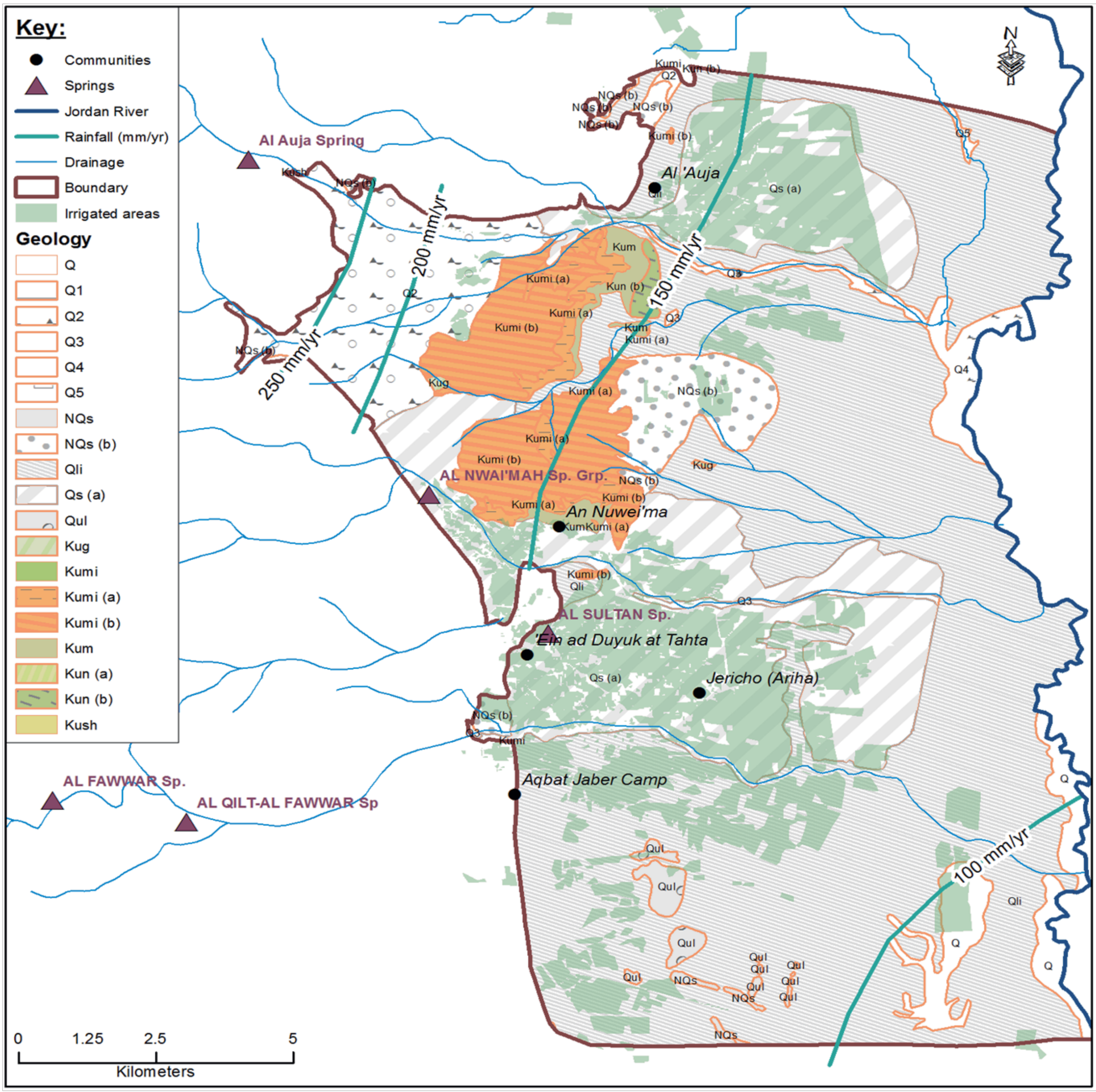

Figure 1: Overview map of the study area: geology, precipitation, irrigation areas, springs and model boundary.

The main challenges for the development of a sound groundwater model for the Jericho-Auja area are related to:

> the estimation of annual pumping rates from the agricultural wells due to insufficient monitoring and the existence of unregistered wells,

> a sufficiently realistic understanding of the lateral inflow processes from the limestone formations of the Mountain Aquifer along the western model boundary,

> the limited spatial and temporal distribution of water level observations

> and the complexity of the hydraulic parameter distribution in the Shallow Aquifer regarding horizontal and lateral transitions between coarse and fine siliciclastic detritus along the western Jordan Valley boundary and the alternation of alluvial deposits and lacustrine marls or gypsum layers of Lake Lisan, the Dead Sea precursor.

Results

A diligent budget assessment indicates that the average annual total replenishment of the Shallow Aquifer of Jericho-Auja for the period of 2000-2014 amounts to ca. 9 Mm^3/a with ca. 6 Mm^3/a through lateral inflow from the deep Cretaceous limestone formations of the Eastern Mountain Aquifer along the western model boundary and ca. 3 Mm^3/a of surface water recharge including predominantly surface runoff, precipitation and water from the Auja reservoir, but also network losses and agricultural and waste water return flow. Interestingly, the simulations show that the increasing trend of well abstraction during the investigated period leads to a compensatory lateral inflow from the Mountain Aquifer. In 2013/2014 when the estimated pumpage exceeded 12 Mm^3/a, the predicted total lateral inflow increased to 8 Mm^3/a, which needs further examination.

It was shown that the model is suitable for the planned purpose and goals described in the introduction, which are groundwater flow prediction, MAR planning, and application as assessment and verification tool for testing and optimizing alternative water strategies and IWRM implementation concepts. This allows the simulation of the impact of different agricultural, socio-economic, and industrial development scenarios under changing climatic conditions on the water level stability of the alluvial Shallow Aquifer. An optimized operation strategy for the aquifer was developed for the mid-term range until 2035 by MAR planning and optimization as part of the implementation of an integrated IWRM approach.

Further Research Needs

The continuous improvement of the understanding of the Shallow Aquifer system in the Jericho-Auja area and the capability of its reliable management should be a component of the IWRM concept for the Catchment Cluster West.

To reduce possible ambiguities and uncertainties of the groundwater flow model,

> all production including unregistered wells should be equipped for reliable and precise monitoring of pumpage,
> it is recommended to assess the capabilities of the current water level monitoring network and to appropriately implement necessary adjustments to achieve a better and optimized spatial representation taking the model results into account,
> the understanding of the sedimentary setting of the aquifer must be improved to identify homogeneous areas, lateral and horizontal permeability contrasts, and preferential flow paths, and, in turn, to define promising locations for new productive wells and groundwater observation sites.
> The concern of an increasing number of agricultural production wells that are affected by increasing salinities and other pollutants should be motivation to create the scientific basis for appropriate measures for groundwater protection by
> monitoring the spatial and temporal distribution of suitable hydrogeochemical and tracer components and water isotopes
> developing and implementing conceptual transport models.

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Capacity Development

The model was developed by Dr. Muath Abu Sadah, who did is Ph.D. under the supervision of the Göttingen group and who founded his own Consultancy company HEC. UGOE, RWC, HEC, and PWA conducted two workshops on the Shallow Aquifer model in Göttingen and Ramallah in 2016 and 2017. This demonstrates a successful knowledge transfer as well as the implementation of high-level modelling skills in the area. Furthermore, it ascertains that the research results will be further refined to the benefit of the local population

Typical well installation in the Jericho-Auja area (© Muath Abu Sadah)

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Overview photograph of the Feshcha spring area at the NW Dead Sea shore (© Jawad H. Shoqeir).

The Marsaba-Feshcha groundwater basin and Ein Feshcha spring group: vulnerabilities, risks, water resources potential

Jawad H. Shoqeir[1], Joseph Guttman[2], Anat Yellin-Dror[3]

KEY FINDINGS

The understanding of the hydrogeological setting of the Marsaba-Feshcha groundwater basin was refined by the construction of new geological cross sections based on the integration of a comprehensive and heterogeneous data pool.

The Marsaba-Feshcha groundwater basin, which discharges to the Dead Sea is considered to have one of the highest potentials for future water development with an average annual discharge of 45 - 80 MCM/a. However, water quality of this discharge is affected by high salinity levels, classifying it as brackish.

Vulnerability and risk maps were developed based on both, the improved understanding of the hydrogeological setting and the water quality analyses in the upstream aquifer and the Feshcha springs.

Introduction and Objectives

The Marsaba-Feshcha (M-F) groundwater basin is considered as one of the most potential promising future resources to be developed for the Palestinians in the Eastern Aquifer basin. In order to include this resource in the Palestinian Water Strategy, several requirements must be considered. Two of the most important goals that largely determined the work flow are the assessment of the current and the expected water quality in the future as well as the development of a sustainable exploitation concept as part of an overall IWRM strategy.

Both, the refinement of the understanding of the structural and hydrogeological setting of the M-F groundwater basin and an appropriate risk and vulnerability assessment were the key elements of a sustainable water resources development concept for the M-F groundwater basin. Main products and a synthesis of the conducted research are the risk and vulnerability maps, which are required by the different decision makers and stakeholders and fundamental for the planning process.

Methodology

Developing hydrogeological cross sections

The work program to develop a refined understanding of the M-F groundwater basin covered a broad study and evaluation of a comprehensive, heterogeneous data pool including well logs, recharge zone geometry, the hydrogeological characteristics of the various geological layers, and more.

As a result, new hydrogeological cross sections were constructed (Figure 1) that are essential for an improved understanding of the hydrostratigraphy especially for the lower parts of the M-F groundwater basin and to evaluate the characteristics of groundwater movement and aquifer recharge.

It could be shown that the groundwater flow is directed to the southeast, towards the central part of the Feshcha spring group and that water in the Hundaza and Shdaima well

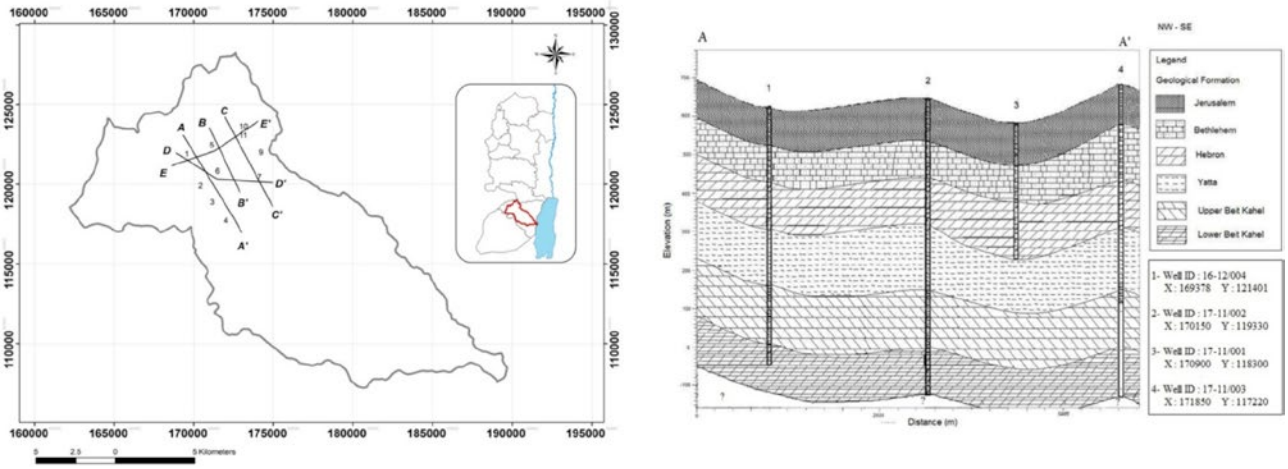

Figure 1: Left: Location of geological cross section in the Daraja catchment from Bethlehem to the Dead Sea; Right: Example of the geological cross section A-A' between the wells Herodion 1, 2, 3 and Hundaza.

fields is abstracted from the lower aquifer before the mixing. Groundwater flow in the M-F groundwater basin is structurally constrained by the strike directions of the main anticlines and synclines.

According to the 3D model of Flexer et al. (2001), Bensabat et al. (2004), and our own findings the sustainable pumping potential in the Mizpe Jericho well field is estimated at ca. 8 MCM/year. Pumping rates today amount to ca. half of that. Enlarging the well field by adding new wells is therefore one measure to be considered in the Palestinian Water Strategy and future action plans. The site is believed to be well-suited for capturing the fresh water before salinity increases significantly southward.

Figure 2: Göttingen University and Hydro-Engineering Consultancy team installing water quality sensors.

Construction of risk and vulnerability maps

To support the development of alternative planning and management options for a sustainable implementation of the IWRM concept in the western part of the Lower Jordan Valley the refined understanding of the structural and hydrogeological setting was merged with the relevant geographical information such as topography, soil distribution, and drainage maps, as well as with the geochemical characterization of the water quality in space and time. As a result of superimposing all layers of information assists in identifying existing and potential point and non-point pollution sources.

The key elements of synthesis process are vulnerability and risk mapping, which are essential tools for water resources development and to define groundwater protection measures. The new interpretation level will be used by decision makers and stakeholders like the Palestinian Water Authority to optimize their integrated water resources planning and management processes and to identify priority actions and measures.

The risk assessment scheme used for the risk map of the M-F groundwater basin is based on the intrinsic vulnerability map constructed using the PI method and the hazard map.

Results

Increasing water demand for domestic, touristic, agricultural and industry purposes is a major driver for water scarcity and competition for water resources. This potentially leads to real economic, social, or political crises considering the required per capita minimum demand, the sanitary conditions, and a constrained economic and social development.

The risk and vulnerability maps produced (Figure 3) are ready to be applied in the water resources planning and management process framed and conducted by the higher and subordinate Palestinian Water, Agricultural, and Environmental Authorities.

Our recommendation is to construct new wells within the western flank of the Nabi Musa syncline and the flanks of the Marsaba anticline, where the thickness of the saturated zone is maximal. The drilling upgradient should be accompanied with monitoring of the water level and water quality at the downgradient end.

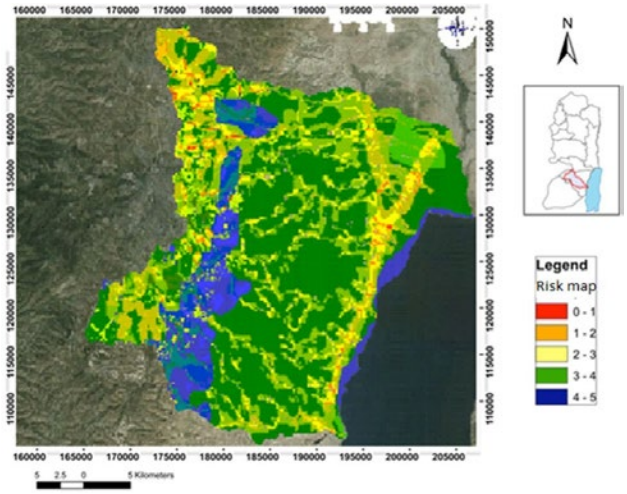

Figure 3: Risk Map of M-F Basin using my-Observatory (NEED TO BE EXPLAINED).

Further Research Needs

Further research should concentrate on the refined geological and hydrogeological model in the vicinity of the outlet of the Feshcha Springs, to be able to better capture the different water qualities. It can be assumed that the regional outlet of the karst system was located close to this spring, developed by karstification processes during historic lowest levels of the Dead Sea.

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Participants of an onsite training at Hazzir spring, Jordan (© Felix Grimmeisen)

Early Warning System for spring water contamination in Wadi Shueib

Felix Grimmeisen[1/2], David Riepl[3], Nico Goldscheider[1], Julian Xanke[1]

A considerable share of the water supply in the Jordan Valley region relies on groundwater captured from wells and spring discharge. A major supply challenge of this semi-arid region is the intermittent and highly variable water availability. Moreover, leaky sewer systems lead to frequent water quality problems including fecal contamination of groundwater.

Wadi Shueib, located ca. 20 km west of the capital Amman, was chosen as a test site to develop an online hydrometric monitoring network. In several measurement campaigns, water quality parameters including fecal bacteria and isotopic composition of the local karst springs were analyzed to design an adapted measurement concept for high-resolution monitoring. Among others, state-of-the-art optical measurement methods are used, which comprise the first steps in the development of an early warning system for spring water contamination.

In the Wadi Shueib Catchment, time series correlation analyses showed that infiltrated rain water transfers the fecal contamination in the karst groundwater system quickly to the springs. This mechanism threatens the local water supply. Since a continuous monitoring of E. coli bacteria is not yet feasible by an automated measuring system, a parameter combination, which indicates bacterial contamination, was developed.

An empirical relationship was identified between major rain events and subsequent bacterial contamination. Including the parameters electrical conductivity and turbidity in the analysis led to a more robust correlation (Figure 1), which forms the basis of the EWS as illustrated in Figures 2 and 3.

KEY FINDINGS

A combination of monitoring parameters was identified that enable a high-resolution monitoring of the spring water quality. Based on this monitoring set-up, an early warning system (EWS) for spring water contamination could be developed and implemented.

Should specific parameters exceed the defined threshold values, the operators are warned by a remote alarm system and water pumping can be stopped until peak concentrations fall below the threshold value again.

The EWS improves the safety of the drinking water supply in the cities As-Salt, Jordan (approx. 90,000 inhabitants) and in Jericho, West Bank (approx. 22,000 inhabitants).

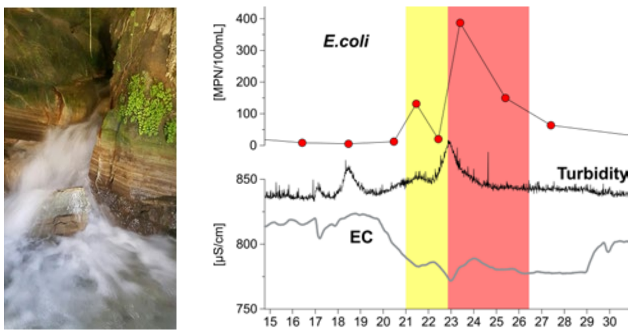

Figure 1: Discharge at Baqqouria spring (left) and relation between E. coli, Turbidity and electrical conductivity (EC) (right).

The measurement data of the monitoring stations are transferred online to a database, where automated combined signal analyses are performed. The construction of the telemetric functionality of the monitoring network at the karst springs was realized in cooperation with the project industrial partner SEBA Hydrometrie GmbH & Co. KG. The measurement data are visualized at an online platform developed by the industrial partner Disy Informationssysteme GmbH and are permanently available for retrieval.

A database algorithm calculates continuously the risk potential in near real time and warns about a possible contamination of the spring water. Should turbidity or electrical conductivity increase at a spring in a specific time sequence during the course of a large rainfall event, the system sends a warning via email. Thus, affected drinking water suppliers can be informed about a high risk for microbial contamination.

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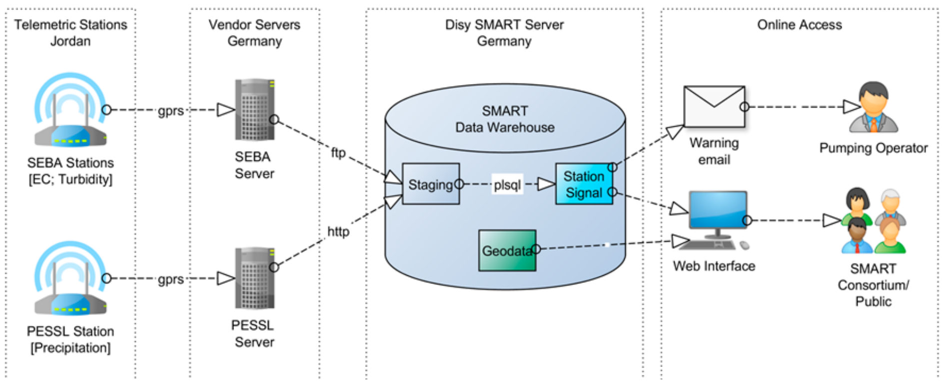

Figure 2: Schematic illustration of the Early Warning System components.

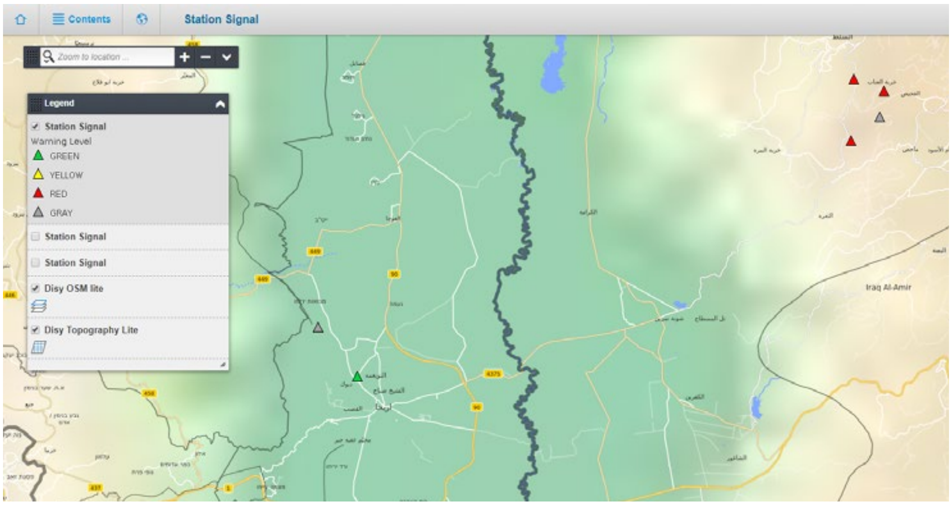

Figure 3: Example for the visualization of the station signal including background geo-data of the project region.

After a successful testing period in Wadi Shueib, a similar set-up was implemented at Sultan Spring in Jericho (West Bank), which serves as the only water supply source of the city. The measurement data of the monitoring stations are accessible in an online portal every hour. All users of the online portal can search, analyze, and visualize the current as well as historical data and diagrams. Additionally, the online portal provides various background geo-data for the project region.

In November 2016, a technical training on high-resolution monitoring and the functionality of the EWS was organized together with UGOE and SEBA and held for employees of Jordanian and Palestinian water authorities and water suppliers.

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Wadi As Salt, Jordan (© Julian Xanke)

Vulnerability and risk mapping to strengthen the link between wastewater treatment and groundwater protection in the hot spot area Wadi Shueib

Julian Xanke[1], Anna Ender[1], Tanja Liesch[1], Nico Goldscheider[1]

To improve the spring water quality in Wadi Shueib, it is important to delineate protection zones, reduce pollution and identify the source of the contaminants. Typically, karst aquifers are characterized by a wide range of variation in flow velocity and rock porosity. Therefore, defining protection zones is a major challenge. Flow velocities strongly depend on karst system characteristics. In large conduits, flow velocities can reach tens to hundreds of meters per hour, whereas the flow velocity in the aquifer matrix is typically less than a m/day.

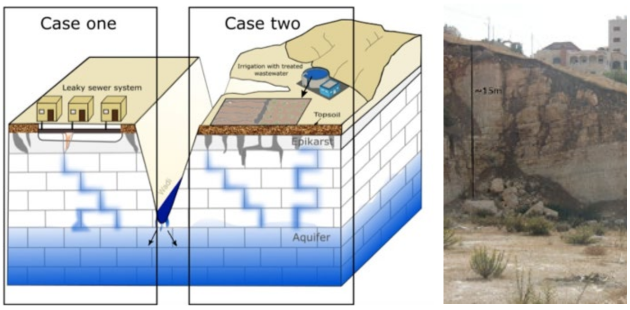

Figure 1: Left: Schematic overview of the potential contamination risks of leaky sewer pipes and irrigation with TWW. Right: Wadi as Sir Formation with Epikarst and thin topsoil layer in the northeastern part of Salt.

KEY FINDINGS

At the interface between groundwater protection and land use planning, two aspects are considered regarding the hazard potential of wastewater infiltration into the underground:

Case one:
Subsurface waste water infiltration by leaking sewer pipes.

- A vulnerability map shows areas of different priority for rehabilitation of the sewer system

Case two:
Infiltration of treated wastewater (TWW) used for irrigation.

- The spring catchment vulnerability map shows areas and their potential of being used for irrigation with treated waste water

Vulnerability and risk mapping represent an important tool for decision making and urban planning to ensure groundwater protection.

By combining existing methods on vulnerability mapping in karst environments, the risk of groundwater contamination in different areas within the Wadi Shueib as well as the Wadi Wala catchment were assessed. Here, geological and hydrogeological maps as well as soil maps and digital elevation models (DEM) serve as the basis. At the interface between groundwater protection and land use planning, two aspects are discussed (Figure 1 - left) considering the hazard potential of wastewater infiltration into the subsurface:

Case one

> considers subsurface infiltration of wastewater caused by leaky sewer lines. The vulnerability of the groundwater was assessed based on the geology and its natural protective function against contamination from both the surface and subsurface.

Case two

> focuses on the impact of irrigation with treated waste water (TWW) on spring water. In addition to the protective function of geological layers, the main wadi courses and fault zones, case two considers the protective function of the topsoil layer (O-factor) and karst specific infiltration conditions and karst geomorphologic features (C-factor).

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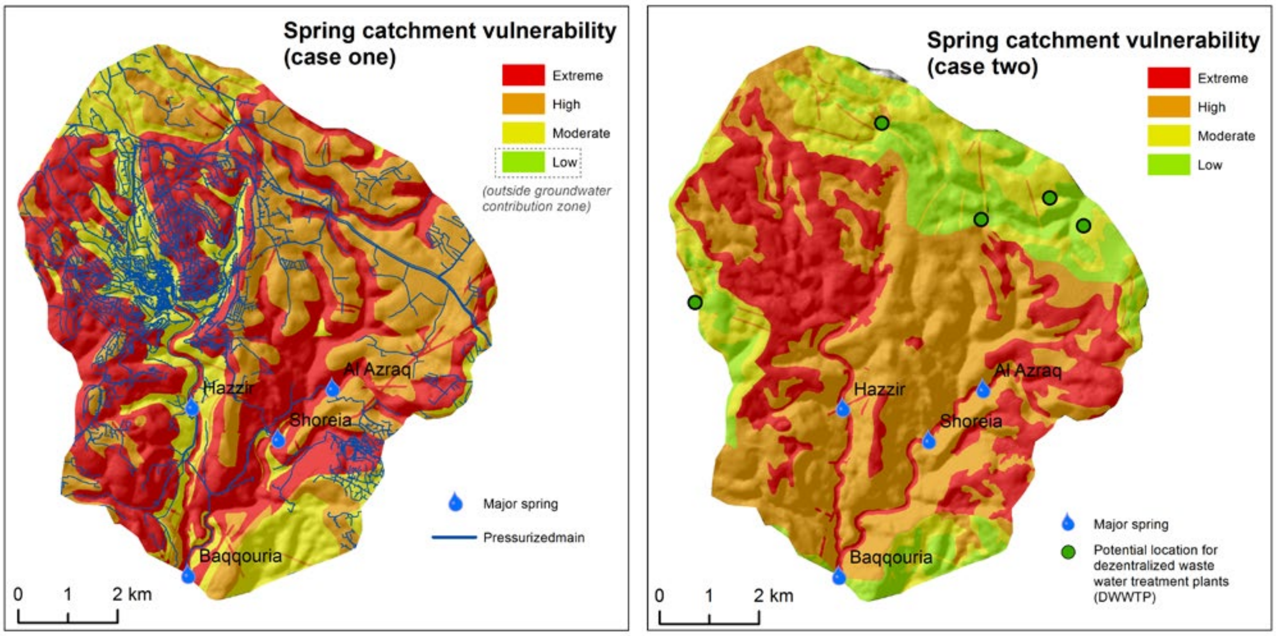

Figure 2: Left: Rehabilitation concept for the sewer systems in the upper Wadi Shueib based on vulnerability assessment. Right: Impact of irrigation with treated wastewater on groundwater based on vulnerability assessment.

Results of the vulnerability and risk mapping are important for decision making regarding the reuse of TWW for irrigation and urban planning. The approach can be transferred to other karst areas and adapted to the site-specific characteristics.

Case one

> Red areas of the vulnerability map (Figure 2 - left) indicate high priority areas for rehabilitation of the sewer network, whereas green areas tend to be less important.

Case two

> In red areas (Figure 2 - right), restrictions of irrigation with TWW are highly recommended, since pollutants can quickly reach groundwater. In contrast, in green areas the use of TWW for irrigation is regarded to be less critical.

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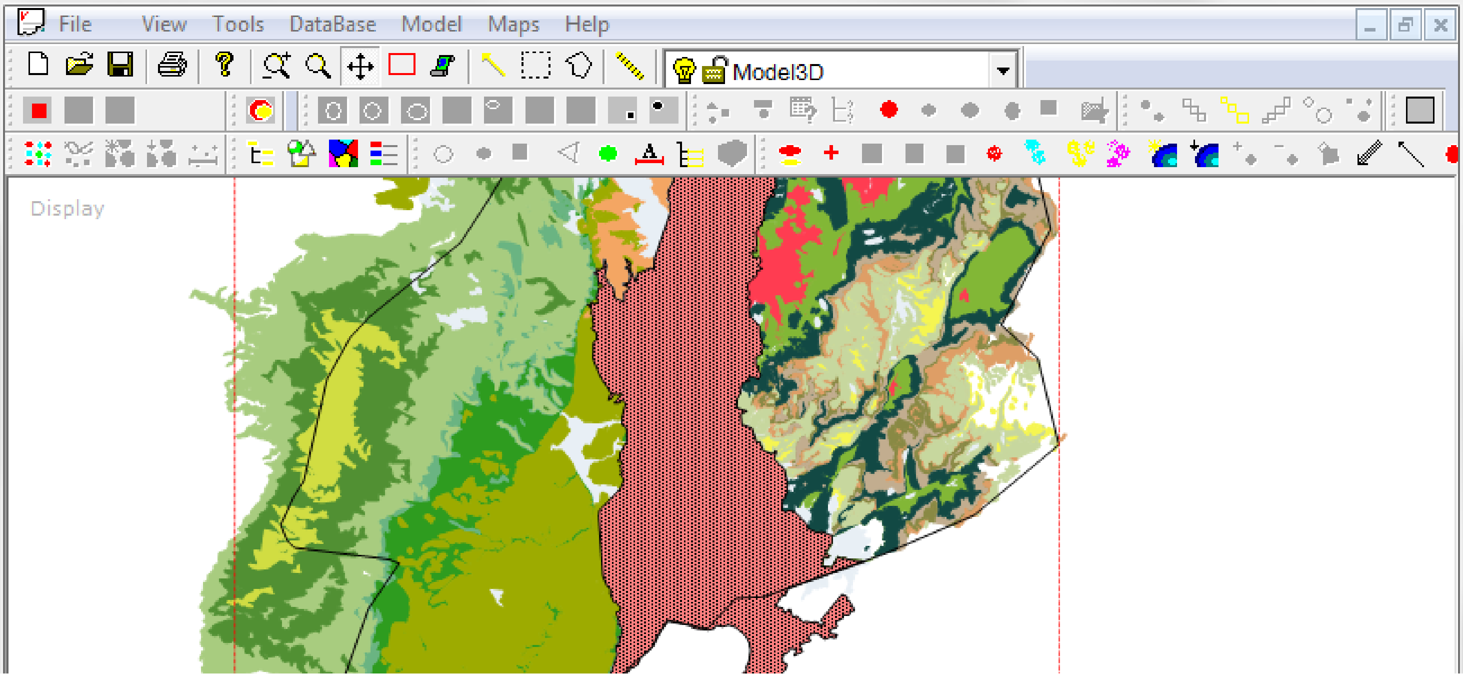

Transboundary Hydrogeological Model of the Lower Jordan Valley

Jacob Bensabat[1], Julia Sahawneh, Heinz Hötzl[2], Joseph Guttman[3]

KEY FINDINGS

We developed a novel approach for the construction of a 3D model of the Lower Jordan Valley, providing a better understanding of the regional flow patterns.

Introduction and Objectives

The starting point comprised the following layers of data and information:

> Geological structure of the area in the Western valley flanks, the Alluvial Valley Fill and the Eastern valley flank (provided by Joseph Guttman for the West and by Julia Sahawneh for the East).

> Database of wells, springs and rainfall stations for the eastern and the Western parts.

> Geographical information.

Methodology

Data Integration

Construction of integrated Database Layers for wells, springs and raingauges

The collected data was organized so it could be integrated into three database layers: wells, springs, and rainfall. There was a need to harmonize the codification of the data to allow the integration, mainly adopting a single coordinate system for the whole area and a unique identifier (a long integer) for each item in each database (a single well, a single spring and or a single raingauge). We also incorporated the available time series of measured data.

Construction of the conceptual model of the LJV

The initial conceptual model of the LJV was created in the previous stages of the project. To meet the requirements of the numerical groundwater flow model planned to be implemented during SMART-MOVE the conceptual model was subjected to substantial updating and modification.

First, a decision was made with regard to the geological layers to be included in the model (early stages of the SMART project). According to this decision, which has remained stable since then, the geology was prepared through the preparation of structural maps (of the bottom Judea formation in west and the bottom Kurnub in east). In addition, isopach maps of the layers above and below the structural maps as wells as maps of the ground surface elevation.

The construction the 3D geological model included the following steps:

1. Outline of the model borders (remained stable since the beginning of work);
2. Identification of geological features with potential impact on groundwater flow processes (essentially faults and flexures).
3. Construction of a 2D triangular mesh encompassing the model area, with relatively high resolutions around the geological features (to allow numerically stable changes in layer topography).

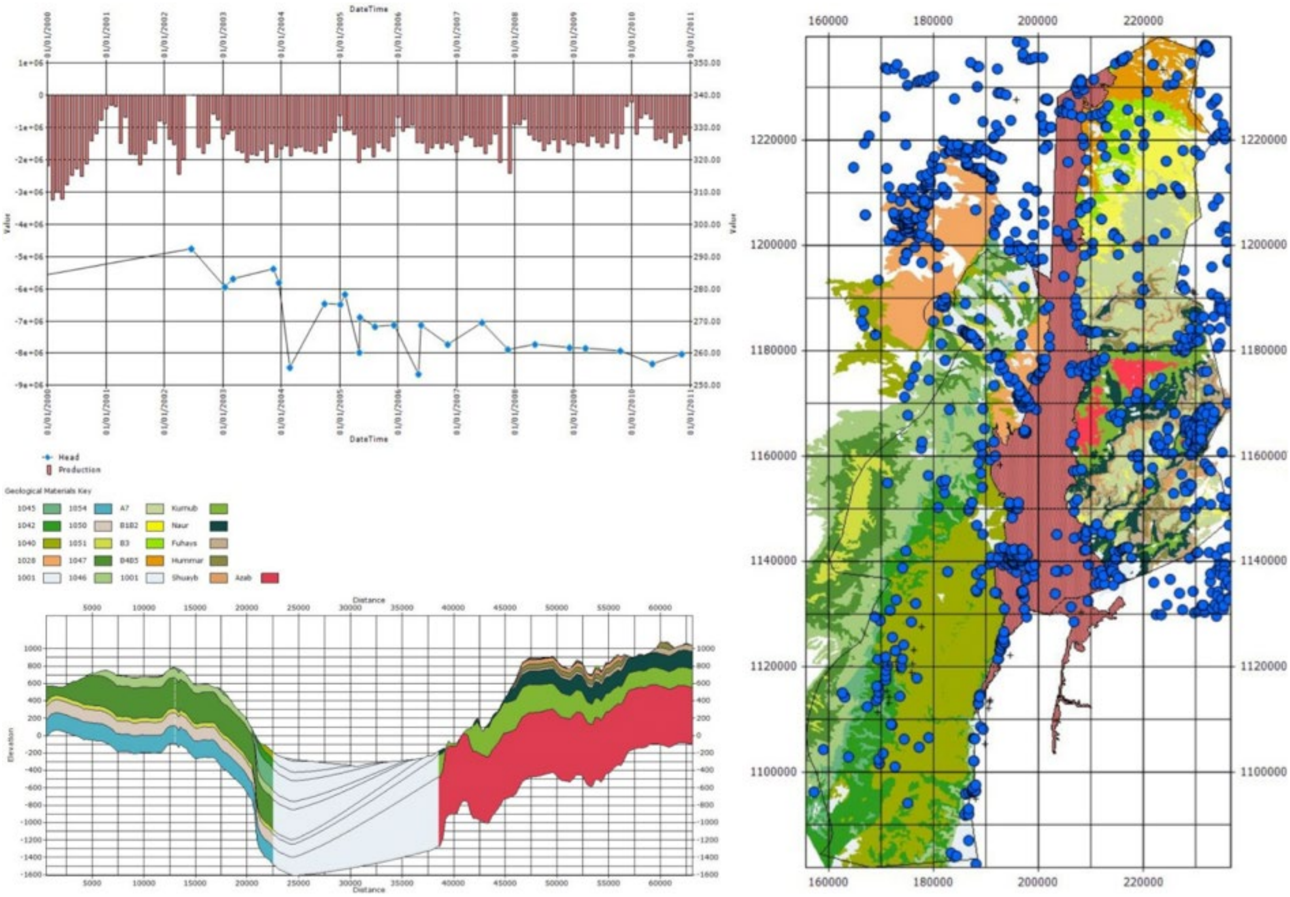

Figure 1: Integrated database of the Transboundary Hydro-Geological Model of the LJV. Upper left: Herodion-2 well head elevation and water production time series. Right: Map representation of the 3D hydrogeological model of the LJV and well locations. Lower left: Arbitrary W-E-cross section through the model area.

4. Construction of the 3D mesh setting ground surface topography and the elevation of the bottom Judea and bottom Kurnub and distribution of layers thickness above and below these levels via interpolation.
5. The quality control of the process was by comparing vertical cross sections generated by the model and the ones created from geological investigation (J. Guttman in the west and J. Sawahneh in the east). Despite numerous attempts, this process did not converge, i.e., we were not able to produce a 3D model that is compatible with the geological cross-sections. The key reason for this gap was related to the fact that the cross sections were not created solely on the basis of the structural maps that were made available to us, and also the lack of precision of the structural maps and or the isopach maps. In view of this problem, we adopted a completely different approach for the generation of the 3D geological model.

New approach for the generation of the 3D geological model

In order to overcome the problem in the construction of the 3D geological model we developed a different and potentially more robust approach. This approach relies on two assumptions:

1. The Geological map represents a reliable description of the regional geology;
2. The isopach maps bear much less uncertainty than the structural maps.

This approach requires the availability of geological maps in vector format, which were obtained from the Geological Survey of Israel (GSI) for the west and from the Ph.D. Thesis of Julia Sahawneh. Starting from points on the ground surface, located at the intersection between two layers (one with zero thickness and one with full thickness), we could generate the geological structure at this point by making use of the isopach maps. Using this approach, we first created points along these intersecting polygons. Then we populated the areas inside each polygon by a local interpolation procedure. This process created a DEM (Digital Elevation Model) of the regional geology. Matching the west parts and the eastern parts provided a 3D geological structure that is fully compatible with the geological map and depends on the accuracy of the isopach maps, which can be improved as the lithology from new wells becomes available.

Construction of the computational model

With the geological model constructed, the computational model of the LJV was defined using the finite element approach:

1. Determining boundary conditions;
2. Determining initial conditions;
3. Setting values of the hydraulic parameters of every layer (hydraulic conductivity, vertical anisotropy, effective porosity and specific storativity);
4. Setting values of the replenishment coefficients for each one of the conductive outcrops.
5. Including pumping wells;
6. Including monitored springs.

A simulation period of 20 years was set, 1990-2010. The model is undergoing a calibration process aiming at producing a satisfactory history matching of the measured heads.

All the modeling work was carried out with EWRE software: VASP for data integration, analysis and visualization and for the generation of computational models; FEAS for groundwater flow simulation.

Results

> A completely new approach for the generation of 3D geological models at large geographical scales;
> Easy to use Database management system, incorporating wells, springs and rain stations;
> Computational model that can be used for regional water balances.

Further Research Needs

We produced a mature model encompassing the entire LJV. Depending on research priorities, this model could be used for the evaluation of regional water balances, for large scales water resources management, development of water resources and well fields. It could also be used to generate more refined local models for specific problems.

Capacity Development

EWRE delivered a workshop in April 2018 on the use and application of EWRE software for members of the consortium. Due to the amount of material that needs to be covered there would be a need for at least two additional workshops.

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French Type Treatment Wetland of BAUER Resources (© Roman Breuer)

Reverse Osmosis unit for brackish water desalination (© Oliver Jung)

Rotary drilling at Deir Alla MAR site (© Julian Xanke)

Implementation of Innovative Water Technologies

> Potential and viability assessment of Managed Aquifer Recharge (MAR)

> Planning of MAR systems and their implementation

> MAR for controlled recharge of karst groundwater systems

> Membrane desalination of brackish groundwater

> Performance and suitability of decentralized WW treatment (DWWT) technologies

> Implementation of decentralized wastewater management and reuse systems

> Competence facility for decentralized wastewater management

> National Implementation Comittee NICE for integrated WW management in Jordan

> Implementation of early environmental educational programs in schools (Water Fun)

Surface water storage reservoir at Auja, Palestinian Territories (© Muath Abu Sadah)

Managed aquifer recharge (MAR) planning for the Jericho-Auja area

Florian Walter[1/4], Bernd Rusteberg[1], Muath Abu Sadah[2], Abdelrahman Tamimi[3], Torsten Lange[4], Martin Sauter[4]

KEY FINDINGS

The alluvial aquifer system around Jericho-Auja is overexploited.

MAR implementation at the study area is an obligatory measure but requires the installation of additional deep wells and hydro-infrastructure for the collection, treatment and reuse of waste water in irrigated agriculture in the context of the integrated management of the local conventional and non-conventional water resources (IWRM).

Spring discharge from numerous springs present a great water potential and is, therefore, the most important source of water in the area. Corresponding surpluses should be used together with surface runoff directly for Managed Aquifer Recharge, while additional local water resources should be used for irrigation purposes.

Three infiltration sites are suggested to allow for the controlled recharge of the shallow alluvial groundwater system (one site at Auja, two sites at Jericho).

The site in Auja is proposed to be implemented as pilot facility.

MAR infiltration ponds should be implemented together with passive infiltration wells in order to maximize the recharge efficiency.

Water transfer from neighboring basins and even from more distant areas will be required in order to ensure sustainable agricultural development and to avoid the depletion of the alluvial shallow aquifer system.

Introduction and Objectives

MAR studies at Jericho and Auja conducted during the SMART-MOVE project were based on the results of the prior SMART II project and earlier studies (e.g. Rusteberg et al., 2014, 2014a, 2014b; Rahman, 2011; Rahman et al., 2012). The prior research already stated the overexploitation of the shallow alluvial aquifer system. The aquifer was identified as suitable for MAR purposes. Preliminary studies were conducted in order to select appropriate infiltration sites for controlled aquifer recharge. The present research studies performance and impact of different MAR implementation strategies in the context of an integrated management of all available water resources, especially with regards to the alluvial groundwater system, taking different climatic and socio-economic development scenarios into consideration. The research finally aims at the development of recommendations for MAR implementation in the study area and, specifically, on the installation and operation of a MAR pilot plant at Auja village.

Methodology

Based on the results of the European project Gabardine (Rusteberg et al., 2012), a new integrated MAR planning approach has been developed and applied to the case study of Jericho-Auja (Figure 1). It consists of ten steps that are aligned in an iterative manner and designed to be applicable for any given case study that aims at the assessment of MAR feasibility and recommendations for MAR implementation. The central element is the development and comparison of alternative MAR strategies as key measure in the context of IWRM implementation. The

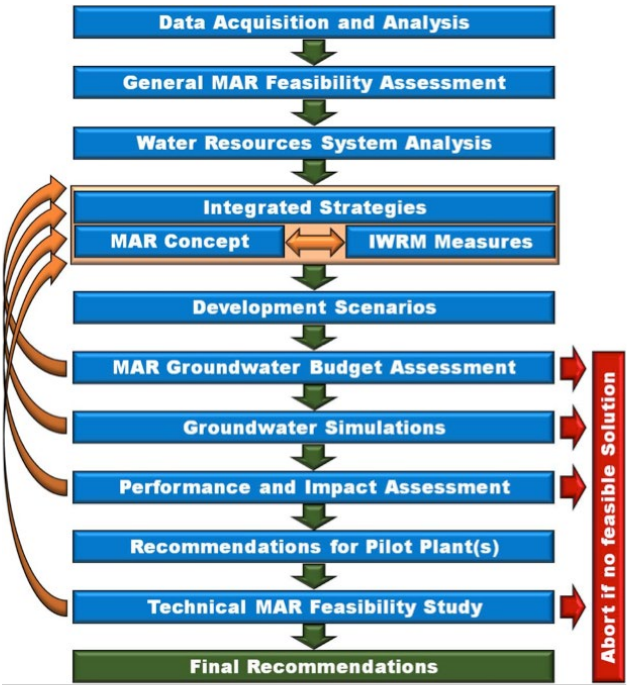

Figure 1: Illustrated overview of suggested integrated MAR planning approach (Walter, 2018).

impact and performance of each strategy as a combination of measure, is analyzed by water budget assessments and groundwater-simulations for different climatic and socio-economic development scenarios.

Results

Three suitable locations were identified: one at Auja village and further two at the City of Jericho (Figure 2). For each location the implementation of new hydro-infrastructure is required. It is suggested to use spring discharge and surface runoff as a source of MAR. Since the existing water transport and distribution network implies high losses of water, maintenance and modernization measures are required. Existing canals and pipelines require rehabilitation and their extension to minimize water losses during transport and to enable the efficient water transfer from the springs to the individual MAR location. These measures refer to all springs in the area: Auja, Nueimah Spring Group, Sultan Spring and the Qilt Spring Group.

The suggested locations are downstream of the Wadis where storm flood events occur on a highly irregular basis. The construction of additional earth dams at Wadi Nueimah and Wadi Qilt is required for the retention of surface water runoff. Further additional pipelines are needed to transfer the captured surface water to the MAR infiltration sites. Pre-treatment, for example by settling pits, is required to reduce sediment load. Detailed information on the dimensioning and cost of all hydro-infrastructure required for MAR implementation is provided by Rusteberg et al. (2018).

Table 1: MAR-Strategies that were analyzed at the Jericho-Auja case study.

IWRM STRATEGY	SPRING DISCHARGE	RETENTION OF SURFACE RUNOFF	TREATED EFFLUENT REUSE	DEEP WELLS
A	X	-	-	-
B	X	-	X	X
C	X	-	X	-
D	X	-	-	X
E	X	X	-	-
F	X	X	X	X
G	X	X	X	-
H	X	X	-	X

Table 1 presents different strategies for MAR planning and ma-

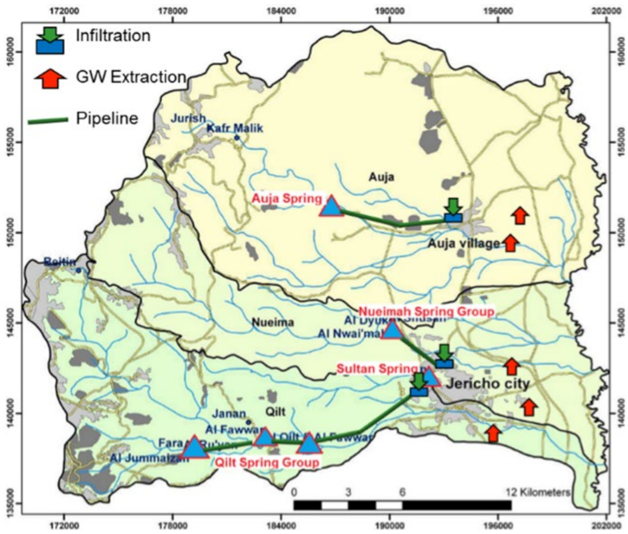

Figure 2: Schematic of suggested MAR locations in the Jericho-Auja Wadi Cluster.

nagement. Strategy performance and impacts were studied by water budget assessments and groundwater flow simulations for different development scenarios. The results show clearly that MAR cannot be implemented as single, isolated water resources management measure but should be part of an overall IWRM implementation strategy. Due to the water potential of the deep carbonate aquifer system, the construction of deep wells in both municipalities is highly recommended. Further, the reuse of treated waste water contributes significantly to the resilience of the water resources system against high hydrological variability.

Figure 3 shows that, after covering the total water requirements just by means of spring discharge, according to strategy A, little water surplus would be available for controlled groundwater recharge (blue columns), resulting in large water deficits. The accumulated water deficit after balancing for 20 years is 193.5 MCM (black line). This deficit, averaging about 8 MCM per year, can only be partially covered by controlled groundwater recharge.

The remaining water deficits would have to be covered by shallow wells and other local water resources to ensure irrigation development. Figure 4 clearly shows the effects of the 5-year dry period after 10 years. During this period, no spring discharge can be provided for controlled groundwater recharge and the water deficits exceed 12 (MCM)/ a. As expected, additional

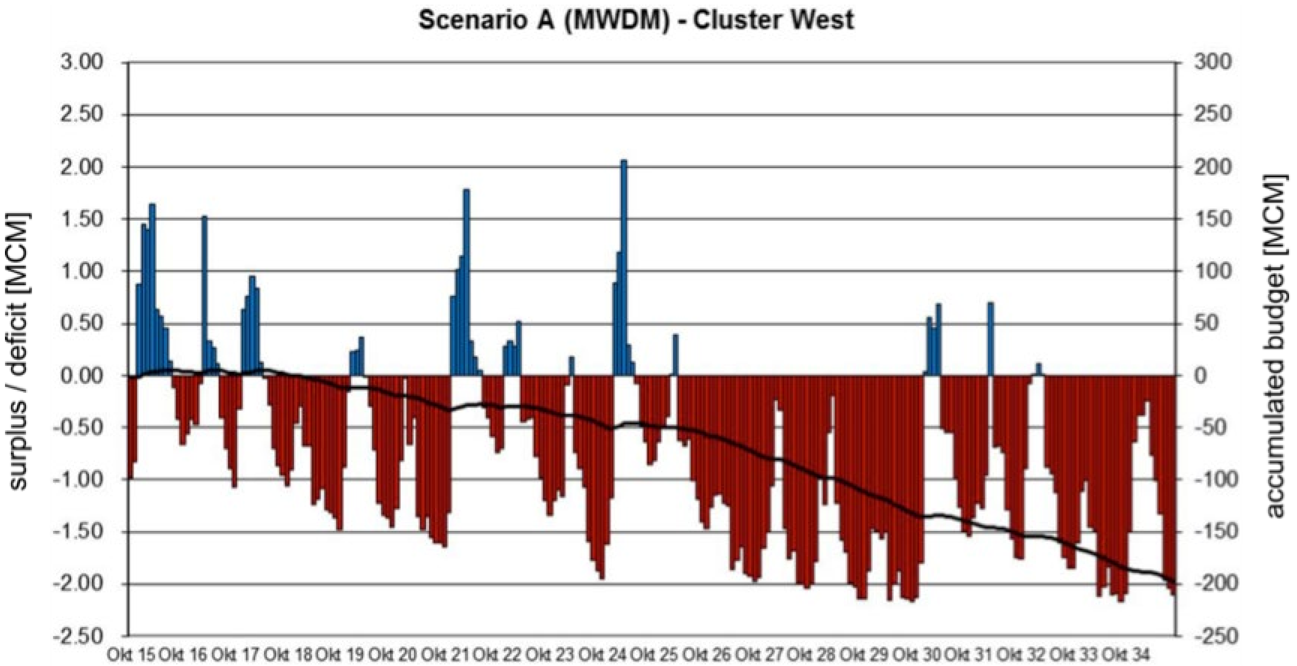

Figure 3: Water budget assessment for MAR strategy A for the upcoming 20 years under the assumption of moderate climate conditions.

local water resources should be activated to cover or minimize water deficits. The results show the need for an integrated water management approach.

Figure 4 shows the results of the water budget calculations against the background of the dry climate scenario (MDDM) for strategy F. The influence of the extended dry period of 10 years is clearly visible. Groundwater recharge can only be carried out within a few months, with almost significant water deficits during the extended dry period. During this period, monthly water deficits average nearly 1 MCM. The accumulated budget line assumes negative values after 7 years, resulting in an accumulated water deficit of 94 MCM at the end of the 20 years planning horizon.

The assessment was supported by groundwater flow modelling (Abu Sadah, 2017). By analyzing the impact of the designed measures for different climate and socio-economic development scenarios, the MAR locations (Figure 2) could be optimized.

Figure 5 compares the impact of different MAR strategies on the future evolution of the mean groundwater level in the study area, taking into account the dry climate scenario and full agricultural development. In the case of the so-called „Do

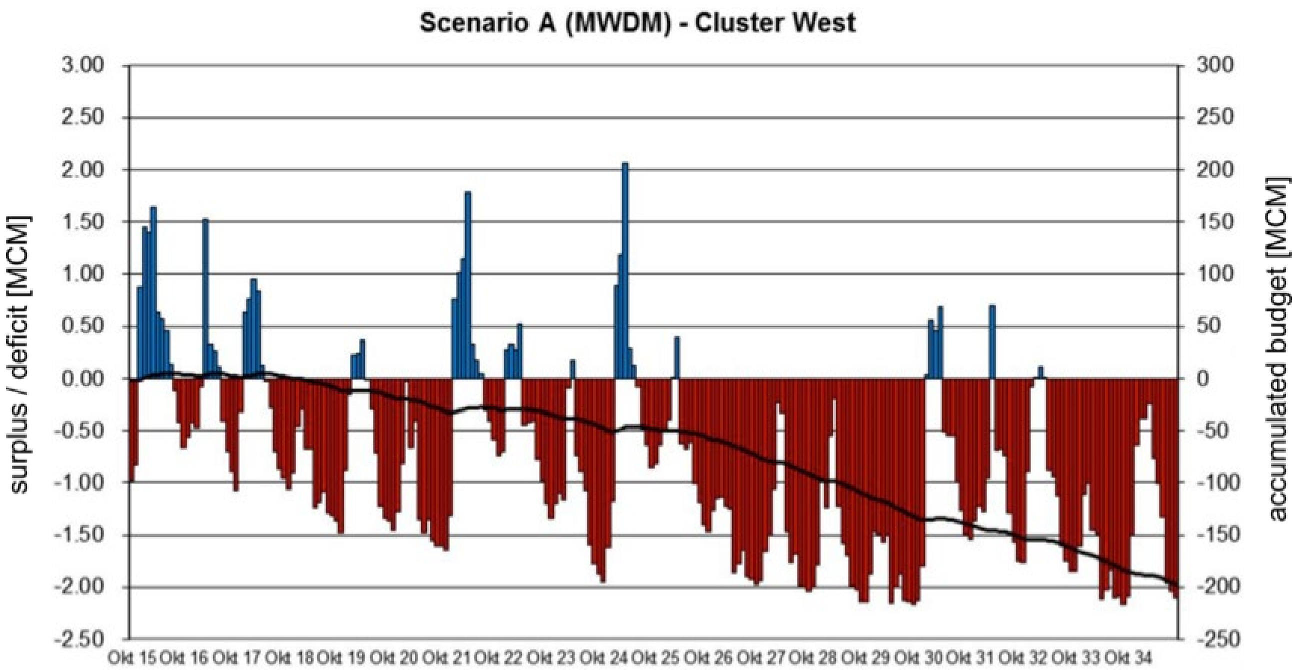

Figure 4: Water budget assessment for MAR strategy F for the upcoming 20 years under the assumption of dry climate conditions.

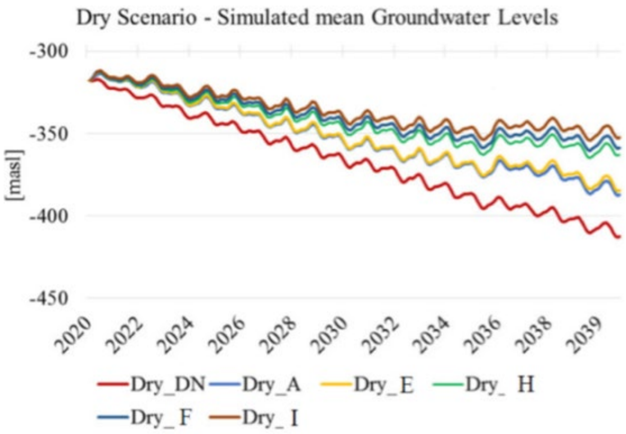

Figure 5: Simulation of mean groundwater levels for all three MAR sites under extreme climatic scenario with agricultural extension for all developed strategies (Walter, 2018).

Nothing Approach“ (DN: Without MAR implementation: lower red line), the groundwater level decreases drastically during the simulation period of 20 years. By MAR implementation as part of the integrated strategy F the groundwater level draw-down can be reduced by more than half of the total.

Strategy I (dark red top line), not previously considered, refers to the import of treated wastewater from El-Bireh, near the city of Ramallah to be applied for irrigated agriculture. The import of sewage gives a slight improvement compared to strategy F, but groundwater level decrease is still significant. The necessary extension of the irrigated area, despite integrated water management and MAR implementation, can only be realized at the expense of an accelerated lowering of the groundwater table of the shallow alluvial aquifer.

The water budget assessment and groundwater simulation studies revealed that additional water imports to the area from neighboring basins and even from more distant areas will be required in order to ensure sustainable agricultural development and to avoid the depletion of the alluvial shallow aquifer system.

Further Research Needs

It is highly recommended to install at least one MAR pilot plant in the area, preferably at Auja. It should be fed by spring discharge and retained surface runoff from the Auja dam. The plant should be designed as passive infiltration ponds with additional dug wells to increase infiltration rates. At least two ponds should be installed in parallel to switch operation regularly to maintain the ponds, especially against clogging. The experiment should be combined with tracer tests and monitoring of the groundwater level and quality around and downstream the test facility. Furthermore, it is highly recommended to combine the pilot plant with a new deep well. The well should supply the local municipality and farms directly and not be used for MAR. It should compensate for withdrawing water from the spring to use for the experiment.

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Site characterization in a gravel pit north of Deir Alla for MAR planning (© Julian Xanke)

Managed aquifer recharge (MAR) along the eastern lower Jordan Valley - General Potential and Deir Alla Test Site

Julian Xanke[1], Elias Salameh[2], Amer Salman[3], Tanja Liesch[1]

KEY FINDINGS

The assessment of the potential for managed aquifer recharge (MAR) along the eastern Lower Jordan Valley, based on geological, hydrological and geophysical surveys, identified eight compartments for temporal groundwater storage with a volume up to ca. 120 Mm³ (MCM).

Further local field surveys and a conceptual and numerical model for MAR, using water from King Abdullah Canal (KAC) at the Deir Alla test site (infiltration basin with an area of 24,000m²), showed an expected infiltration rate of about 1 MCM/a.

Cost-benefit analyses show that 1 MCM generates an added value of 0.75 Million JD per year for agricultural use. For domestic use in Deir Alla, 1,531 households could benefit with an equivalent water value of 1.926 Million JD.

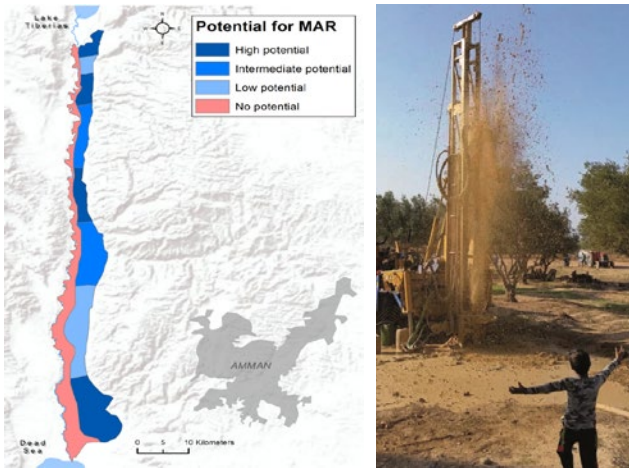

Figure 1: Left: Groundwater fountain by rotary drilling from borehole in Deir Alla. Right: Potential for Managed aquifer recharge in the Jordan Valley.

Managed aquifer recharge (MAR) represents a powerful technique in water resources management, especially in semi-arid regions, to bridge gaps in water supply by temporal subsurface storage of surface water.

The Jordan Valley plays a key role in the agricultural sector in Jordan and is widely used for the production of field crops, vegetables and fruits. As a consequence, local groundwater sources have been successively overused in the past with the result of declining groundwater tables. Furthermore, the high variability in water availability exacerbates the situation. Here, MAR can be used to improve the water situation by subsurface storage of surface water.

A study was conducted to evaluate the storage potential of the alluvial deposits along the Eastern Jordan Valley based on geological, hydrological and geophysical surveys. Derived from geological and hydrogeochemical characteristics eight compartments were identified with different potential for subsurface storage (Figure 1) with a total potential of up to 120 Million m³. The fine sediments of the Lisan formation, which outcrop towards the Jordan River, reveal no storage potential.

The Deir Alla/Suleikath area in the Jordan Valley served as the main implementation site for MAR in the eastern cluster and was assessed by multiple geological and hydrogeological investigation methods. This included the drilling of observation wells, acquisition and analysis of hydrogeological data, the completion of a MAR adapted monitoring network and the delineation of the hydrogeological site setup. These tasks represent the preliminary work for the setup of the MAR implementation site.

The investigations showed that the first 40 meters below ground level (bgl.) are composed of incised layers of fine sediments and gravels with a groundwater table depth of 5 to 15 meters bgl. Measured average infiltration rates of 9.8×10^{-5} m/s in a gravel pit and average hydraulic conductivity values of 6.8×10^{-5} m/s in the aquifer suggest that artificial recharge and storage of substantial amounts of water is feasible.

Further calculations recommend that the water level in the surface infiltration pool should not be higher than 2.5 meters, otherwise water will not completely infiltrate due to ongoing clogging processes. At the test site, with the given pool size of 24,000 m^2, the maximum possible annual infiltration volume is about 1 MCM.

A further assessment using a numerical groundwater model (Figure 2) suggested the necessity of several infiltration cycles per year, reflected in the on-site measured infiltration rates and hydraulic conductivity values. Two similar scenarios were chosen to better describe the dynamics of the aquifer as a function of different changes in infiltration and abstraction:

1. Seven infiltration cycles per year with an infiltration time of 14 days for each cycle and a constant groundwater abstraction during the year. This results in an annual infiltration of about 0.735 MCM and an annual abstraction of about 1 MCM. The infiltration phase lasts ca. 7 months.

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2. Ten infiltration cycles per year with an infiltration time of 14 days for each cycle and a constant groundwater abstraction during the year. This results in an annual infiltration of about 1 MCM and an annual abstraction of about 1 MCM. The infiltration phase lasts about 10 months.

With the given infiltration pool size, the amount of annual infiltration depends strongly on the initial water level in the pool, the infiltration rate and the clogging factor.

An economic assessment for the Deir Alla test site was conducted considering the added value when water is used for agricultural and for domestic purposes. The results of the cost-benefit analyses showed that 1 MCM generates an added value of 0.75 Million JD per year for agricultural use. For domestic use in Deir Alla, about 1,531 households could benefit with an equivalent water value of 1.926 Million JD.

This study revealed that the applied workflow of investigating the local potential of MAR can also be transferred to other locations along the Lower Jordan Valley. However, since MAR projects are susceptible to a variety of factors that can limit the operation time or usability of the infiltrated water, a guideline for MAR implementation in the Lower Jordan Valley was developed addressing the necessary steps and measures from planning to implementation and operation and maintenance.

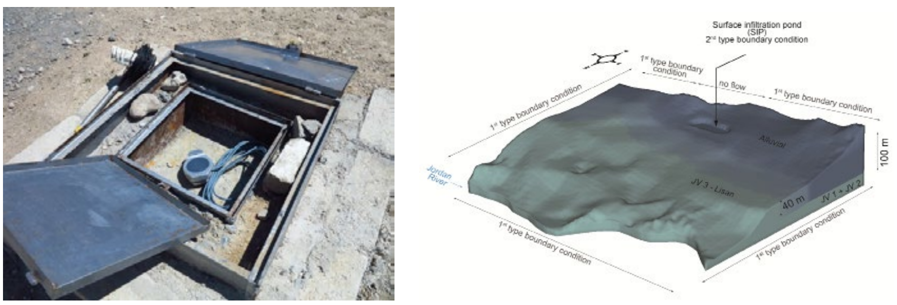

Figure 2: Left: Observation well in the Jordan Valley. Right: Numerical model of the test site in Deir Alla.

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Surface water storage reservoir Wadi Wala (© Julian Xanke)

Managed aquifer recharge (MAR) into a karst groundwater system at Wadi Wala and protection against pollution for the downstream Hidan wellfield, Jordan

Julian Xanke[1], Tanja Liesch[1], Nico Goldscheider[1]

KEY FINDINGS

- Storm water harvesting and storage via managed aquifer recharge (MAR) is a promising approach to combat water scarcity in semi-arid regions, but is challenging in karst areas
- The Wala reservoir stores flood water since 2010 and recharges the underlying karst aquifer system.
- Significant groundwater-level rise in a wellfield downstream the reservoir is observed in response to the annual average infiltration of about 6.7 million m3 (MCM).
- Dry and bare soil cover in the catchment leads to high sedimentation in the reservoir, which continuously decreases the infiltration rate and, thus, the proportion of artificially recharged water in the abstracted groundwater.
- The Hidan wellfield downstream the MAR site in Wadi Wala is an important drinking water resource, but is regularly contaminated, especially after runoff events.
- The results of a tracer test demonstrate high groundwater vulnerability due to fast signal response in the nearby abstracted groundwater from infiltrating NaCl-enriched tracer solution in the wadi bed.

Introduction and Objectives

Karst groundwater resources in the semi-arid region of Jordan were heavily overused in the past decades due to a rapidly growing population and increasing water demand. Managed aquifer recharge (MAR) is a promising approach to balance the high variability in water availability by subsurface storage of surface water and recovery during dry periods. However, the hydraulic anisotropy and heterogeneity of karst aquifers is a particular challenge for the application of MAR and requires comprehensive hydrogeological investigations. This study focuses on flood water capturing at the Wala reservoir, the recharge into a moderately karstified aquifer and its recovery in the Hidan wellfield 7 km downgradient. The wellfield is an important source of drinking water supply to Jordan's capital Amman, the city of Madaba and surrounding communities. The wells are fed from a karst aquifer and are drilled along Wadi Hidan adjacent to Wadi Wala. Beside highly variable precipitation events during the winter season, permanent groundwater seepage downstream the reservoir generates variable runoff towards the wellfield, which successively percolates at different infiltration pools along the wadi. This often causes turbidity and contamination with fecal bacteria in the wells, making the water unusable for drinking.

The high climate variability leads to a filling of the reservoir by floods in winter, which can also lead to an overflow from time to time. In summer, the reservoir can dry out due to constant infiltration and strong evaporation.

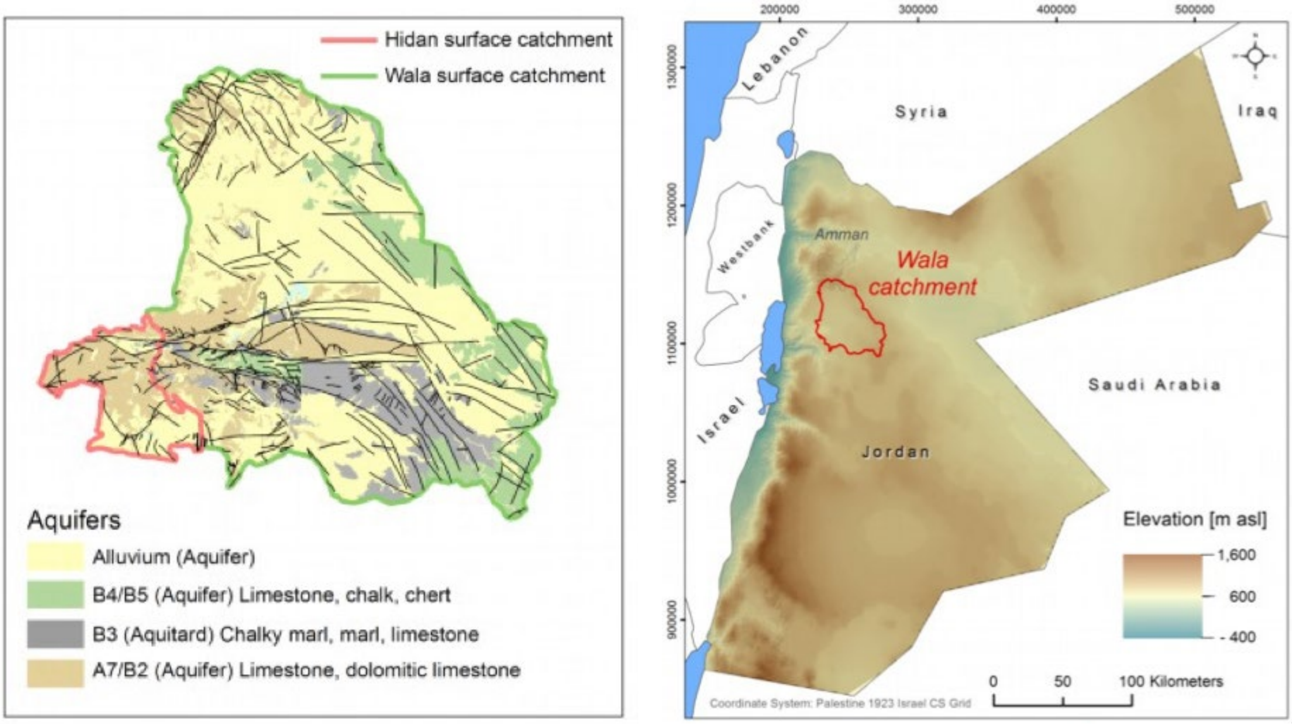

Figure 1 location of the Wala catchment in Jordan, its geological setup and the location of the reservoir and wellfield (reproduced from XANKE et al 2016).

Methodology

The main focus was on the development of a comprehensive hydrogeological conceptual model and the development of a combined protection zone concept for the karstic environment of the reservoir and the wellfield considering the interaction of surface water and groundwater. Therefore, hydrological, hydrogeological and hydrochemical data of the reservoir and the aquifer were evaluated over a period of approximately 10 years. To identify surface water-groundwater interaction through the losing stream along the Wadi, a tracer test was conducted at Hidan wellfield using dissolved sodium chloride (NaCl). Therefore, a dry pool in the karstified streambed north of the wellfield was selected as the injection point of an amount of 300 kg NaCl, which was pre-dissolved in 2 m^3 of water. In a next step, a combined protection approach was developed for the surface catchment of the Wala reservoir and the downstream Hidan wellfield. An intrinsic karst vulnerability map was developed and adapted to account for the regional characteristics and the catchment separation by the Wala Dam and the interaction of surface water and groundwater. The groundwater vulnerability mapping method is based on two principal factors, the overlying layers (O factor) and concentration of flow (C factor), which characterize the allogenic and autogenic recharge processes in karstic environments.

Results

Floodwater from intense rainfall events during winter season is captured in the reservoir and infiltrates naturally into the

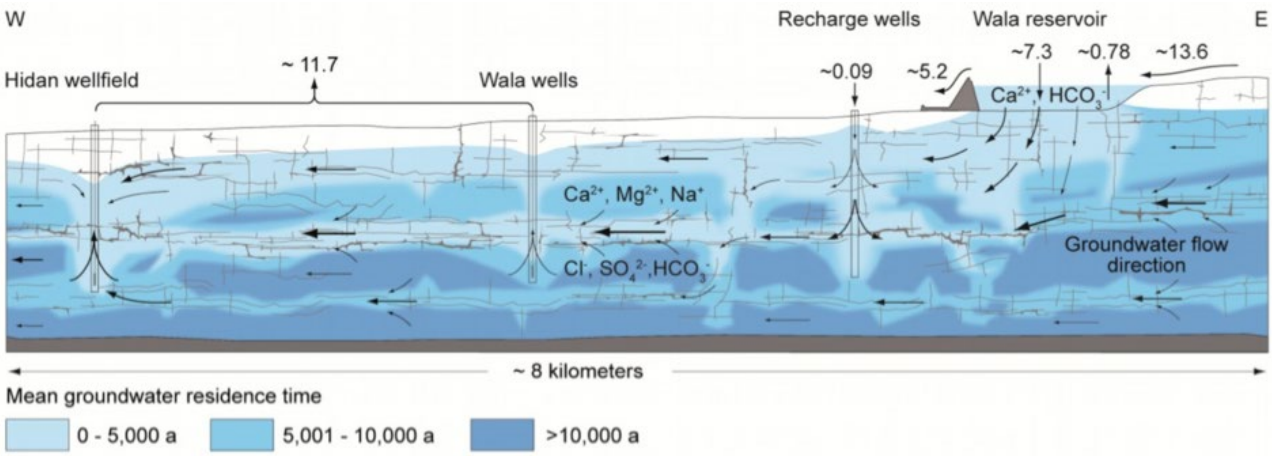

Figure 2: Schematic cross section along Wadi Wala showing the mixture of recent surface water with groundwater of higher mean residence times. The numbers of the water balance are in million cubic meter (XANKE et al 2015).


Dried up reservoir at Wadi Wala (© Wasim Ali)

underlying karst aquifer. It is also partly injected into recharge wells. Hydrogeological surveys proved the impact of the reservoir infiltration on the wellfield and water balance calculations stated a proportion of about 57% of recharged water (74.1 million cubic meters) on the total abstraction (129 MCM) from 2002 to 2012. However, sedimentation in the reservoir successively clogged the infiltration path and reduced the storage capacity and consequently caused more frequently a spilling of the reservoir. The infiltration of low-mineralized surface water into the highly mineralized groundwater caused a fluctuation of the salinity mainly during the first years (2002-2006). Consequently, this mixture of surface and groundwater of different salinities enhances also the dissolution of carbonate rock, which further enlarges the flow paths in the underground. Carbon-14 dating revealed mean groundwater residence times of several thousand years, which indicate a large storage capacity of the aquifer. The heterogeneous distribution of the residence times is caused by strong groundwater withdrawals and artificial recharge along with karst-specific aquifer characteristics (Figure 2; XANKE et al. 2015).

The tracer test demonstrates the high vulnerability of the aquifer to surface water infiltration along the wadi course. The applied tracer solution fully infiltrated after ca. 7 h with a first arrival of the tracer in well CD 3243 after 1 h and a tracer peak after 8.9 h (Figure 3). Based on the conducted tracer transport simulation a tracer recovery of ca. 65.2% was calculated, suggesting transport of the missing part by groundwater flow to the west or loss to other discrete conduits or fractures that are not connected to the wells (XANKE et al. 2017).

The vulnerability map was transformed directly to a protection zone map for the well field with minor adjustments. Protection zone I is assigned to Wadi Wala with a 100 m buffer on each side and a 50 m buffer around each well. The relatively large extension of zone I was chosen because the water in the wadi is in direct contact with hazardous activities (housing, agriculture and farming). The outer border of protection zone II was delineated according to the top of the Ghudran formation with a minimum distance to the wadi of 350 m. This includes the steep slopes along Wadi Wala, where rainfall does not infiltrate


Spillway discharge after intensive runoff event at Wadi Wala (© Hesahm Alhesa)

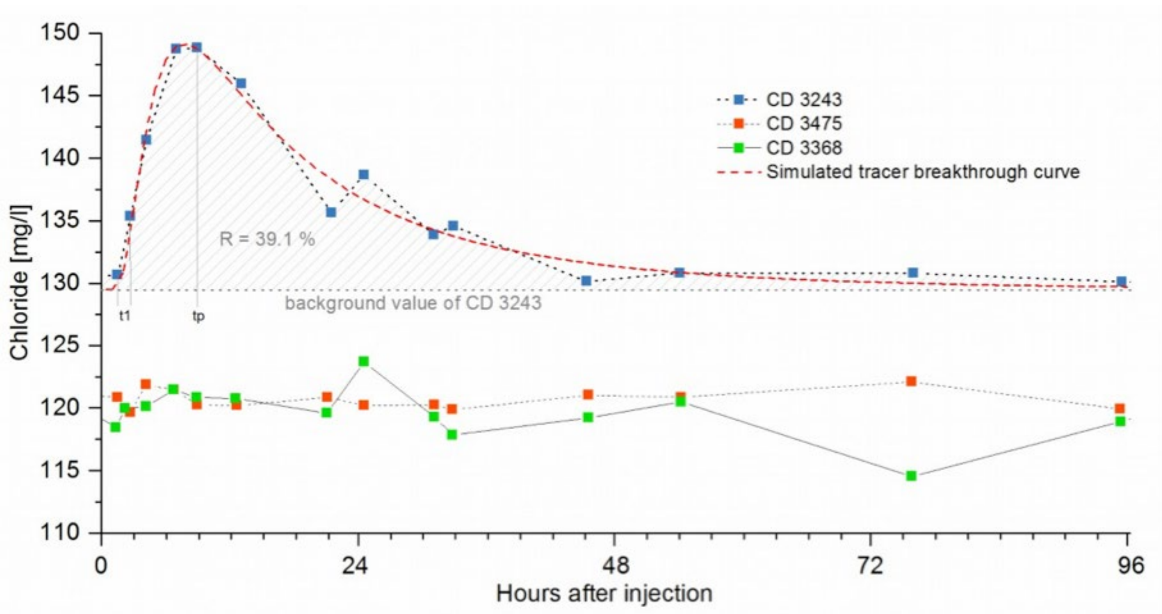

Figure 3: Chloride concentrations during the tracer test in well CD 3243, CD 3475 and CD 3368 of Hidan wellfield. (XANKE et al 2017).

and generates fast runoff. Protection Zone IIIa comprises the rest of the Hidan wellfield catchment. In the reservoir catchment, protection zone II corresponds to the highest water level of the reservoir plus a buffer zone of 350 m, zone IIIa reaches up to 700 m asl, and zone IIIb covers the rest of the Wala catchment (Figure 4; XANKE et al. 2017).

Further Research Needs

In general, MAR is a promising approach to increasing the availability of freshwater in semi-arid areas. However, the use of MAR in karst areas is rather rare due to its characteristically hydrogeological properties. Therefore, a future assessment of the MAR potential in semi-arid areas is a promising research area, where the investigation approaches and results from the SMART studies at the Wala reservoir can be helpful.

Capacity Development

During the work on the Wala reservoir, Hidan wellfield and the development of management strategies, representatives of the Jordanian water authority (Ministry of water and irrigation) and the local operators of the reservoir (Jordan Valley Authority) and the well field (Water Authority Jordan) worked closely together. The planning and execution of the tracer test, which was carried out in close cooperation with the German Federal Institute for Geosciences and Natural Resources (BGR), was also used to bring this form of investigation closer to the local water experts.

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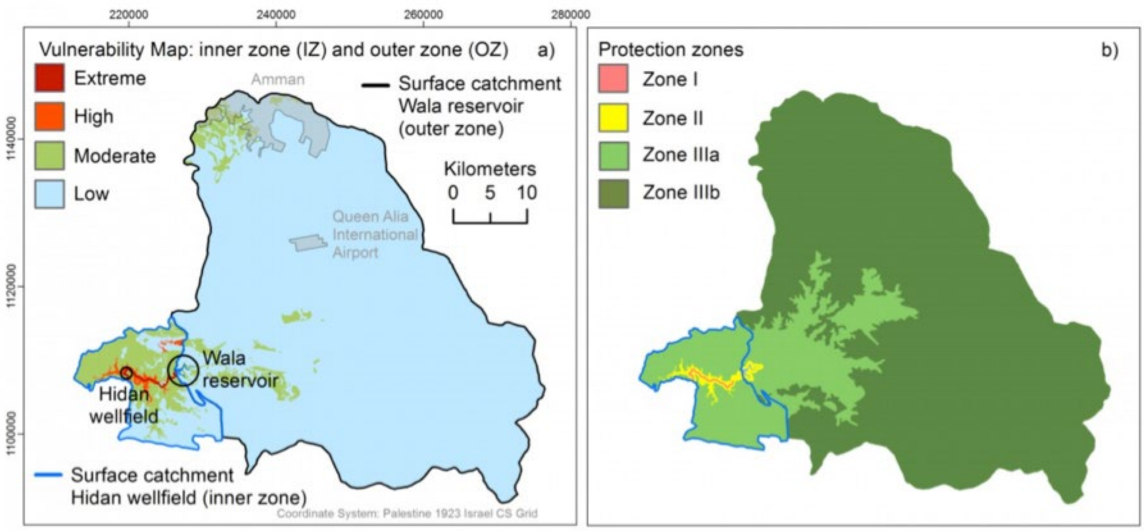

Figure 4 Vulnerability map of Hidan and Wala catchment and b) the combined protection zone concept. (Xanke et al 2017).

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Brackish water desalination plant Karameh, Jordan (© Heinz Hötzl)

A Handbook on Brackish Water Usage in Water-Scarce Regions – The Jordan Valley

Oliver Jung[1], Florencia Saravia[1], Gudrun Abbt-Braun[1], Harald Horn[1], Amer Marei[2]

KEY FINDINGS

- The utilization of brackish groundwater in the Lower Jordan Valley is explored.
- A handbook on Brackish Water Usage in Water-Scarce Regions is established.
- The handbook aimed to be used by private operators, farmers and policy makers.
- Membrane desalination in the Lower Jordan Valley under certain conditions is demonstrated.
- The handbook is available in English and Arabic.

In the Lower Jordan Valley (LJV) membrane desalination technology can play an important role in local water management by accessing brackish ground water as an additional water source. Recognizing the potential of membrane desalination, farmers in the LJV have already begun using the technology as early as 20 years ago. However, inland brackish water desalination is particularly challenging to operate in a sustainable manner, which is the reason why SMART-MOVE included the creation of a handbook on brackish water usage specifically for the LJV and Jordan as a reference for private operators, farmers and policy makers.

The DVGW Research Center, Water Chemistry and Water Technology, at the Engler-Bunte-Institut (EBI) explored in the framework of the SMART-MOVE project and in collaboration with local authorities the utilization of brackish groundwater in the Lower Jordan Valley.

The handbook connects current practice in the LJV (overview in Table 1) with common practice and technology choices in already established markets. Offering both, an English and Arabic version, it is available as a print and online edition:

> https://wasserchemie.ebi.kit.edu/english/918_3174.php

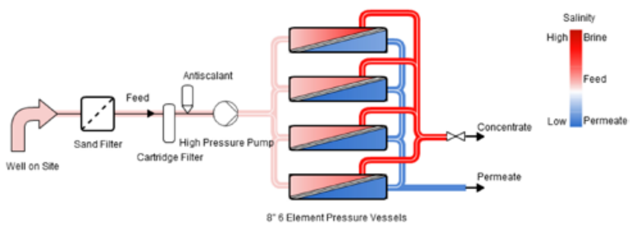

Figure 1: General layout of a typical RO-unit on a farm in Jordan.

Table 1: Desalination systems on farms in the Lower Jordan Valley.

N = 64	UNIT	MIN	MAX	MEAN
Capacity	[m^3/h]	15	100	42
Product Capacity	[m^3/h]	10	70	27
Recovery	[%]	40	78	64
Feed salinity (TDS)*	[mg/L]	1300	7000	3150
Brine salinity (TDS)*	[mg/L]	1300	18000	7950
Permeate salinity (TDS)*	[mg/L]	23	800	195

*TDS: Total Dissolved Solids

It could be shown that investment into more complex, more efficient systems could offer the benefit of abstracting less groundwater while not necessarily raising the cost of product freshwater. The handbook also demonstrates that membrane desalination in the Lower Jordan Valley can be used in a sustainable manner if certain conditions are met. Those conditions were identified as follows:

> controlled abstraction of brackish groundwater
> usage of efficient desalination systems with good pretreatment and high (>70 %) recovery
> compilation of a plan of usage which covers year-round everyday production
> waste-management plan to discharge brine into the dead sea or brine usage as resource
> support from policy makers to facilitate sustainable brine management

The handbook has been translated into Arabic to increase outreach and distribution and raise awareness among farmers about potentially compromised future business opportunities due to unsustainable desalination practice and techniques. The handbook can also be used as a tool for operators to increase stability of current systems by showing and explaining important parameters, the importance of keeping records and how to use this information to facilitate troubleshooting and learn more about their system.

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Figure 2: a) RO modules of a typical farm unit in Jordan; b) well in Jordan; c) pond for product storage and blending on a farm in Jordan; d) system housing and feed water tank in Jordan. (Pictures: Oliver Jung).

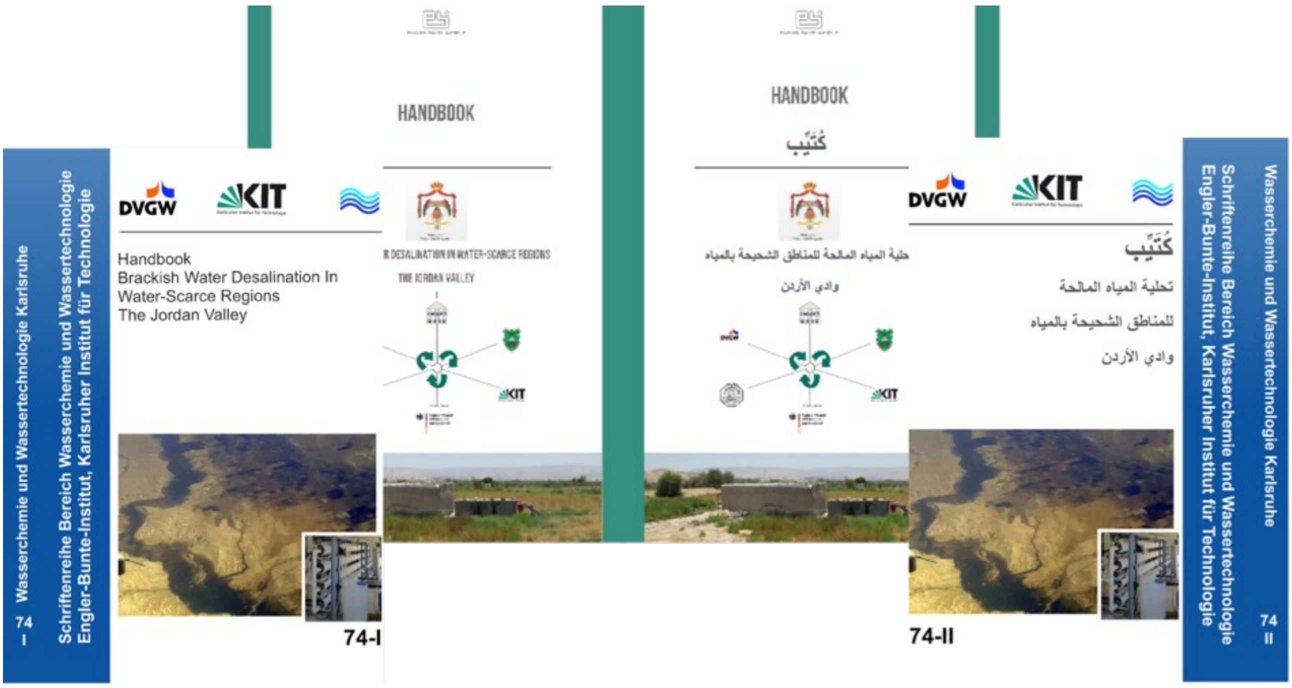

Figure 3: Front cover of the Handbook on Brackish Water Usage in Water-Scarce Regions – The Jordan Valley (English and Arabic) - center/back: online edition; ambient/front: print edition

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Wastewater Research, Demonstration and Training site at the BDZ, Germany (© UFZ)

Treatment performance and suitability of EU-Certified DWWT-technologies treating wastewater representative for Jordan

Marc Breulmann[1], Mi-Yong Becker (née Lee)[1], Manfred van Afferden[1], Anwar Al-Subeh[2], Ali Subah[2], Roland A. Müller[1]

KEY FINDINGS

The results clearly show that EU-certified DWWT-technologies are fully capable of treating strong wastewater representative for Jordan.

Post-certification of the EU-certified DWWT-technologies under local Jordanian socio-economic and climatic conditions should be mandatory.

A Jordanian certification system should be built on four pillars:

1) Products
- Prefabricated and engineered plants for treating domestic wastewater and domestic grey water, designed up to 5000 PE (population equivalents)
- Treatment of wastewater to specific quality categories (effluent and reuse categories)
- Materials: Requirements for concrete, PVC, etc.
- Proof of water tightness for the entire system, upgrading of individual elements (UV-Unit; E.Coli)

2) Requirements for Approval
- Acceptance of existing foreign certification
- Minimum requirements for treatment performance
- Largest tank to be tested for stability
- Smallest system to be tested for treatment performance
- Additional operational test (4 weeks) for specific conditions (sand storms, rocky ground, radiation)

3) Permission and Control
- Certification body (RSS, JSMO) established as notified body by the MWI (national certification body) --> Water Authority/PMU
- Compliance with water quality regulation (PMU/WAJ)
- Positive list of certified manufacturers and their systems

4) Operation and Maintenance (O&M)
- Training for O&M personnel
- Declaration of O&M parameters in Arabic

Figure 1: Left: A dosing station (22 m³) and a container with a mixing tank inside. Right: The distribution system for loading and O&M of the DWWT-technologies at the BDZ.

Small wastewater treatment systems can contribute to cost-effective decentralized solutions in rural areas (MASSOUD, et al., 2009).

Within the European countries, all wastewater treatment systems (up to 50 PE) must be certified according to EN 12566-3 (DIN EN 12556-3, 2005). In Jordan, no such standards for DWWT-technologies and their O&M exist. Therefore, a certification system for manufacturers, operators and products is required in Jordan to ensure a minimum quality and performance standards for wastewater treatment and reuse solutions in Jordan. Furthermore existing certification systems help to support the process of decision-making.

Wastewater in Jordan is typically concentrated (e.g. $BOD_5 > 500$ mg/L) which is due to water scarcity and therefore low water consumption (ca. 40-70 L/capita/day). EU-certified smaller treatment systems are not automatically designed and tested to purify such concentrated wastewater containing high levels of BOD_5, ammonium, phosphorus etc.

This study compared the treatment performance and suitability of conventional DWWT-technologies treating wastewater representative of Jordan.

A three-phase experiment was carried out with mean BOD_5 concentrations of 300, 600 and 1200 mg/L in Phase I, II and III, respectively, at the BDZ site in Leipzig (Figure 1 - right). Modified wastewater with increasing BOD_5, N, P, TSS concentrations was prepared (MAISONNAVE et. al., 2011). For simulating different wastewater compositions, a dosing station with a storage tank and a mixing tank was constructed at the site (Figure 1 - left).

Figure 2 A: High strength wastewater influent (extreme left) and finally treated effluents collected from selected DWWT-technologies.

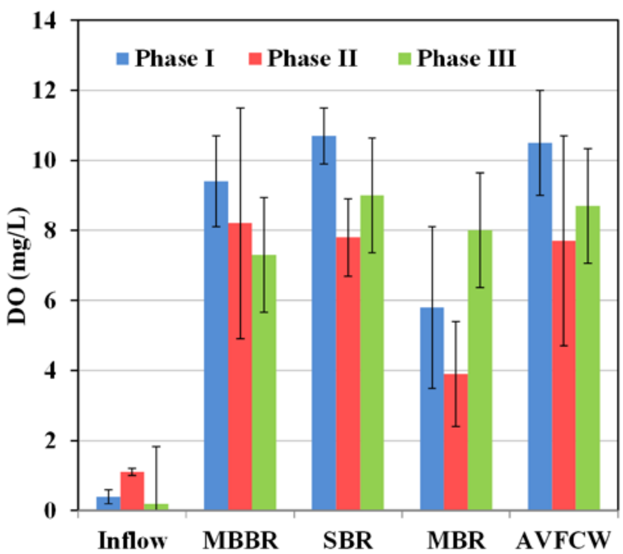

Figure 2 B: DO inflow and outflow concentrations for different treatment systems in three experimental phases.

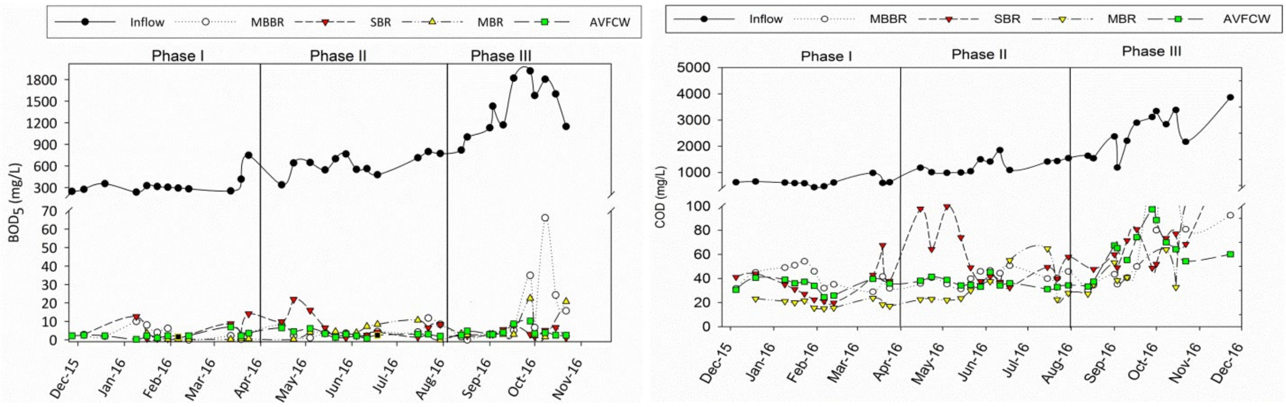

Figure 3: Mean inflow and outflow concentrations of BOD5 (left) and COD (right) that were observed for different technologies in three experimental phases.

Four DWWT-technologies (4-8 PE) were used in this study:

1) Moving Bed Biofilm Reactor (MBBR),

2) Sequencing Batch Reactor (SBR),

3) Membrane Bioreactor (MBR),

4) Aerated Vertical-flow Constructed Wetland (AVFCW).

24-h mixed samples were collected and analyzed on a weekly basis from each treatment system.

The results with a mean BOD_5 and COD concentration of <10 and <70 mg/L in the effluent from the systems showed a mean BOD5 and COD removal of 99% and 97%, respectively (Figure 3).

The removal of TN, TP, E. coli and TSS was also highly efficient and no sign of clogging or fouling were observed. Mean DO concentrations were also in the range of 7 to 10 mg/L in the outlet of all the systems (Figure 2 B).

It can be concluded that these four selected DWWT-technologies are fully capable of treating wastewater representative of Jordan (BOD_5 > 500 mg/L) and can be adapted to operate in rural areas of Jordan.

However, a post-certification of the EU-Certified DWWT-technologies under local Jordanian socio-economic and climatic conditions should be mandatory before the final permitting process. Beside the post-certification of technologies, a future Jordanian system should also include the organizational framework as well as the certification of the O&M personnel.

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Septic tank installation (© UFZ)

Real-Scale Implementation of Decentralized Wastewater Treatment and Reuse Systems

Nabil Wakileh[3], Thomas Gester[1], Jaime Nivala[5], Johannes Boog[5], Manfred van Afferden[5], Bassim Abbassi[5], Naser Almanaseer[4], Stephane Prigent[2], Roland A. Müller[5]

Jordan is one of the world's most water scarce countries, where groundwater resources are indispensable for potable water supply.

Jordan is striving to set a regional example of a successful implementation of Integrated Water Resources Management (IWRM) concepts and it is expected that it will be the reference case for IWRM knowledge, methods, and application in the Middle East.

The objectives of full-scale implementation of decentralized wastewater treatment technologies were to:

a) demonstrate that pilot technologies installed at the Research and Demonstration Site for Decentralized Wastewater Management in Fuheis, Jordan are also suitable for use at full scale,

b) demonstrate that private homeowners and communities can benefit from reuse of treated wastewater,

c) assess the process of implementing decentralized wastewater treatment and reuse systems in Jordan.

The SMART-Projects supported the Jordanian government by implementing ten full scale systems for decentralized wastewater treatment and reuse as components of an IWRM in the Wadi Shueib region. The construction of the treatment systems was supported by the companies: WAKILEH Contracting, ATB WATER GmbH, and HUBER SE. Examples of the construction sites are shown in Figure 1.

The installed technologies include:

> treatment wetlands (aerated and not aerated)
> sequencing batch reactors (SBR)
> modified septic tanks (MST) and a
> membrane bio-reactor (MBR).

KEY FINDINGS

Within the framework of the SMART project, different decentralized wastewater treatment technologies were implemented at full scale to demonstrate solutions for sustainable integrated wastewater treatment and reuse (Klinger et al. 2015):

- Seven systems at the household level (15 – 35 population equivalents PE)
- Three systems with sewer (100 – 300 PE)
- Operation, maintenance and monitoring over five years
- SBR, Modified Septic Tanks and treatment wetlands were demonstrated as suitable technologies
- Operation and maintenance (O&M) was identified as the key factor for sustainable implementation.

Figure 1: Left: Construction of Modified Septic Tank (Aerated Fixed Bed Reactor). Right: Load-controlled SBR (PUROO).

Seven of the systems were installed at household level (15 – 35 inhabitants); and three systems with sewer (100 – 300 PE) to serve larger populations.

The installed MSTs are fixed bed technologies with active aeration. MST is sized to be a one-tank system that entails anaerobic treatment chambers followed by one aerated section with an air pump providing oxygen for intense mixing and pollutant degradation.

This aerobic chamber is filled with fixed bed media (plastic media), making the system more robust against shock loads. The system is characterized by low O&M and land requirements.

In addition to classic SBR systems, a new generation of load-controlled SBR (PUROO) was installed at house level. The system works without electric pumps and valves. Since the operation is carried out with compressed air, the energy requirement of the technology is very low (30 kWh per inhabitant per year). The SBR system was honored in 2014 with the international GreenTech Award.

Ecotechnologies such as aerated horizontal sub-surface flow treatment wetlands have high treatment capacities for organic carbon, nitrogen and pathogens, low O&M requirements and are resilient against variable hydraulic and pollutant loads. One such ecotechnology was installed at the Princess Rahmeh College in the Balqa' Governorate, and now provides wastewater treatment for approximately 1,500 students (Figure 2 - right).

The reuse of treated wastewater for some of the full-scale systems is accomplished by subsurface irrigation systems (Figure 2 - left), or, if the treatment system was equipped with an additional disinfection unit, the treated effluent could be directly used for unrestricted surface irrigation.

It was demonstrated that several technologies developed and optimized at the Research and Demonstration Site for Decentralized Wastewater Management in Fuheis can be successfully implemented at full scale, with treatment performance results similar to those observed at pilot scale.

In general, decentralized wastewater treatment technologies have been demonstrated to be an appropriate solution for

Figure 2: Left: Subsurface irrigation system for treated wastewater. Right: Wastewater treatment plant at Princess Rahmeh College (Aerated Horizontal Filter).

small settlements in Jordan for which connection to centralized wastewater treatment plants is not a cost-effective option. A critical factor in the success of decentralized wastewater treatment technologies is a well-defined operation and maintenance scheme.

Based on the experience of operation and maintenance of the 10 real-scale systems installed during SMART II the following recommendations can be given:

> Real-scale systems reach similar treatment performances as at pilot-scale but require regulation and regular O&M
> Privately owned DWWTP require co-operation of the private site-owner regarding their awareness for the general water scarcity and the importance of proper O&M
> Simple treatment configurations (modified septic tanks, French-type wetlands) should be favored for private owned real-scale implementations due to low O&M requirements
> An implementation concept that favors governmental or publicly owned and operated DWWTP would be more favorable for proper operation (centralized management of conjoined decentralized systems)
> Implementation of regulations for O&M could improve operation of real-scale DWWTP

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Aerated Horizontal Filter at Princess Rahmeh College (© UFZ)

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Fuheis Competence Facility for Decentralized Wastewater Treatment, Jordan (© UFZ)

Competence Facility for Decentralized Wastewater Management

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KEY FINDINGS

In 2010 the „Competence Facility for Demonstration, Research and Training" started its operation in Fuheis, Jordan. At the multifunctional site, various approaches have been implemented to promote integrated wastewater treatment and reuse in Jordan:

- 13 different pilot-scale treatment systems operated with real wastewater
- On site laboratory for wastewater analysis and research
- Proven treatment technology adaptation to the Jordanian conditions (effluent quality, robustness, low operation and maintenance requirements)
- Agricultural and garden plots for reusing treated wastewater
- Hands-on education at university level
- Capacity development program for technicians, planners and decision maker

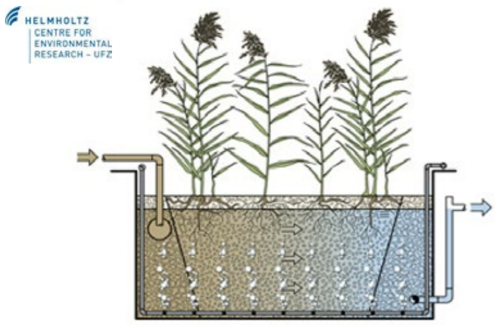
Climate change, dynamic demography and increasing migration, have become existential challenges, especially for efficient water management in arid and semi-arid regions.

The Jordanian Ministry of Water and Irrigation has identified the treatment and reuse of wastewater as an essential component to mitigate extreme water scarcity and protect groundwater resources.

In this context, the competence facility at Fuheis was opened in co-operation of the UFZ, Al-Balqa Applied University and the companies: WAKILEH Contracting, ATB WATER GmbH, HUBER SE and BAUER Resources GmbH.

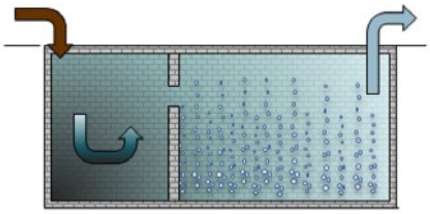
The wastewater treatment systems at the site include the following technologies: Sequencing- (SBR) and Continuous- Batch Reactors (CBR), Modified Septic Tanks (activated sludge and fixed bed type), Membrane Bioreactor (MBR), Sludge Dewatering Reed Bed, Anaerobic Bioreactor and Ecotechnologies: Vertical Flow, Aerated and Raw Wastewater (French Designs) wetlands.

Aerated Treatment Wetland



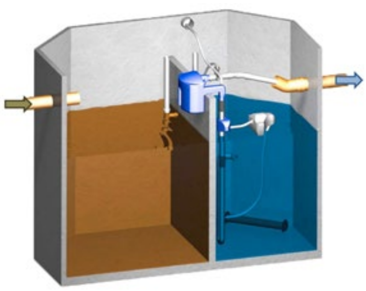
- > Combined secondary treatment & disinfection
- > Robust & resilient treatment
- > Low operation & maintenance requirements

Modified septic tank



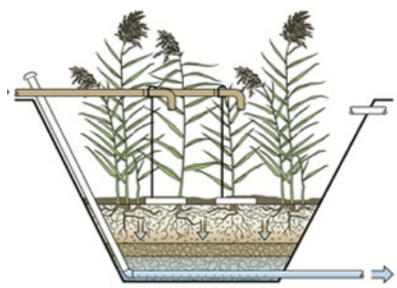
- > Combine anaerobic and aerobic treatment
- > Low operation and maintenance requirements
- > Compact design

Load controlled SBR (Puroo)



- > Combined secondary treatment & disinfection
- > Compact & energy efficient design
- > Simple installation

French-type Treatment Wetland



- > Combined sludge & wastewater treatment
- > Robust and resilient treatment
- > Alternating operation allows sludge to turn into compost

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Research at the facility focuses on (i) technology optimization & adaptation; (ii) nutrient recycling; (iii) pathogen removal; (iv) wastewater reuse; (v) sludge management & groundwater recharge.

Several wastewater treatment technologies could be adapted to the Jordanian conditions such as requirements of high effluent quality, robust treatment and low operation and maintenance requirements.

The technology optimization lead to the development of new German guidelines (DWA-A 262) for the design of ecotechnologies for decentralized wastewater treatment (DWWT), which define state of the art technologies and can be used as a basis for authorities to implement DWWT.

The reuse of treated wastewater can be directly investigated using agricultural and garden plots. The test plots are planted with lemon trees that are commonly produced in Jordan and have relatively high irrigation requirements. Small garden plots demonstrate further possible ways to reuse treated wastewater at household level.

Furthermore, the competence facility serves as Training and Capacity Development platform. It is used by students to conduct their PhD, Master and Bachelor studies or to gain further qualified training. Ministries, local companies, donors and other interested parties use the facility to increase their knowledge on different wastewater treatment systems and reuse options, including their operation and maintenance requirements.

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Handing over the Decentralized Wastewater Management Policy for Jordan (© UFZ)

National Implementation Committee for Effective Integrated Wastewater Management in Jordan – NICE

Mi-Yong Becker (née Lee)[1], Manfred van Afferden[1], Marc Breulmann[1], Anwar Al-Subeh[2], Ali Subah[2], Roland A. Müller[1]

KEY FINDINGS

The inter-ministerial and cross-sectorial committee NICE – National Implementation Committee for Effective Integrated Wastewater Management in Jordan – was established in project phase SMART I.

The NICE 'Implementation-Office' was opened in the Jordanian Ministry of Water and Irrigation in 2012.

NICE regulation was adopted by the Jordanian cabinet in 2016 through the:

- „National Framework for Decentralized Wastewater Management in Jordan" and
- Decentralized Wastewater Management Policy of Jordan, …*
- *…which is the first policy of its kind in the Arab World.

NICE identified:

- Hot spots of groundwater contamination by domestic wastewater,
- Site and technology selection methodology,
- Effluent standards for treatment plants serving less than 5000 population equivalents,
- National approach to operation and maintenance of DWWT plants.

The results presented here belong to the BMBF-funded projects: "Implementation Office Amman" NICE I and NICE II (Funding numbers: 02WM1212/02WM1458, Project leaders: Dr. Manfred van Afferden and Mi-Yong Becker (née Lee). Both projects contributed to the overall objective of the SMART project to sustainably implement IWRM approaches with a special focus on DWWM. Since the NICE project is still ongoing, the results presented here should be considered as a preliminary overview. Detailed results can be found in the specific NICE project reports.

The Ministry of Water and Irrigation (MWI) and the SMART joint research project jointly prepared and supported the implementation process of integrated wastewater management systems across rural and urban settlement areas.

In 2013, the Ministry of Water and Irrigation established an inter-ministerial National Implementation Committee for Effective Integrated Wastewater Management (NICE) in order to develop regulatory and administrative tools for implementing integrated wastewater management systems in Jordan.

While the NICE committee unites decision-makers from various Jordanian ministries and authorities as well as other important national stakeholders, the NICE Implementation Office in the Jordanian Ministry of Water and Irrigation is the committee's management unit. It facilitates and moderates the NICE work flow and framework setting process. Figure 1 depicts the structure of the NICE Steering Committee.

Figure 1: Members of the NICE Steering Committee.

The NICE office supports the committee and the technical working groups by providing scientific and technical advice, administrative support, and by moderating the inter-ministerial process from a neutral point of view.

The committee structures its thematic work in technical working groups on various aspects of sustainable wastewater management:

> groundwater protection,
> technology selection,
> urban planning,
> participatory planning,
> economic feasibility,
> standards & monitoring and operation & maintenance.

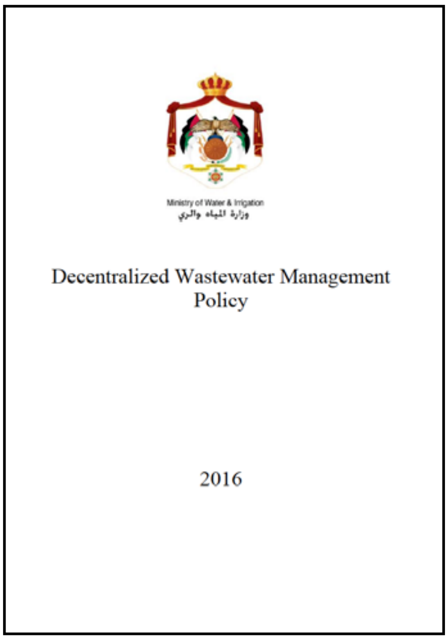
By 2016, NICE produced key elements for integrated wastewater solutions in Jordan including technology and reuse standards, procedures for site development, prioritized implementation areas in Jordan, operation & maintenance schemes which were compiled to the National Framework for Decentralized Wastewater Management in Jordan.

These contributions enabled Jordan to take part in instruments of international development cooperation for integrated wastewater management systems focusing on rural and suburban areas.

Based on the National Framework a draft for a Decentralized Wastewater Management Policy was developed by the MWI with support from the NICE Implementation-Office.

In 2016, the Jordanian Cabinet adopted both, the "National Framework for Decentralized Wastewater Management in Jordan" and the "Decentralized Wastewater Management Policy" (Figure 2). While being a milestone for Jordan, it is the first policy for decentralized wastewater management in the Arab world.

UNDP rates the Jordanian Policy for Decentralized Wastewater Management as a "significant step" of Jordan towards the use of wastewater as a resource.


Ministry of Water & Irrigation
وزارة المياه والري

Decentralized Wastewater Management Policy

2016

Figure 2: Cover page of the Jordanian DWWM Policy from 2016.

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Since 2017, the committee has taken over the coordination of investment projects targeting integrated wastewater infrastructure in Jordan and upon request of the National Committee, the NICE-Office continues its work (01.06.2017 – 30.11.2019).

Strategies will be developed and coordinated to further implement integrated wastewater management concepts in Jordan.

The current objectives of the National Committee are the:

(i) development of a framework for certification of wastewater treatment plants (≤ 5000 PE) and for O&M personnel for integrated wastewater systems in Jordan.

(ii) recommendations for the use of integrated wastewater management concepts towards implementing the SDG 6 reuse target for Jordan.

(iii) development of a draft directive on the use of IWRM concepts in rural and suburban settlements with refugee influx (host communities).


Suburb of Amman (© Manfred van Afferden)

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Further information about the NICE and the Implementation-Office is available at: www.ufz.de/nice-jordan

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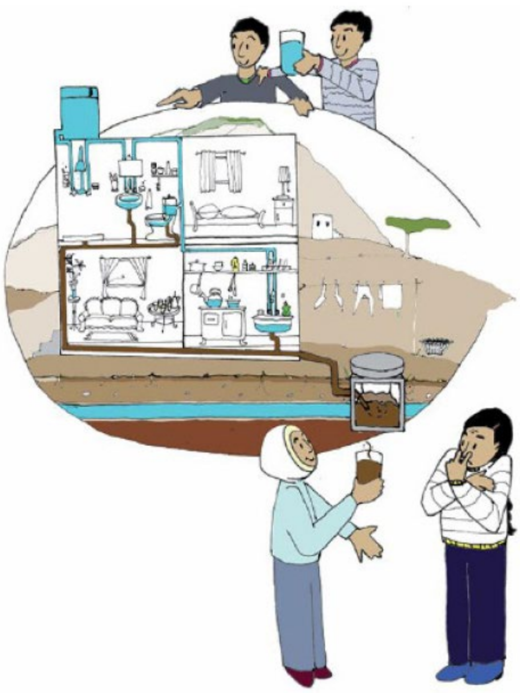
Water Fun – hands, minds and hearts on Water for Life!

Ruth Goedert[1], Jaime Cardona[1], Manfred van Afferden[2]

Early environmental education is a key element towards the permanent anchoring and strengthening of a nationwide IWRM concept that ensures the effective use of all water resources. Decentralized Wastewater Treatment is just one component, but its application is central to protecting valuable groundwater resources in water-shortage countries such as Jordan. For full social acceptance the principal elements of the decentralized approach need to be understood. To promote this goal the educational program "Water Fun" has been developed and successfully implemented.

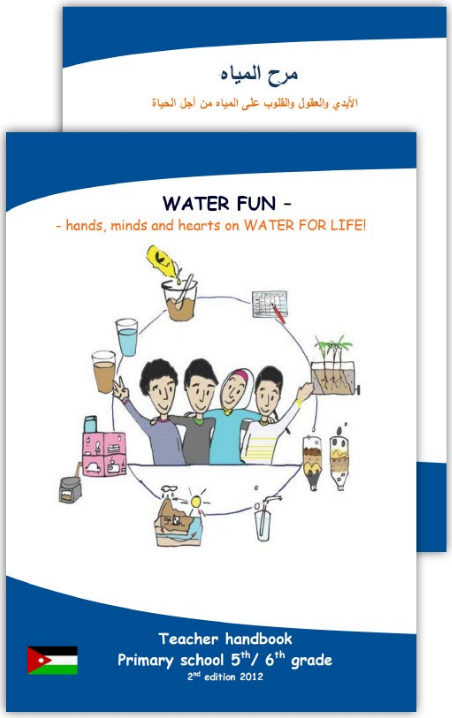


KEY FINDINGS
Design of the website "Water Fun – hands, minds and hearts on Water for Life!": http://www.waterfunforlife.de
Teacher handbook „Water Fun" in Arabic and English
Illustrated student handbook „Water Fun"
Six consecutive lesson concepts including four class room experiments for the primary school level
Project week concept on water quality, wastewater treatment and reuse (bench top & experiments) for less than 5 € per school
Overall achievement: 118 primary school teachers in Jordan and Palestine teaching around 5,000 students in 5th and 6th grade

"Water for life!" - this title is borrowed from the United Nations International Decade for Action "Water for Life" (2005 – 2015). The goal of the UN Water Decade is to encourage action for the fulfillment of the Sustainable Development Goals related to water resources. Jordan and Palestine are committed to achieving these goals and the title represents these countries' focus on sustainable water management.

„hands, minds and hearts on..." - This progressive educational triad promotes students' active and critical engagement with their teaching topic and its elements in a balanced but comprehensive manner. The methods were specifically designed to structure the learning processes in order to impart knowledge, raise awareness and support new attitudes and behaviors in line with sustainable development.

Together with BDZ, UFZ implemented the teaching program "WATER FUN - hands, minds and hearts on Water for Life!"



Under the motto "Water for Life!" the 'Water Fun' educational program builds for the future of the water sector and addresses the topics water protection and wastewater treatment targeting primary school education.

The program uses an integrated didactics concept for water in nature and in human livelihood. It provides teachers with background information and detailed explanations to guide students through the various teaching units.

The topics of the teaching program are conveyed by experiments and activities for primary students in a manner that fosters enjoyment and interest in thinking about natural and engineering phenomena, through experimenting, open discussion, and discovering and understanding physical processes related to water resources.

The program concept is reflected in the program title:

> Water Fun… - Students should have fun during the teaching units and should also have the opportunity to use their creativity, satisfy their curiosity, and exercise and deepen critical thinking.

After all, children like to have fun and they will also protect things that they like. This way they develop the awareness, interest, strength, and courage to take responsibility for water protection in Jordan and Palestine.

The teaching program delivers the associated message in a manner tailored for primary school students while its pedagogical concept takes the conditions in Jordan and Palestine into account with regard to water as a scarce resource.

The teaching program is designed to stimulate and improve reflection capacity as regards to water consumption, wastewater production and components, wastewater treatment and the potential reuse of treated wastewater.

Special classroom activities and experiments help students and teachers to train their "engineering" skills and understand and accept (treated) wastewater as a very valuable resource for irrigation in Jordan and Palestine.

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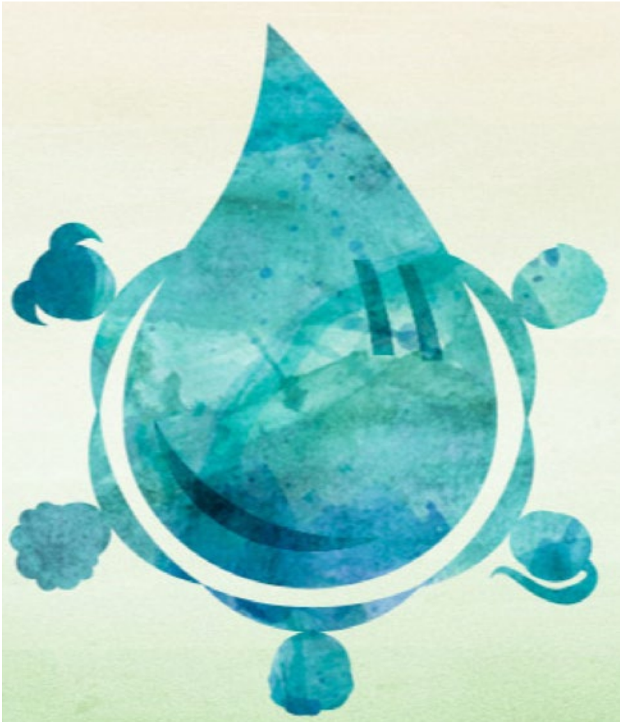

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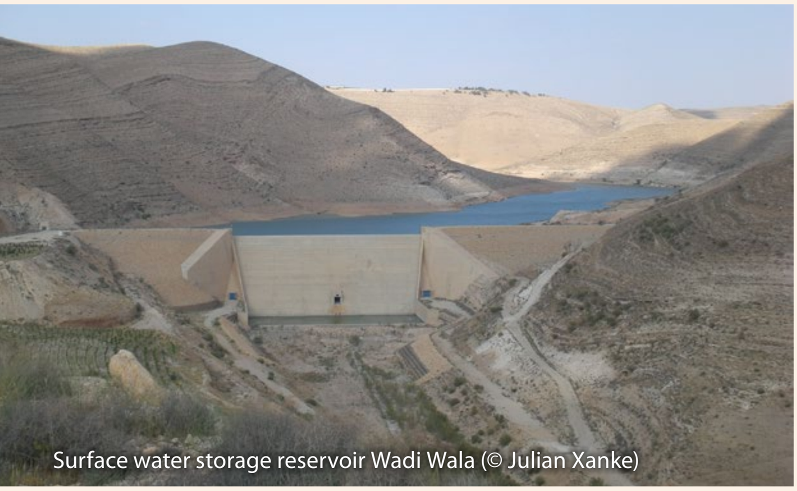


Surface water storage reservoir Wadi Wala (© Julian Xanke)

Brackish water desalination plant Karameh (© Heinz Hötzl)

Open section of King Abdallah (Ghor) Canal south of Sumeini, Jordan (© Heinz Hötzl)

Integrated Planning for IWRM Implementation

> Standardized procedure for sustainable water resources planning

> Improving the resilience of water resources systems by system upgrades

> Water strategy development as a combination of structural IWRM measures

> Assessment of water resources system performance by the WEAP model

> Evaluation of alternative water management scenarios by WEAP and MODFLOW

> Socioeconomic and political context of IWRM implementation in the LJV

> Economic assessment of alternative water plans

> GIS-based decsion support to identify lowest-cost wastewater management solutions

> The SALAM initiative: Resolution of the water deficit problem in the Middle East

Open section of the Israel National Water Carrier in the highlands between Lake Tiberias and the coastal plain (© Heinz Hötzl)

IWRM Concept and WEAP-Application, Cluster West

Bernd Rusteberg[1], Muath Abu Sadah[2], Abdel Rahman Tamimi[3], Martin Sauter[3]

KEY FINDINGS

Development of a participative standardized water resources planning approach to support sustainable water resources development both sides of the Lower Jordan river;

Identification of hydro-infrastructural measures to upgrade the existing water resources system at the so-called catchment Cluster West and to activate the remaining water potential by deep wells, surface runoff retention, controlled groundwater recharge and waste water reuse inside the basin and surrounding areas;

Even with the implementation of all measures, the water sector demand during the planning horizon of 20 years cannot be covered. Future water crises will particularly affect the mountain area near Ramallah;

In spite of all efforts, significant future water imports into the study area will be required to ensure sustainable development.

Introduction and Objectives

This section presents a summary of the work on water resources planning which were developed in a representative Palestinian sub-catchment of the Lower Jordan Valley (LJV) in order to demonstrate and improve the resilience of the water resources system against high hydrological variability and extreme drought events as well as the water resources planning process itself. Detailed information is provided by Rusteberg (2018a).

The so-called Cluster West Jericho-Auja in the Palestinian Territories of the Lower Jordan Valley is representative for many areas in the Lower Jordan Valley (LJV) with regards to its water resources system as well as the prevailing dry climate and socio-economic conditions. The lower parts of the 3 watersheds Auja, Nueimah and Qilt have considerable development potential with regards to trade and tourism. Furthermore, suitable climate and high land fertility result in a great agricultural potential. Therefore, the LJV is of major importance for Palestinian crop production. Jericho city with 25,000 habitants is the major urban center. The south-western urban parts near Ramallah present industrial and commercial potential (Figure 2). The difference in elevation between the lower and upper parts is ca. 1,000 m. All water sectors present significant and increasing water deficits. The water resources need to be further developed and the Integrated Water Resources Management (IWRM) concept to be implemented in order to guarantee sustainable development, especially of irrigated agriculture as most important economic sector, in spite of increasing drought conditions due to climate change.

IWRM implementation requires the activation and conjunctive use of all available water resources by structural measures in the first place. Therefore, the present research focuses on the outline of a water plan for the upgrade of the existing water resources system (WRS), consisting of a combination of hydro-infrastructural measures to improve the resilience and robustness of the WRS against high hydrological variability and extreme dry conditions.

Methodology

For the sustainable development of water resources in the Lower Jordan Valley both sides of the Jordan River and upgrade of the existing water resources systems, a generalized participative water resources planning approach has been developed within SMART-MOVE, based on the IWRM principles.

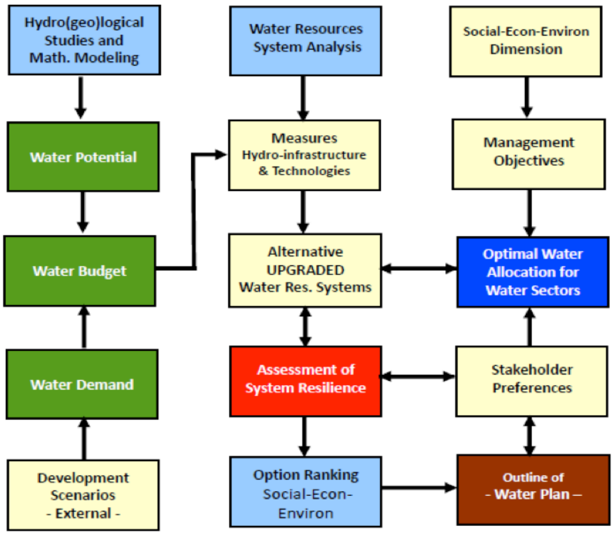


Figure 1: Water Resources Planning Approach (Rusteberg, 2018a)

The standardized and clearly structured procedure ensures transparency of the decision-making process and, therefore, acceptance of the suggested water development plans. The planning concept has been developed in close cooperation with the regional stakeholders and decision makers. The step-wise approach leads to the development of water plans on basin level with high robustness against hydrological variability and extreme events, taking the social, environmental and economic performance into consideration. Figure 1 presents a flow chart of the water resources planning approach. The approach has been built from an engineering point of view and as such it concentrates on the identification and dimensioning of so-called structural IWRM measures to improve the resilience, robustness and performance of the water resources system. Following the planning approach, an integrated water plan is developed which identifies the required hydro-infrastructural and technological interventions for sustainable system upgrade and operation. The transparency and standards of the suggested planning approach may serve as basis for any negotiation between the partner countries on the transboundary management of their water resources. The step-wise procedure requires water budgets forecast based on different scenarios for socio-economic development and climatic conditions during the planning horizon of 20 years. Further steps relate to the analysis of the water resources system to identify potential measures for the upgrade of the existing hydro-infrastructure as well as stakeholder consultations on the development goals, water management objectives and selection of representative technical (water supply), socio-economic and environmental indicators.

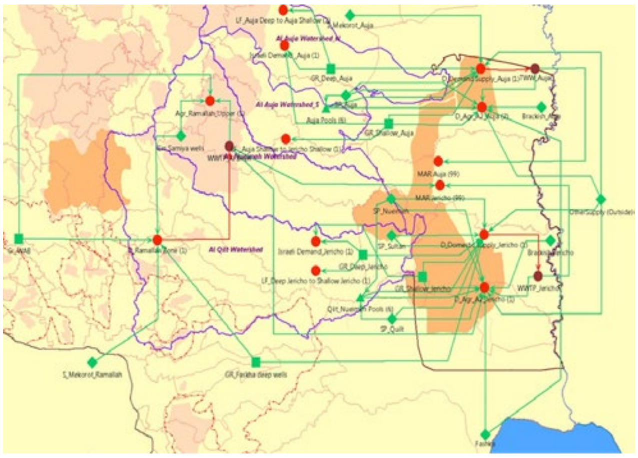


Figure 2: Division of Cluster West in Budget Zones.

Alternative IWRM-strategies are being defined as a combination of potential hydro-infrastructural interventions. The impact of those strategies on system resilience (water demand coverage, water deficit, water supply reliability) has been accessed by the Water Evaluation and Planning System WEAP (weap21.org) and Groundwater modeling. For these investigations, the catchment cluster, due to different socio-economic and physical characteristics was divided into 3 areas. Figure 2 illustrates the division into the so-called Auja Area, the Jericho Area and Ramallah (East) Area.

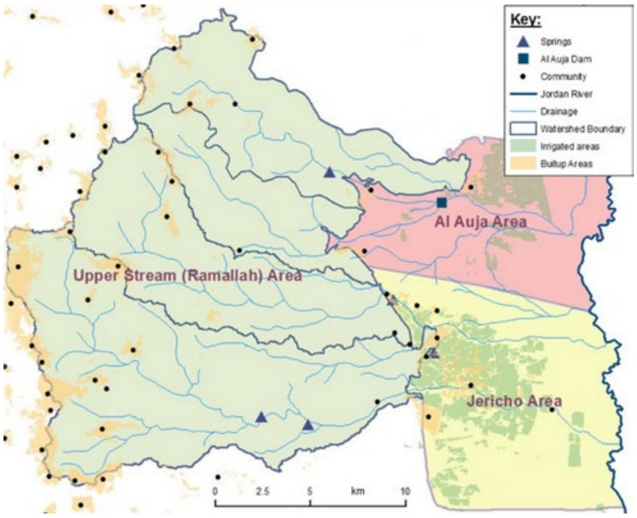


Figure 3: Representation of the Water Resources System at Cluster West with the WEAP model.

The schematic representation of the water resources system with the water sources and water supply nodes as basis for the application of the WEAP model is depicted in Figure 3. It already includes the different potential measures for system upgrade according to Table 1.

The identification and dimensioning of the IWRM measures was accomplished in close collaboration with the project partners, as well as with Palestinian and Israeli stakeholders and decision makers. Table 1 defines a set of alternative IWRM strategies as combined structural measures, with the individual measures

Table 1: IWRM Strategies for the upgrade of the Water Resources System at Cluster West.

IWRM STRATEGY	SURFACE RUNOFF RETENTION (SPRING SURPLUS FOR CONTROLLED MAR)	SHALLOW AND DEEP WELL INSTALL-ATIONS (MOUNTAIN AREA AND VALLEY)	FULL TREATMENT AND REUSE OF LOCAL WASTEWATER FROM THE VALLEY	TREATED EFFLUENT IMPORT FROM AL-BIREH	DEEP WELLS IN MOUNTAIN AREAS ABOVE FESHCHA SPRINGS AND TRANSFER TO RAMALLAH	BRACKISH WATER TRANSFER FROM FESHCHA SPRINGS	ADDITIONAL WATER IMPORT
A	X						
B	X	X					
C	X	X	X				
D	X	X	X	X			
E	X	X	X	X	X		
F	X	X	X	X	X	X	
G	X	X	X	X	X	X	X

being gradually aggregated. All strategies consider the rehabilitation of the water distribution network together with the installation of pipelines to minimize water transfer losses. The most efficient usage of spring discharge for water supply and Managed Aquifer Recharge (MAR) is considered an obligatory measure and basis for all strategies. Not explicitly listed is the so-called do-nothing (business as usual) approach, which assumes that no system upgrades will be implemented and that the existing water resources system will continue to be managed in its unchanged form. All strategies aim at further extension of the irrigated land in the valley around Jericho-Auja to the maximum irrigable area with the next 10 years (RUSTEBERG, 2018a).

The IWRM strategies were compared in technical (water supply), socio-economic and environmental terms. Due to the major research objective, special attention has been given to the improvement of system resilience, taking a moderate and a dry climate scenario into account. The following water supply indicators were considered: Total water supply delivered, unmet demand, demand coverage and water supply reliability. For more detailed information please refer to Rusteberg (2018a), Rusteberg et al. (2018d) and corresponding project deliverables (www.iwrm-smart-move.de).

Results

Table 2 presents the water cost of the different measures as Average Incremental Cost (AIC), taking all construction, operation and maintenance cost into consideration. The calculations are based on a planning horizon of 20 years. The results show that controlled groundwater recharge by efficient usage of spring water surpluses and surface runoff is a most cost-effective measure.

The import of brackish water from the Feshcha springs is also an economic measure which would contribute significantly to the expansion of irrigated agriculture and the improvement of the system resilience against drought events. The water cost for the construction of deep wells in the valley exceeds already USD 0.40/m^3. The reuse of wastewater is still quite expensive, as the wastewater collection network needs to be significantly expanded. Furthermore, treated effluent import requires the construction of a pipeline from El-Bireh to the irrigated areas in the valley. The implementation of deep wells in the mountains of Feshcha is to be questioned due to the high water costs, but could be used to strengthen drinking water supply in the subarea of Ramallah East.

The assessment of water supply indicators for the different IWRM strategies and climatic scenarios show that in the case of the Do-Nothing approach, independent of the prevailing climatic conditions, large water deficits will occur in the future, which partially may be covered at the cost of a further overexploitation and emptying of the shallow alluvial Aquifer in the valley.

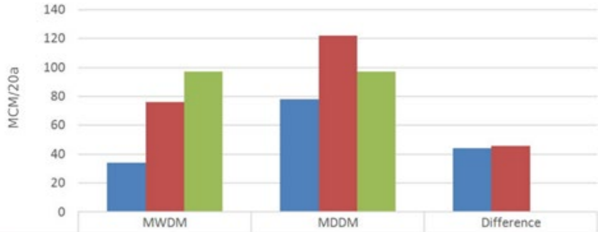
By implementing the suggested structural measures to activate the remaining local water potential as well as of adjacent areas, the water supply security and resilience of the water resources system can be significantly improved over periods of drought so that the implementation of all measures is strongly recommended from that point of view. The studies also prove the positive social impact of all interventions due to the above

Table 2: Average Incremental Cost of structural measures as part of integrated strategies.

	IWRM-MEASURES AS PART OF INTEGRATED STRATEGIES						
AVERAGE INCREM. COST	GW recharge with spring water surpluses	Flood Water Retention to enhance GW recharge	Deep wells in the area	Treated effluent reuse from Jericho WWTP for direct irrigation	Treated effluent import from El-Bireh	Deep Wells at Feshcha and transfer to Ramallah East	Brackish water imports from Feshcha springs (extra cost for desalination in brackets)
USD/M^3	**0.07**	**0.27**	**0.41**	**0.49**	**0.45**	**0.87**	**0.35** (0.39)

reason. Preliminary studies on water cost and cost-benefit relations indicate the economic viability of the suggested measures (Rusteberg et al., 2018b).

But it also became evident that even after implementation of all measures, the steadily increasing water demand cannot be fully



	MWDM	MDDM	Difference
Auja	34.05	78.07	44.02
Jericho	76.25	122.14	45.89
Ramallah East	97.24	97.24	0

Figure 4: Total additional required water to be imported over the planning horizon of 20 years (2015-2035), taking the moderate climate scenario (MWDM) and the dry scenario (MDDM) into account.

covered, so that additional water imports into the study area will be necessary to enable sustainable development. According to Figure 4, depending on the climatic conditions, an average of 10 to 15 million m^3 (MCM) of additional water is required per year, with water deficit values being significantly above the mean during the dry periods. Future water crises will particularly affect the sub-area „Ramallah East" (Figure 3), provided that no further measures are being implemented. The already existing and further expected water shortages in the catchment cluster are representative for the situation of many areas in Palestine.

The development of wastewater reuse in irrigated agriculture in exchange (tradeoff) with fresh water from deep wells is certainly a key component of sustainable and integrated water management in the study area. Therefore, also wastewater imports from more remote areas, such as e.g. from Jerusalem, into the irrigated areas around Jericho-Auja should be taken into consideration. With regard to the options for significant freshwater imports, reference is made to the SALAM subproject (Rusteberg et al., 2018c).

Further Research Needs

Further research needs on the SMART-MOVE line of integrated water resources planning and management are:

> Validation of the innovative planning approach to support IWRM implementation in a participatory process together with stakeholders and decision-makers at regional and transboundary level;
> Need for innovative concepts to strengthen institutional development to anchor the IWRM principle in Palestine and Jordan;
> Studies on the import of treated wastewater from more remote areas into the Jericho-Auja irrigation area, i.e. from the Jerusalem area, to strengthen agricultural development;
> Strategies for the conjunctive management of brackish water, sewage and groundwater resources in the Jordan Valley for the purpose of sustainable agricultural development with special attention to resource conservation, in particular to avoid soil salinization;
> Spatial discretization of water sector demand and expected deficits during the next two decades for the entire West Bank, in particular urban areas, as a basis for integrated water resources management and „water trade" between neighboring sub-basins;
> Studies on how to realize additional fresh water imports, especially from seawater desalination at the Mediterranean coast, in the context of a transboundary management of water resources.

Capacity Development

Capacity development measures were realized at the Palestinian Water Authority (PWA) in Ramallah, Westbank, focusing on water resources planning, WEAP and MODFLOW applications in the study area.

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Jericho agro-industrial park (© PIEFZA)

Socio-economic and political context of Integrated Water Resources Management in the Lower Jordan Valley

Abdel Rahman Tamimi[1], Bernd Rusteberg[2], Subhi Samhan[3], Hazem Kittani[3], Issam Nofal[4], Muath Abu Sadah[3/5], Torsten Lange[6]

KEY FINDINGS

Public participation in policy formulation is the key issue for integrated water resources management.

Regional cooperation is the major possibility to meet the growing water demand; it will enhance the socioeconomic development of Palestinians.

The socio-economic development is the shortest way and the precondition for peace and regional stability.

Good governance and socioeconomic incentives to the farmers will guarantee sustainable management.

The Jordan River basin has a large potential to be a good model for the Water-Energy-Governance-Food nexus.

A plan for an Interministerial and Cross-sectoral IWRM Committee for the Palestinian Territories as basis for discussion has been developed and provided to PWA and MoA.

Objectives

The main objective of the conducted work is to highlight the socio-economic and the political frame of the integrated water resources management (IWRM) in the Lower Jordan Valley.

Lower Jordan Valley importance for the Palestinians

The Palestinian Jordan Valley extends from Jericho in the south to Bisan in the north and covers an area of about 1.5 million dunums, which equal 25% of the total area of the West Bank. The Jordan Valley is a unique region that has attracted visitors from around the world. It has unique geographical and environmental characteristics unparalleled anywhere else. Moreover, the Dead Sea is the lowest and most saline body of water in the world. The sea itself is abundant in minerals of therapeutic value. Many tourists seeking to heal various skin, artery, and joint ailments are attracted to the region. The region has 81 tourist sites, including those of significant archeological and natural value. It is also the oldest continually inhabited area in the world. The Jordan River is one of the most outstanding symbols of the „Holy Land" and together with its surrounding area a natural heritage to the people all over the world. The Jordan Valley is not only considered the food basket for Palestinians, but also bears additional economical potential due to export of various crops, e.g. dates (Figure C.2 1).

The large potential for urban development of the Jordan Valley area is very suitable for the expected demographic expansion for the West Bank. It is the only remaining Palestinian area that can absorb large scale urban development.

Diagnosis of the situation

Currently, groundwater is the main source of water for Palestinians. The magnitude of renewable groundwater resources

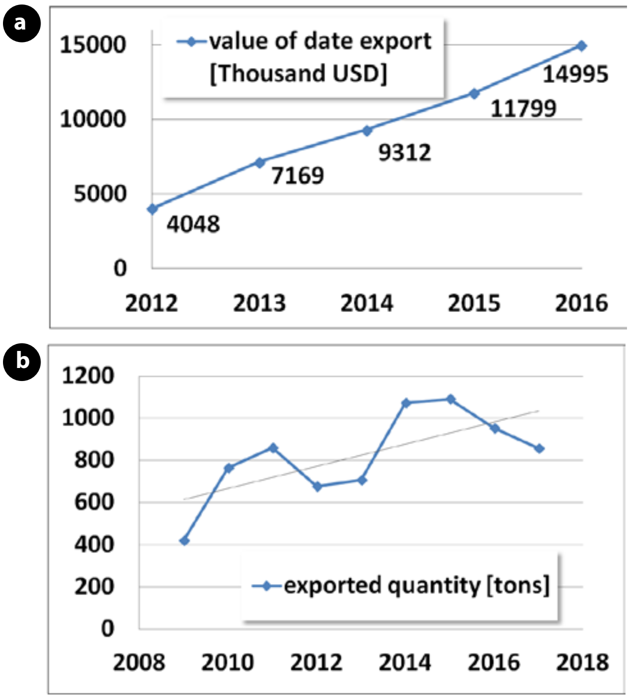


Figure C.2 1: Realized annual exports of agricultural products from the Jordan Valley: (a) value of date exports 2012-2016, (b) quantity of exported agricultural products in tons 2008-2017

in the Palestinian Territories varies from the official 729 MCM/year (679 MCM/year in the West Bank and 50 MCM/year in the coastal aquifer of Gaza) that is stated in the Oslo interim agreement. Although the official value for the West Bank appears to be overestimated, it was not re-evaluated since then. According to the agreement the annual renewable groundwater resources for the West Bank is distributed over the three major aquifer basins with replenishment volumes of 362 MCM, 145 MCM, 172 MCM for the Western, the North-Eastern and the Eastern basin, respectively. In addition, surface water, represented mainly by the Jordan River, is not yet accessible to the Palestinians due to Israeli control and imposed restrictions. However, the fresh water flow rate through the river is quite low due to the limited release from Lake Tiberias.

Challenges

To develop well harmonized concepts for institutional development and capacity building as part of the IWRM implementation process the challenges or leverage points were derived from the assessment of the initial situation, the overall objectives, and the necessary participative discussion process with the affected decision makers, stakeholders, and academia.

The main national interest is how to meet the demand of the Palestinians in the Jordan valley under uncertain socio-economic, environmental, and political conditions. The challenges are manifold:

> fragmentation of governance,
> zonal fragmentation of administration and control in the West Bank,
> general uncertainty of the political, economic and demographic development,
> unequal accessibility and distribution of water,
> groundwater over-pumping caused by insufficient regulation or insufficient enforcement of regulations,
> weak role of the tariff in the efficient use and the awareness of the value of water,
> generally high risks for groundwater pollution due to difficult legal implementation of groundwater protection-based vulnerability,
> no proper mechanism for stakeholder participation competition among different water sectors,
> social and cultural perceptions.

Summary and Recommendations for Actions and Measures

According to the identified challenges the Palestinian Authority has to define and implement adequate measures and action plans. It is important to properly inform policy makers about the water related problems and challenges and to urge politicians to keep the water issue high in the political agenda. This is especially true also for the obtainment of the Palestinian Water

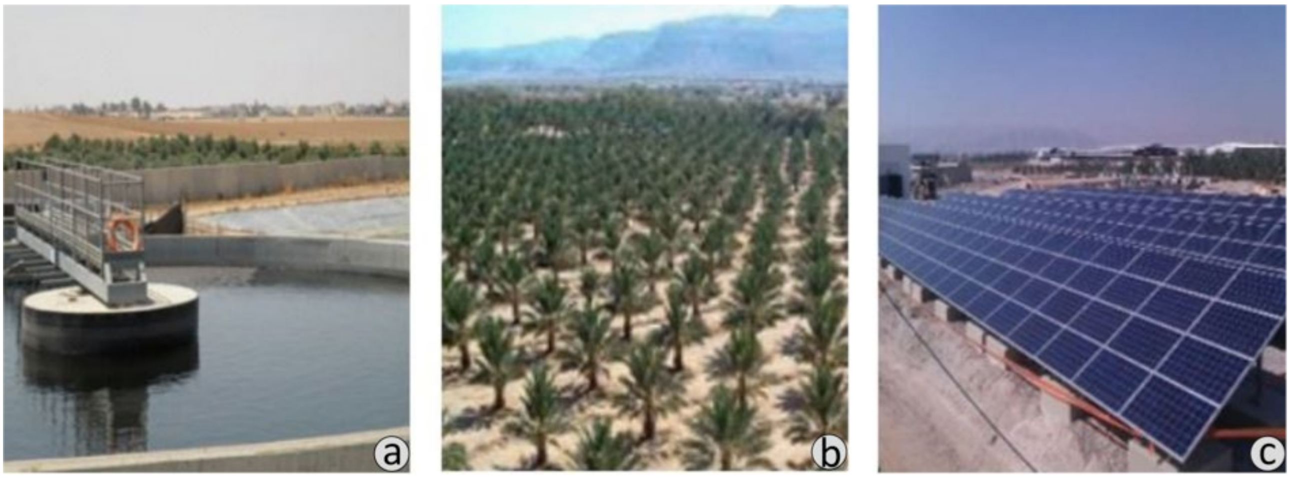


Figure C.2 2: Recent and continuous optimization and intensification of land use and agriculture in the Jericho area, Lower Jordan Valley: (a) Jericho wastewater treatment plant, (b) dates farm, (c) solar energy farm installation of the Jerusalem District Electricity Company in Jericho.

Rights in their resources in the realistic prospect of a full Palestinian sovereignty in not too far a future.

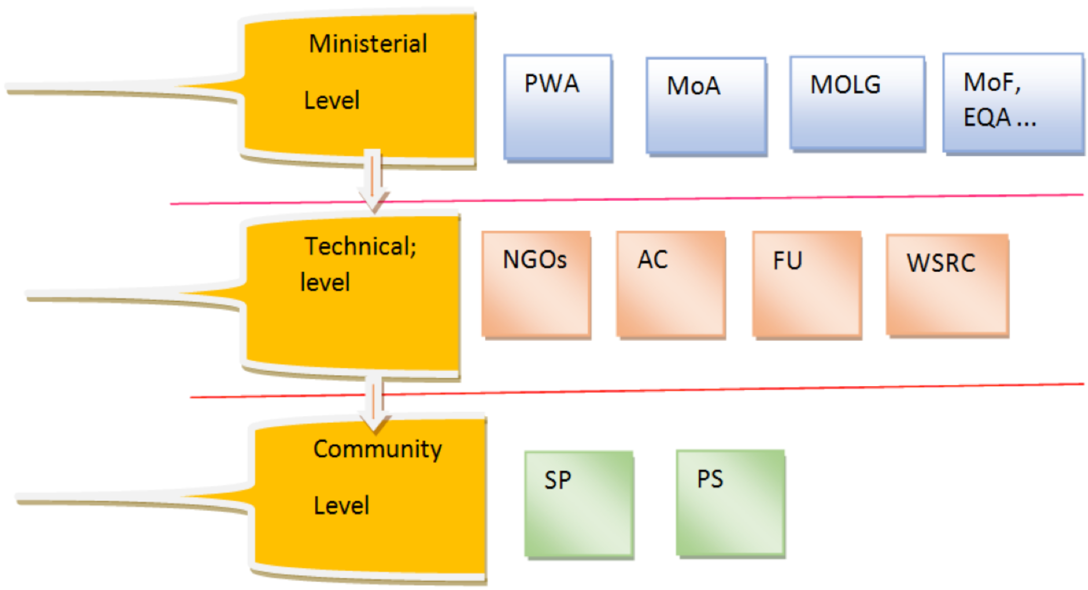
1. The national IWRM reform strategy and actions

> Implement the new Water Law#4 and formulate all related regulations including water resources protection, pollution prevention, water tariff optimization, water resources development and monitoring, etc.
> Ensure separation of authorities among various governmental bodies and ministries to ensure a more coordinated and integrated water management approach.
> Develop a clear regulation for stakeholder participation in decision making related to water management and institutionalize such regulation. As one of the options, a plan for an Interministerial and Cross-sectoral IWRM Committee for the Palestinian Territories as basis for deeper discussion has been developed and provided to PWA and MoA (Figure C.2 3). The suggested framework will be a plattform to support the national efforts and definition of priority strategies for IWRM implementation and to cope with water scarcity and drought events.

Furthermore, it will enhance the regional cooperation to jointly maximize the benefits of sustainable and integrated water resources management, enabling transboundary cooperation and the implementation of collective measure for climate change adaptation.

2. Measures at technical level

> Promotion of a national water saving plan and environmental measures and certify the new saving tools.
> Decentralized wastewater treatment plants for rural and no urbanized areas to be promoted with focus on natural and biological treatment technologies.
> Grey water treatment and reuse at household and group of household level needs to be encouraged. This can also be coupled with modified percolation pits to ensure localized sanitation solutions.
> Guidelines and manuals need to be produced to assist people in better understanding, managing, operating and maintaining the new technological solutions.
> Cooperation with Jordanian Partners to adopt and adjust successful DWWT concepts und guidelines for the Palestinian conditions.



- PWA: Palestinian Water Authority
- MoA: Ministry of Agriculture
- MOLG: Min. of Local Government
- MoF: Ministry of Finance and Planning
- NGOs: Non-Governmental Organizations
- PS: Private Sector
- AC: Agricultural Cooperatives
- FU: Farmers Union
- WSRC: Water Sector Regulatory Council
- SP: Service Providers
- EQA: Environmental Quality Agency
- PS: Private Sector

Figure C.2 3 Suggested Structure for the IWRM Implementation Committee in the Palestinian Territories

3. Measures at Social and Cultural Level

- National strategy on public awareness needs to be implemented and national campaign needs to be started to improve public knowledge about the advantages of the water saving practice and installation of devices.
- To organize information sessions and arrange visits for pilot locations to change public perception on the reuse of treated effluent.
- Using local media to disseminate and communicate the main messages of encouraging people to engage in national campaigns for water savings or to highlight various issues related to wrong perceptions and practices related to water and wastewater treatment, reuse and disposal.

4. Development of a regional cooperation plan,

comprising the following steps:

- Decision makers define a complete national vision about the expectations on transboundary cooperation, with water and wastewater management as a top priority.
- Decision makers elaborate and propose a negotiation procedure.
- The common regional interests and development goals are defined in the negotiation process.
- An implementation plan is developed and agreed.

5. Other key policy issues

comprising:

- Using the technological possibilities for reducing the agricultural demand such as new technology of automation of the irrigation and using saline water tolerant crops.
- Public awareness campaigns for reuse of marginal and non-conventional water.
- Socioeconomic incentives for the farmers.
- Taking institutional and administrative measures to reduce non-technical non-accounted water.
- Promoting the concept of the Water-Energy nexus.

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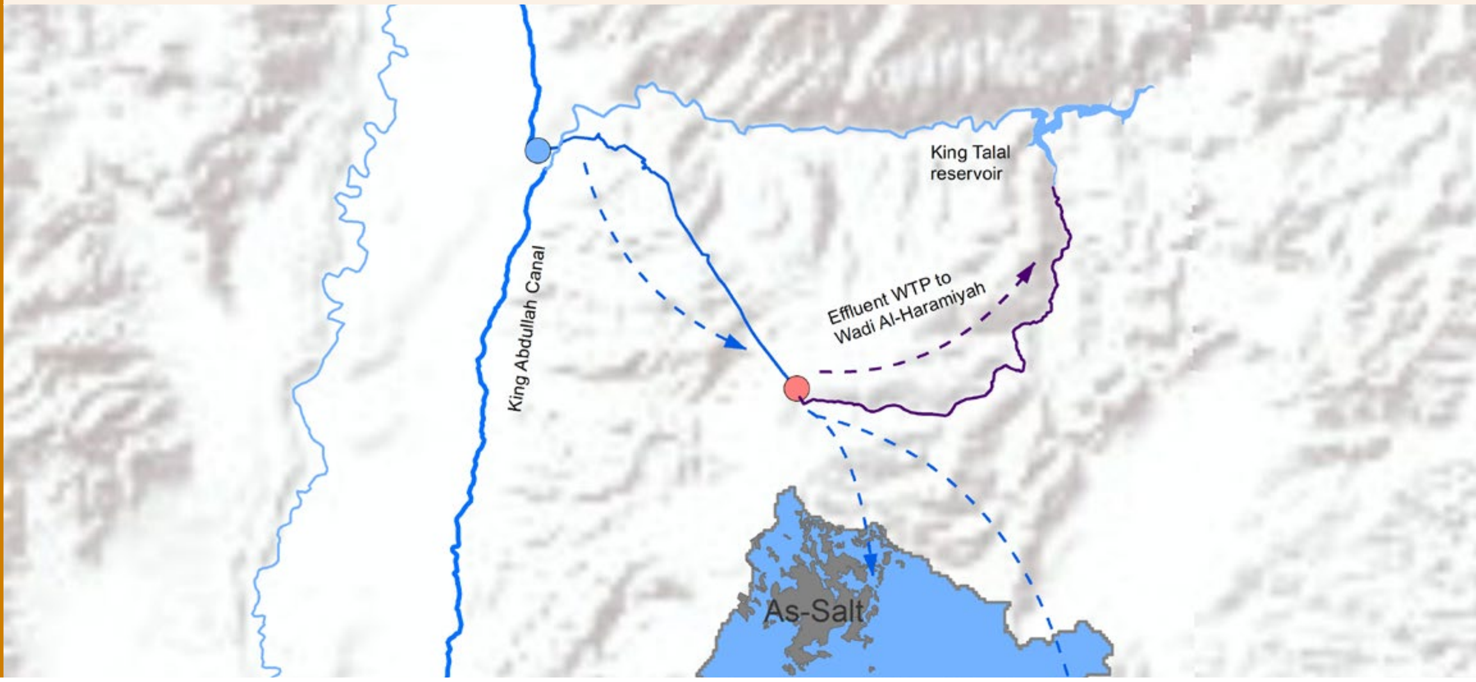
References and further Reading
Further detailed information about the different studies can be found on the project website www.iwrm-smart-move.de



Economic assessment of alternative water plans in Jordan

Heinz-Peter Wolff[1], Patrik Frick[2], Julian Xanke[2], Jochen Klinger[2]

KEY FINDINGS

In a first study the cost structure of the pumping system for the section between Deir Alla, Zai water treatment plant (WTP) and the Dabouq Reservoir (75 MCM/year) was analyzed. The evaluation revealed that a successive shifting of water treatment stages to the Jordan Valley could save up to 10 to 21 Million Jordanian Dinar (JD) over a period of 25 Years.

A second study compared the current practice of freshwater import with possible water quality improvements in the Wadi Shueib (Hazzir spring). None of the two alternatives shows a significant advantage over the other as the additional charges on the budget of the water administration are similar and savings from the reduction of water imports do not cover the expenses of the required measures for the considered water quality improvement in Wadi Shueib.

Economic assessment of an adapted water distribution strategy

The imbalanced distribution of natural fresh water resources and their local pollution due to urbanization and anthropogenic land use is a major challenge in the region. The water transfer and supply in Jordan relies on a distribution system that bridges not only large distances but also great height differences between the source locations and demand areas. A central role in the Jordanian water strategy plays the King Abdullah Canal (KAC). Currently about more than 200 Million m^3/a (MCM/year) of fresh water is conveyed over a distance of more than 100 km via this open channel system, from Lake Tiberias, the Yarmouk River and Mukeibah well field to Deir Alla in the Jordan Valley. From there, ca. 75 MCM/year water are pumped to the Zai water treatment plant (WTP), located 1,200 m higher, and further to the Dabouq Reservoir. In a next step, the water is supplied to Jordan's capital Amman and to the city As-Salt in the upper part of the adjacent Wadi Shueib.

The costs for operation and maintenance as well as further extension of the described water network are quite high for a resource-poor country such as Jordan. Thus, one of the SMART-MOVE objectives was to propose an adapted alternative water distribution strategy combined with a detailed economic assessment.

It is estimated that about 10% of the water to be treated at Zai WTP is discharged as effluent into Wadi Al Haramiyah, where it causes environmental damage due to heavy metals and other contaminants. From the water management perspective, the potential to improve the system is on the economic assessment of the Deir Alla – Zai WTP – Dabouq Reservoir system, where two water management aspects are economically assessed:

1. Cost structure of the pumping system Deir Alla - Zai WTP – Dabouq Reservoir
2. Construction of a new water treatment plant in Deir Alla in the Jordan Valley

The first case allows the determination of the costs per cubic meter of water, pumped to Zai WTP, and the calculation of the cost savings if case two is applied (including the avoidance of environmental damage due to effluent discharge to the Wadi).

The necessity of importing fresh water into the Wadi Shueib is necessary, since water demand exceeds the local available fresh water availability and the discharge of wastewater into the karst aquifer periodically pollutes the local springs and thus makes them unusable. Therefore, in a second study the water import costs (status quo) were compared with alternative methods and their costs.

Results show that about 0.625 Jordanian Dinar (JD) per cubic meters are spent for pumping costs (2015), of which ca. 77% are consumed by electricity supply (Figure 1, left). Cost savings for an effluent volume of 2 MCM would reach about 45 Million JD after 25 years, and up to 70 Million JD over a 100 years period, if the avoidance of environmental damage is accounted for. Calculations include an average cost development of 5.5% and a discount rate of 3% per year. Considering the costs for a new water treatment plant, (about 35 Million JD) a net present value of about 10 Million JD (pumping costs) and of up to 35 Million (pumping costs + environmental damage) can be generated within 25 years.

Economic assessment of alternative water plans for Wadi Shueib

Wadi Shueib, located west of Amman gives home to more than 120,000 inhabitants. Due to its vicinity to Amman and the relatively high population growth (almost 3% according to Jordan's Department of Statistics) it is declared as focus area in terms of improved water management. The area faces a set of urgent water management challenges that are set at the inter-section of competing municipal, industrial and downstream agricultural demand. At the same time water resources pollution (e.g. leaky sewer network) causes problems that are likely to aggravate in the near future. In this regard, the situation in the Wadi Shueib can be considered as an example for many of the problems in the region.

Currently, in Wadi Shueib water demand is partly covered by water imports, since e.g. Hazzir spring cannot be used for drinking water supply due to pollution.

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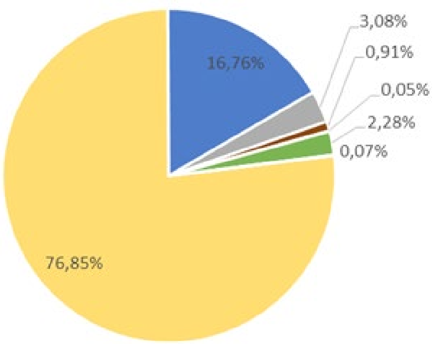
This study assesses the freshwater import (status quo) vs. quality improvement in the Wadi Shueib (Hazzir spring). The latter includes the scenario of an improved water treatment and the scenario of a rehabilitation of the sewer network.

The economic evaluation of investments in water infrastructure and water management alternatives focused predominantly on the application of methods from partial investment analysis such as cost-benefit-analyses (CBA) or cost-efficiency-analyses (CEA).

Results show, that both scenarios imply increased burden on the budget of the water administration since savings from the reduction of water imports do not cover the expenses of the required measures (Figure 1, right). However, since only the Hazzir spring is considered, these numbers can change in the case of contamination of the other springs. Furthermore, non-economic aspects like the advantage of a standalone water supply that does not depend on water, were not considered.



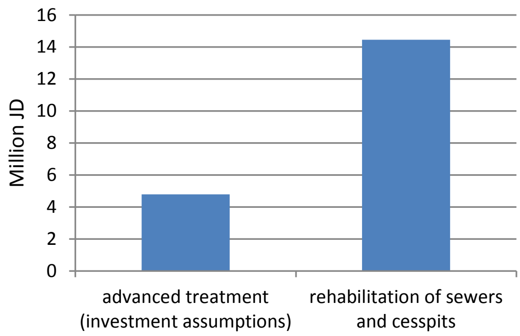


Figure 1: Economic assessment of an alternative and optimized water infrastructure as a water planning component in Jordan – left: cost structure of the Deir Alla - Zai WTP pumping system, right: cost differences between status quo and alternative solutions.

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WOLFF, H.P. (2017): Economic assessment of alternative water plans for Wadi Shueib/Jordan. - SMART Move project report.

Wastewater treatment plant close to As-Salt (© Julian Xanke)

Water management scenarios for Wadi Shueib using WEAP and MODFLOW models

Paulina Alfaro[1], Tanja Liesch[1], Julian Xanke[1], Nico Goldscheider[1]

KEY FINDINGS

Groundwater abstraction in the Jordan Valley needs to be reduced to stabilize the groundwater table.

Full implementation scenarios, ideally combined with low resources pressure (LRP), will improve the system.

The measures planned in the new water strategy, e.g. the closure of illegal wells and use of treated waste water (TWW), mitigate the stress on the system.

Currently, reclaimed waste water does not provide sufficient quantities for the actual demand.

Water management scenarios for Wadi Shueib and downstream in the Jordan Valley were developed and studied using a water allocation model (WEAP) for both basins and a numerical groundwater flow model (MODFLOW) in the Jordan Valley. The simulation results from the latter are included in WEAP being able to analyze all elements of the water system with one setup, for instance, water demand of domestic users and agriculture or the effect on the water balance of alternative water sources for irrigation.

For the period 2010-2025 different scenarios were simulated based on the documented and projected agricultural and urban development in the Jordan Valley under different hydrological conditions (average rainfall + low rainfall) and three groundwater abstraction scenarios (increase, no increase and reduction of groundwater abstraction by 40%). A set of pre-defined environmental indicators was applied in the evaluation and selection process. The results were visualized and presented to the stakeholders and decision makers in a comprehensible way to provide a straight forward method to analyze the modeling results and understand the effects of the scenarios to draw appropriate conclusions for alternative water strategies.

Results show that hydrological conditions (Figure 1), being average (a) or dry (b) only have a minimal influence on the groundwater table, and a stabilization can only be achieved, if irrigation decreases by at least 40%.

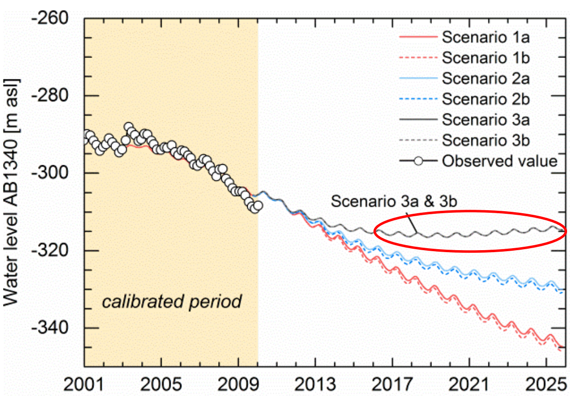

Figure 1: The results of the different hydrological scenarios combined with different agricultural development show that stabilization of the groundwater table can be achieved if irrigation decreases by at least 40% (Alfaro 2017).

To counteract this negative trend of declining groundwater levels different implementation scenarios were assessed:

1) The business as usual (BAU) includes the reduction of water losses, the rehabilitation of sewer lines and the closing of illegal wells.

2) The full implementation (FI) additionally considers the increase of the capacities of waste water treatment plants (WWTP), better household connection to the sewer network, the reduction of arable land and household roof rainwater harvesting.

3) Furthermore, the full implementation plus scenario (FI Plus) in addition considers the construction of decentralized waste water treatment plants (DWWTP) and the enlargement of the Wadi Shueib dam.

These three different implementation scenarios were combined with a low resource pressure (LRP) and a high resource pressure (HRP), mostly being dependent on population growth.

Different indicators were used to evaluate, if the system recovers or stays under stress (Figure 2). The results show that if the FI Plus scenario is applied, the JV will fall below the severe stress line by 2022 due to the reduction of groundwater withdrawals, while the measures of the BAU scenario are only suitable to stabilize the stress on a very high level. Thus, it can be concluded, that only the additional measures of the FI scenarios as an increase of the capacities of WWTP or construction of new DWWTP are able to mitigate the stress on the system. Furthermore, increased WWTP capacities would help to provide more reclaimed waste water, which at the moment cannot be provided in sufficient quantities for the actual demand.

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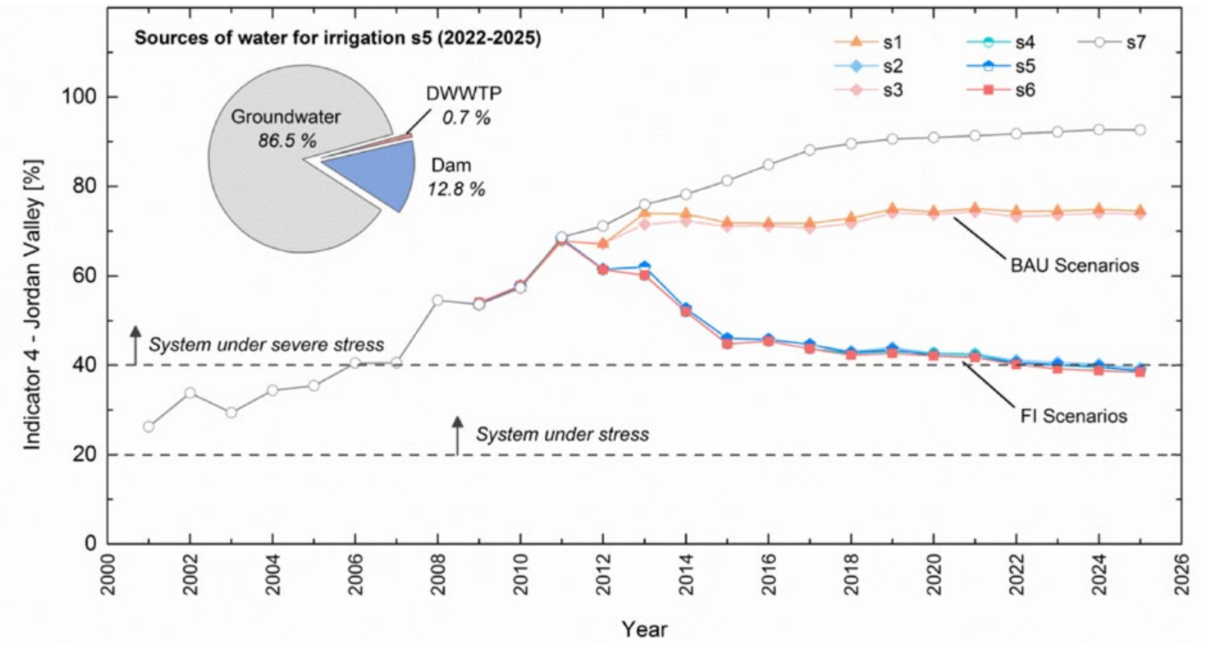

Figure 2: The JV falls under the severe stress line by 2022 through the reduction of groundwater withdrawals with the full implementation scenario plus (full implementation plus scenario; Alfaro 2017).

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City of Al-Salt (© Ganbaatar Khurelbaatar)

GIS-based decision support: Assessment of Local Lowest-Cost Wastewater Management Solution (ALLOWS)

Ganbaatar Khurelbaatar[1], Mi-Yong Becker (née Lee)[1], Jaime Cardona[2], Manfred van Afferden[1], Roland A. Müller[1]

KEY FINDINGS

In order to adequately address the challenge of integrated wastewater management at the planning level, the application area / functionalities of the GIS-based decision-making tool „ALLOWS" that was developed under the SMART II project was used for real scale scenarios for Ira & Yarka, Dair-Yusuf, Ajloun Governorate, Al-Salt City, Al-Azraq.

The tool experienced further extension:

- A method was developed allowing a spatial and temporal forecast of population development on basis of historic city planning data and satellite imagery.
- Development of an indicator by using the specific sewer length per inhabitant for decision taking concerning the connection of individual houses to the sewer network.
- Applying ALLOWS in urban/suburban areas in combination with rural settlements in the surrounding.
- Preparation of scenarios based on a combination of central and decentralized wastewater management solutions.
- Application of ALLOWS within a concrete investment project for scenario development.

Currently ca. 40% of the total population of Jordan is not connected to wastewater collection and wastewater treatment and disposal relies on cesspits, which are often poorly managed. As a result, infiltration of untreated wastewater contributes to the gradual deterioration of groundwater quality in Jordan, where water scarcity is a major national concern.

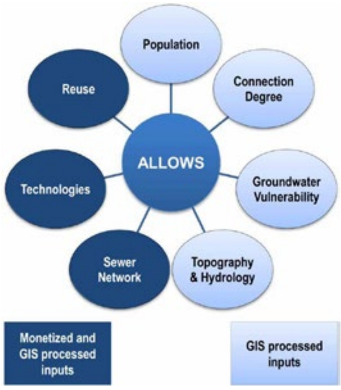

Figure 1: Component scheme of the GIS-based ALLOWS modeling process.

Resolving these complex problems is a challenge for planners and decision makers in the water sector, especially with regard to the identification of suitable development strategies and finance schemes for wastewater infrastructure. Here, integrated and modular sanitation systems can be crucial for improving quality of life in particular in regions with virulent migratory pressures. Modular systems can be flexibly adapted to contingent population dynamics in water scarce regions. Their adaptivity with respect to topography, population dynamics, reuse options, and local climate is very conducive to rural and suburban developments, as high capital and operating costs and long depreciation times for complex sewer networks and pumping stations required for conventional centralized treatment solutions often prevent investments. In contrast, a modular infrastructure is adaptive to sudden changes (migration) and thus can improve local groundwater-dependent water availability, in particular via fresh water substitution with treated wastewater, e.g. in agricultural irrigation, and via the protection of groundwater from infiltration of untreated wastewater. Rather than competing with existing central sewer networks, integrated and modular sanitation systems are complementary measures that are pivotal to a spatially inclusive and sustainable sanitation system.

The ALLOWS-tool provides an integrated analysis of the current situation of wastewater discharge, assists in the development of technical solutions (scenarios), and provides a cost comparison among different scenarios (Figure 1).

A spatial analysis enables high precision assessment of the current wastewater situation and facilitates the development of possible management scenarios under real conditions (Figure 2). These scenarios are based on hydrogeological characteristics, terrain, groundwater vulnerability, connection degree, present infrastructure, population density, and population forecast. Technical data including the length of the required sewer network and the treatment plant capacity form the basis of the economic assessment of the scenarios. Dynamic cost comparison delivers the net present value for each scenario, and thus assists in decision making towards investment in local wastewater solutions.

Since its development, the ALLOWS tool has been successfully applied to several settlements ranging in population size from small rural localities to cities. Depending on the site-specific characteristics of a settlement, several wastewater management scenarios have been developed with ALLOWS. The economic assessment was carried out for each scenario using local and global cost benchmark data. As a result, cost-efficient wastewater management options were identified for each study area.

In order to help prioritize implementation areas in Jordan, the ALLOWS tool was also applied to visualize temporal and spatial predictions of population growth for different types of settlements. For Jordan, ALLOWS has confirmed semi-centralized and decentralized solutions as the more suitable approach for rural areas (Ira and Yarka) and a combination of decentralized and centralized solutions as the more suitable approach for the fast-growing urban area of Al Salt City.

In 2018, BORDA (Bremen Overseas Research and Development Association) and Seecon (Society-Economy-Ecology-Consulting) launched the implementation project for Innovative Sanitation Solutions and Reuse in Arid Regions (ISSRAR). The project is funded by SDC (Swiss Agency for Development and Cooperation) und aims to develop a suitable intervention plan, design appropriate sanitation infrastructure and operational concepts, raise awareness, and build local capacity.

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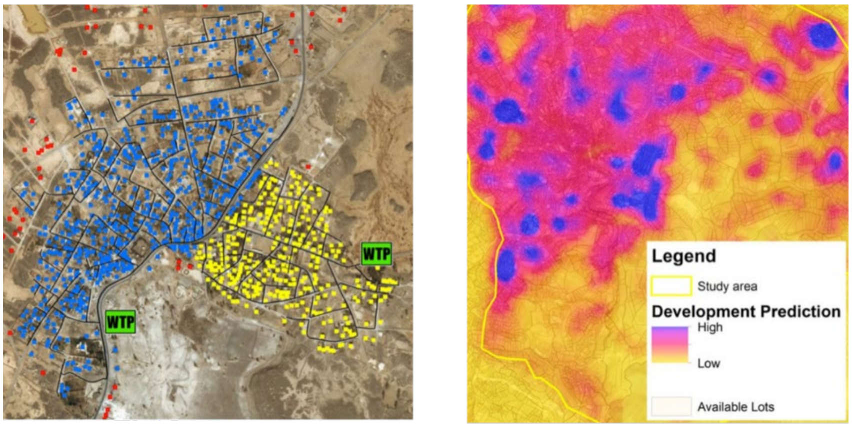

Figure 2: GIS-based decision support for cost optimized waste water infrastructure planning – left: spatial classification of waste water network connectivity in Al-Azraq, right: scenario of temporal-spatial urban development prediction in Wadi Shueib.

UFZ was subcontracted by BORDA in order to assist the project ISSRAR in developing and pre-planning of wastewater management scenarios and identifying the lowest-cost management solution. The town of Al-Azraq (with a population of 17,000 inhabitants as of 2017) in the governorate of Al-Zarqa was selected in the frame of ISSRAR site selection process as the study area based on the application of several local and regional selection criteria, all of which emphasize on the importance of implementing proper wastewater and fecal sludge management solutions.

The application of the ALLOWS tool and a scenario comparison showed that the decentralized cluster solution with gravity sewer network and French-type constructed wetland is the lowest-cost wastewater management solution in Al-Azraq. Although the tanker-based solution has the lowest investment cost requirements, the O&M requirements are the highest, making this solution the most expensive solution in the long-term.

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View to the west coast of the Dead Sea (© Julian Xanke)

The SALAM Initiative: Concepts and Approaches for the Resolution of the Water Deficit Problem in the Middle East at Regional Scale

Bernd Rusteberg[1], Jacob Bensabat[2], Abdel Rahman Tamimi[3], Amer Salman[4], Emad Al-Karablieh[4], Elias Salameh[4], Florian Walter[1/5], Torsten Lange[5], Martin Sauter[5]

KEY FINDINGS

The steadily increasing water demand in Jordan and Palestine during the next two decades, all sectors included, cannot be covered by the available water resources, which are limited.

Both countries already face a total annual freshwater deficit of about 783 Million m^3 (MCM). In 2035, according to SALAM forecasts, additional 1,680 MCM/a of freshwater resources will be required to ensure sustainable development (Figure 1).

SALAM believes that this amount of freshwater just can be produced by seawater desalination (SWD).

Due to the geographical characteristics of the region, transboundary cooperation and water SWAP agreements between Israel, Jordan and Palestine are required to solve the water problem.

In general, SALAM WPOs are capable of providing the additionally required water resources to the region within a reasonable time horizon and in an economically sustainable mode.

While cost of seawater desalination is comparable for all schemes, the total cost of water supply will strongly depend on the water conveyance, water storage and water swap components.

Significant water cost reduction (US$/m^3) could be achieved by employing hydropower generation along the water transport routes, large scale solutions for SWD and low cost renewable energy production (such as solar energy).

An integrated regional water strategy may consist of a combination of SALAM WPOs and SWAP schemes.

The decision with regard to the most appropriate strategy to be implemented will depend more on political agreements than on any other factors. Therefore, prioritization based on engineering and or economic criteria is beyond the stated scope of SALAM.

Introduction

The SALAM initiative was funded by the German Federal Ministry of Education and Research (BMBF) in the context of the SMART-MOVE IWRM project. This research project investigates the present and future water budgets in Israel, Jordan and Palestine, identified the present water deficit as well as the additional required water resources during the next two decades and delineates five so-called Water Production and Transport Options (SALAM WPOs) to solve the water deficit problem in the region. All WPO's rely on the desalination of seawater at different locations and transport of freshwater to demand centres in the region. The group of experts from the region works under the leadership of the Georg-August-University of Göttingen and Rusteberg Water Consulting, receiving support from the National stakeholders MWI (Jordanian Ministry of Water and Irrigation), PWA (Palestinian Water Authority) and MEKOROT (Israel National Water Company).

During the last two decades, Israel has engaged into massive seawater desalination (SWD) and large-scale reuse of treated effluent in irrigated agriculture. These two measures have dramatically improved the water supply situation in Israel and will ensure the matching of the Israeli water demand for the next decades, independent of climatic conditions.

Jordan made all possible efforts to develop it's water resources, including conventional and non-conventional sources of water, but the country is increasingly suffering from water shortages, due to the limited available natural water resources. These shortages will become far more acute in the near future because of population growth, influx of refugees as well as long periods of droughts and dry years, possibly resulting from climate change. The latter has a major impact on the availability of surface and groundwater in the region. Spring discharge, groundwater levels and even the natural inflow to the Lake Tiberias steadily decreases, seriously reducing the water available for abstraction. Palestine, despite all efforts, suffers from similar conditions.

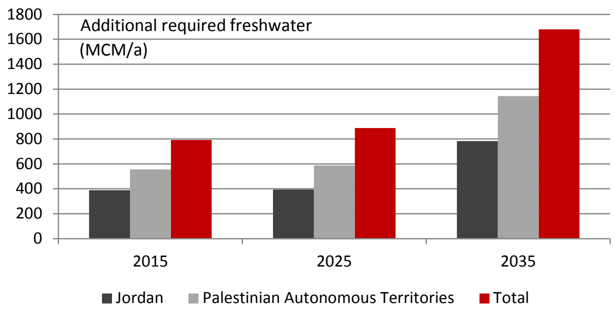

Figure 1: Additional required freshwater resources in 2015, 2025 and 2035

SALAM believes that SWD is the key solution for the water problems in Jordan and Palestine, too. SALAM WPOs are based on three key concepts: Seawater desalination, transport to demand areas and water swap among the three parties.

In addition, SALAM addresses the rehabilitation of two key environmental assets of the region: the Dead Sea, whose water level needs to be stabilized and the Lower Jordan River (LJR), which for decades lacks base flow with adverse effects on local groundwater flow and the ecosystem in the alluvial plain.

Approach

In order to resolve the problem, the SALAM initiative investigates 5 water production and transport options (listed below). According to table 1, SALAM WPO 1 and 5 further consider 3 different levels of water production by seawater desalination, given in million m^3 per year (MCM/a). The SALAM WPOs are characterized as follows:

SALAM WPO 1: Desalination plants at the Red Sea and transport by pipeline to demand areas in Jordan and southern Israel (city of Eilat), partially in exchange for additional Israeli water supply to the north of Jordan, beyond the already existing water SWAP between Israel and Jordan amounting to about 50 MCM/a (red arrows). The substantial extension of the seawater desalination plant at Aqaba, currently under tendering, and water transfer to Amman is being taken into consideration by SALAM WPOs 1-1 and 1-2. The brine could either be discharged directly into the Red Sea or mixed with seawater and transferred by pipeline to the Dead Sea to contribute to the stabilization of the Dead Sea water level (Figure 2/ dashed green line).

SALAM WPO 2: SWD at the Israeli Mediterranean coast near the city of Netanya, due to the very short distance to the Palestinian territories (less than 10 km), conveyance by pipeline to the city of Tul-Karem and from there to demand areas in the northern West-Bank.

SALAM WPO 3: Desalination plant at the Mediterranean coast of Palestine (Gaza Strip) for local water supply together with an additional pipeline from the desalination plant to the city of Hebron, crossing Israeli territory, and from there to other Palestinian cities. Due to high water cost (table 1), alternative water SWAP options between Israel and Palestine could be more appropriate and should be studied during the next phase of the project, should it be funded.

SALAM WPO 4: This option refers to the original Dead Sea-Red Sea Canal project as potential long-term solution for the region, aiming at stabilizing the Dead Sea and transporting substantial amounts of drinking water to the area, investigated by the World Bank (COYNE ET BELLIER, 2012).

SALAM WPO 5: SWD in the Western Galilee, near the city of Haifa, water transport to Lake Tiberias for storage and from there, transport to Jordan and Palestine. The water transport to the Lake may be achieved in different ways: by flow inversion of the Israeli Water Carrier (IWC) between the Haifa area and the Lake, a pipeline parallel to the IWC or the construction of a tunnel. The tunnel option has been considered to estimate the water cost (Table 1). SALAM WPO 5 is a water transfer solution

Table 1: Water Cost of SALAM WPOs as Average Incremental Cost (AIC) in US$/m³

SALAM-WPO	1-0	1-1	1-2	2	3	4	5-0	5-1	5-2
WATER PROD. (MCM/A)	80	230	500	50	50	850	250	500	1,000
WATER COST (US$/M³)	0.64 / 0.80*	1.57 / 1.61*	1.36 / 1.38*	0.73	2.16	- **	0.79	0.67	0.61

* Brine disposal in the Red Sea (/) versus brine disposal in Dead Sea, mixed with seawater

** RSDS-canal project studied by the World Bank (Coyne et Bellier, 2012)

characterized by low water cost, especially for large scale seawater desalination.

Main Results and Conclusions

Each option was studied in a preliminary way with regard to its technical feasibility, in economic terms, its contribution to the resolution of the water problems and its political acceptance. As economic indicator, the Average Incremental Cost (AIC) in US$/m³ is considered. The water cost of each WPO, calculated for a planning horizon of 20 years, is presented in Table 1.

> Five feasible engineering solutions (SALAM WPOs) have been suggested, capable of resolving the acute water problem of the region. Since the cost of seawater desalination is similar for all locations, their cost-effectiveness depends largely on the decisions to be taken with respect to transport routes, storage facilities and water swap options.
> SALAM WPOs 1, 4 and 5 permit the production of renewable energy in terms of hydropower, which would lower the overall cost of water production and transport.
> SALAM WPO 5 would significantly contribute to the rehabilitation of the Lower Jordan River (LJR), since part of the water stored in Lake Tiberias could be discharged directly to the LJR, contributing to socio-economic development in the Lower Jordan Valley.
> SALAM WPOs 1, 4 and 5 would directly contribute to the stabilization of the Dead Sea, a key concern of the neighboring countries.
> An integrated regional water strategy may consist of a combination of SALAM WPOs and SWAP schemes in an appropriate manner, taking other non-conventional water resources, such as treated effluents (reuse) and brackish groundwater into account.
> Since any major infrastructure project requires substantial time period for implementation, there is an urgent need to agree on a regional strategy with mutual benefits for the three countries and to start appropriate measures without delay.

Further Research Needs

> Study of additional schemes for a Water-Renewable Energy-Food SWAP between the three countries and their integration with SALAM WPOs.
> More detailed technical-economic analysis for each of the SALAM WPOs to achieve a refined level of design and to consolidate cost effectiveness of each WPO.
> Further studies on how to improve the cost-effectiveness of SALAM WPOs, e.g. with regards to SALAM WPO 3, where water SWAP between Israel and Palestine seems to be a promising concept instead of water transfer from Gaza to Hebron and surrounding cities by pipeline.
> More detailed water budget studies on the spatial distribution of existing and further expected water deficits in Jordan and Palestine in as a basis for the development of regional water allocation schemes.
> Multi-purpose management of the Lake Tiberias as a central regional water storage reservoir, taking ecological objectives, such as the rehabilitation of the LJR, into consideration.
> Regional waste water reuse concepts, based on centralized and decentralized solutions, contributing to the sustainable development of irrigated agriculture in the LJV.
> Development of alternative regional strategies, composed of different SALAM WPOs and existing and new SWAP schemes, taking the refined water allocation schemes as well as further non-conventional (treated effluent, brackish water) and strategic transboundary groundwater resources into account.
> Investigation of financing schemes and institutional requirements for strategy implementation.
> Development of a peace model for the region that promotes political and social willingness for sharing sources of water, renewable energy and food between Jordan, Palestine and Israel as basis for strategy implementation, supported by the international community.

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Further detailed information about the SALAM studies can be found on the project website: www.iwrm-smart-move.de

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SMART - 12 years of multilateral IWRM research cooperation in the Lower Jordan Valley

Sustainable Management of Available Water Resources with Innovative Technologies

The present publication summarizes key products, achieved during 12 years (2006-2018) of multi-lateral collaborative research collaboration in the Lower Jordan Valley, financed by the Federal German Ministry of Education and Research (BMBF). The so-called SMART projects focused on the Integrated Management of Water Resources and, therefore, the implementation of the IWRM concept, taking innovative water technologies and all available water resources of this extremely water scarce region into account. During the different phases of the SMART project almost 40 partner institutions (industries, technology enterprises, consulting firms, research centers, Universities) with more than 100 renowned researchers and experts as well as numerous students from Germany, Israel, Palestine and Jordan were involved. One of the most important achievements of the SMART projects is the basis of mutual trust which has been created over the years between the partner countries, also on the political level, due to close and trustful cooperation between Israeli, Palestinian and Jordanian stakeholders and decision makers. Inspite of the considerable project achievements towards the sustainable management of conventional and non-conventional water resources, including new concepts for wastewater treatment and reuse, it became obvious that the water crises in the region cannot be solved by local water resources which are limited. According to the results of the recently established SALAM initiative, a SMART subproject, the resolution of the most serious and steadily increasing water deficit problem of the region requires freshwater imports, already at present, in the order of hundreds of million m^3 per year wich can be produced only by seawater desalination.

Antique mosaic map of the Jordan Valley, St. George Church, Madaba, Jordan (© M. Disdero)

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