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Integrated Water Resources Management in the Lower Jordan Valley

Sustainable Management of Available Water Resources with Innovative Technologies – Management Of Highly Variable Water REsources in semi-arid Regions

SMART-MOVE

2015 – 2019

Final Report – SMART-Phase III

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

2019

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Cover images

Front side: View over the Jordan Valley (Author: Heinz Hötzl)

Back side: Antique mosaic map of the Jordan Valley, St. George Church, Madaba, Jordan (Author: M. Disdero)

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Georg-August-Universität Göttingen
Wilhelmsplatz 1
37073 Göttingen
Deutschland
Tel. +49 551 39-0
Fax +49 551 39-9612
pressestelle@uni-goettingen.de

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Editors

Dr. Torsten Lange torsten.lange@geo.uni-goettingen.de
Prof. Dr. Martin Sauter* martin.sauter@geo.uni-goettingen.de

Georg-August-Universität Göttingen
Geowissenschaftliches Zentrum
Abteilung Angewandte Geologie
Goldschmidtstraße 3
37077 Göttingen
Deutschland

Georg-August-University Göttingen
Geoscientific Centre
Department of Applied Geology
Goldschmidtstraße 3
37077 Göttingen
Germany

Tel.: +49 551 39 7911
Fax: +49 551 39 9379

*Corresponding editor

Dr.-Ing. Bernd Rusteberg berndrusteberg@yahoo.com

Rusteberg Water Consulting UG
Himmelsbreite 49
37085 Göttingen
Deutschland

Executive Editing and Layout

Dr. Torsten Lange

Disclaimer

This SMART-MOVE final report is a compilation of the data and research results of the contributing partner institutions, scientists and authors who bear responsibility for the scientific content.

Haftungsausschluss

Dieser SMART-MOVE-Abschlussbericht ist eine Zusammenstellung der Daten und Forschungsergebnisse der beitragenden Partner-Institutionen, Wissenschaftler und Autoren, die für den wissenschaftlichen Inhalt verantwortlich sind.

Project Coordination Team

Project Coordinator: Prof. Dr. Martin Sauter* martin.sauter@geo.uni-goettingen.de

Project Advisor: Prof. Dr. Heinz Hötzl# heinz.hoetzl@kit.edu

Project Management: Dr. Torsten Lange* torsten.lange@geo.uni-goettingen.de

Deputy Coordination: Prof. Dr. Roland A. Müller§ roland.mueller@ufz.de

Deputy Coordination: Prof. Dr. Nico Goldscheider# nico.goldscheider@kit.edu

***Georg-August-Universität Göttingen**
Geowissenschaftliches Zentrum
Abteilung Angewandte Geologie
Goldschmidtstraße 3
37077 Göttingen
Deutschland
Tel.: +49 551 39 7911
Fax: +49 551 39 9379

***Georg-August-University Göttingen**
Geoscientific Centre
Department of Applied Geology
Goldschmidtstraße 3
37077 Göttingen
Germany

#Karlsruher Institut für Technologie
Institut für Angewandte Geowissenschaften
Abteilung Hydrogeology
Kaiserstraße 12
76131 Karlsruhe
Deutschland
Tel.: +49 721 608 43096
Fax: +49 721 608 47603

#Karlsruhe Institute of Technology
Institute of Applied Geosciences
Division of Hydrogeology
Kaiserstraße 12
76131 Karlsruhe
Germany

§Helmholtz-Zentrum für Umweltforschung UFZ
Department UBZ – Umwelt- und Biotechnologisches Zentrum
Permoserstraße 15
04318 Leipzig
Deutschland
Tel.: +49 341 235 1275

§Helmholtz-Centre for Environmental Research
Department UBZ – Centre for Environmental Biotechnology
Permoserstraße 15
04318 Leipzig
Germany

Participants of the SMART-MOVE Transfer Conference 23rd-24th April, 2018 Dead Sea, Jordan (© André Künzelmann).

Contributing Scientist and Authors

- in alphabetical order -

Naser Almanaseer	Al-Balqa Applied University
Noama Shareef	Al-Balqa Applied University
Amer Salman	Arab Technologist for Economical and Environmental Consultation (ATEEC)
Markus Baumann	ATB Water GmbH
Thomas Gester	ATB Water GmbH
Frederic Meunier	ATB Water GmbH
Dennis Alexandersen	BAUER Resources GmbH
Roman Breuer	BAUER Resources GmbH
Stephan Prigent	BAUER Resources GmbH
Uwe Schlenker	BAUER Resources GmbH
Marcela Muñoz Escobar	Bildungs- und Demonstrationszentrum für dezentrale Abwasserbehandlung e.V. (BDZ)
Daniel Gieseler	Bildungs- und Demonstrationszentrum für dezentrale Abwasserbehandlung e.V. (BDZ)
Ruth Goedert	Bildungs- und Demonstrationszentrum für dezentrale Abwasserbehandlung e.V. (BDZ)
Alena Lepilova	Bildungs- und Demonstrationszentrum für dezentrale Abwasserbehandlung e.V. (BDZ)
Gabriele Stich	Bildungs- und Demonstrationszentrum für dezentrale Abwasserbehandlung e.V. (BDZ)
Andreas Abecker	DISY Informationssysteme GmbH
David Riepl	DISY Informationssysteme GmbH
Harald Horn	Engler-Bunte-Institut (EBI), KIT
Oliver Jung	Engler-Bunte-Institut (EBI), KIT
Florencia Saravia	Engler-Bunte-Institut (EBI), KIT
Gudrun Abbt-Braun	Engler-Bunte-Institut (EBI), KIT
Jacob Bensabat	Environmental & Water Resources Engineering (EWRE)
Markus Giese	Georg-August-Universität Göttingen
Torsten Lange	Georg-August-Universität Göttingen
Sandra Oehlmann	Georg-August-Universität Göttingen
Martin Sauter	Georg-August-Universität Göttingen
Sebastian Schmidt	Georg-August-Universität Göttingen
Manfred van Afferden	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Johannes Boog	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Marc Breulmann	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Ganbaatar Khurelbaatar	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Mi-Yong Becker (née Lee)	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Roland A. Müller	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Jaime Nivala	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ

Khaja Rahman	Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Muath Abu Sadah	Hydro Engineering Consultancy (HEC)
Jawad Hassan	Hydro Engineering Consultancy (HEC)
Amer Marei	Hydro Engineering Consultancy (HEC)
Emad Al-Karablieh	Jordan University, Amman
Elias Salameh	Jordan University, Amman
Anna Ender	Karlsruher Institut für Technologie (KIT)
Nico Goldscheider	Karlsruher Institut für Technologie (KIT)
Heinz Hötzl	Karlsruher Institut für Technologie (KIT)
Jochen Klinger	Karlsruher Institut für Technologie (KIT)
Tanja Liesch	Karlsruher Institut für Technologie (KIT)
Julian Xanke	Karlsruher Institut für Technologie (KIT)
Issam Nofal	Ministry of Agriculture, Palestine (MoA)
Joseph Guttman	Mekorot Water Company Ltd.
Julia Sahawneh	Ministry of Energy & Mineral Resources (MEMR)
Ali Subah	Ministry of Water and Irrigation, Jordan (MWI)
Anwar Al-Subeh	NICE-Office for DWWM Implementation, Amman
Nabil Wakileh	Wakileh & Contracting (NAW)
Fares Wakileh	Wakileh & Contracting (NAW)
Nadia Almajrouh	Wakileh & Contracting (NAW)
Abdelrahman Tamimi	Palestinian Hydrology Group (PHG)
Subhi Samhan	Palestinian Water Authority (PWA)
Elmar Dorgeloh	Prüf- und Entwicklungsinstitut für Abwassertechnik an der RWTH Aachen e.V.
Bernd Rusteberg	Rusteberg Water Consulting UG
Florian Walter	Rusteberg Water Consulting UG / Georg-August-Universität Göttingen
Rudolf Duester	SEBA Hydrometrie GmbH & Co. KG
Felix Grimmeisen	SEBA Hydrometrie GmbH & Co. KG
Kai Vogel	SEBA Hydrometrie GmbH & Co. KG

Partners of the SMART-MOVE Consortium

- in alphabetical order -

Germany

ATB	ATB Water GmbH
BDZ	Training and Demonstration Centre for Decentralized Sewage Treatment
BAUER	BAUER Resources GmbH
DISY	Disy Informationssysteme GmbH
EBI	DVGW - Research Center, Water Chemistry and Water Technology, at Engler-Bunte-Institut
KIT-HYD	Karlsruhe Institute of Technology
PIA	Development and Assessment Institute in Waste Water Technology at RWTH Aachen
RWC	Rusteberg Water Consulting
UFZ	Helmholtz Centre for Environmental Research
UGOE	Georg-August-University Göttingen
SEBA	SEBA Hydrometrie GmbH & Co. KG

Israel

EWRE	Environmental & Water Resources Engineering
MEK	Mekorot Water Company Ltd.
MOST	Ministry of Science and Technology
TAU	Tel Aviv University

Jordan

ATEEC	Arab Technologist for Economical and Environmental Consultation
BAU	Al-Balqa Applied University
JUA	Jordan University
JVA	Jordan Valley Authority
MWI	Ministry of Water and Irrigation
NAW	Wakileh & Contracting
WAJ	Water Authority of Jordan

Palestinian Territories

HEC	Hydro-Engineering Consultancy
MoA	Ministry of Agriculture
PHG	Palestinian Hydrology Group
PWA	Palestinian Water Authority

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The solutions developed by SMART-MOVE could not have been achieved without the close and successful cooperation with our local institutional partners at the Ministry and Authorities namely the Ministry of Water and Irrigation (MWI), the Water Authority of Jordan (WAJ), the Jordan Valley Authority (JVA) and the Natural Resources Authority (NRA) in Jordan, the Palestinian Water Authority (PWA) and the Ministry of Agriculture in the Palestinian Territories, as well as the Ministry of Science, Technology and Space (MOST) and the national water company MEKOROT, in Israel.

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We would like to acknowledge particularly all PhD students of all three SMART phases, as they provided substantial input especially through their valuable field investigations combined with a lot of physical efforts, their fresh ideas and focused work to decisively contribute to the great success of the project.

Water, water, everywhere,

And all the boards did shrink;

Water, water, everywhere,

Nor any drop to drink.

From: *The Rime of the Ancient Mariner*
Samuel Taylor Coleridge, 1798

Frequently, an excerpt of this romantic poem of the 18th century is quoted as “Water, water, everywhere, but not a drop to drink”, expressing the desperation of individuals for the essentials.

The situation in the Lower Jordan Valley can possibly be regarded as comparable to that of the crew of the Mariner’s sailing vessel, with the Dead Sea, brackish groundwater, the Mediterranean as well as the Red Sea, surrounding the territory, requiring intelligent and adapted technologies and concepts to bring fresh water to the region.

PART I

Kurzfassung

Deutschland hat sich als Unterzeichnerstaat verpflichtet, an der Erfüllung der auf dem Millenniumsgipfel 2000 der Vereinten Nationen formulierten Milleniumsziele mitzuwirken. Als einen der Schwerpunkte setzten die Bundesministerien für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ) sowie für Bildung und Forschung (BMBF) besondere Impulse im Wassersektor. In diesem, aber auch im Zusammenhang mit weiteren internationalen Aufrufen und Vereinbarungen rief das BMBF im Jahr 2004 die Initiative "Integriertes Wasserressourcen-Management" (IWRM) mit dem Ziel ins Leben, das damit verknüpfte große Potenzial für die sichere Versorgung mit Trinkwasser, die Verfügbarkeit sanitärer Einrichtungen, Umweltschutz und Rehabilitation sowie die nachhaltige wirtschaftliche und soziale Entwicklung auszuschöpfen.

Als ein aufgrund der geopolitischen Situation im Nahen Osten besonders sichtbares Vorhaben der BMBF-IWRM-Fördermaßnahme erfolgte die Förderung des Projektes SMART (Nachhaltiges Management verfügbarer Wasserressourcen mit innovativen Technologien) in drei Phasen zwischen 2006 und 2018 mit Fokus auf der Entwicklung und Umsetzung eines umfassenden und nachhaltigen IWRM-Konzepts für das Untere Jordantal mit den unmittelbaren Nachbarstaaten Jordanien und Israel sowie den Palästinensischen Gebieten. Mit unterschiedlichen lokalen Schwerpunkten erstreckt sich die Projektregion vom Süden des Sees Genezareth bis nördlich des Toten Meeres und reicht in die rechts- und linksseitig gelegenen, gebirgigen Einzugsgebiete des Jordan in der Westbank und im Ostjordanischen Bergland.

Die Projektregion ist aufgrund des heißen und trockenen Klimas charakterisiert durch extreme Wasserknappheit und geht, getrieben durch das schnelle Bevölkerungswachstum, mit einem dynamisch wachsenden Wasserbedarf einher. Verstärkende Stressfaktoren sind die Verschlechterung der Grundwasserqualität, aber auch der reduzierte Abfluss, insbesondere im Unterlauf des Jordans aufgrund der signifikanten Wasserentnahme aus dem See Genezareth, was trotz einer gewissen Kompensationsleistung Israels an Jordanien einen der zentralen politischen Wasserkonflikte in der Region darstellt.

Während die Grundwasserneubildung wegen der extremen zeitlichen und räumlichen hydrologischen Variabilität als Folge der ungünstigen Verteilung des jährlichen Niederschlags und Oberflächenabfluss natürlich limitiert ist, wird durch steigende Grundwasserentnahmen ein wachsendes Defizit erzeugt und lokal durch eine Verschlechterung der Grundwasserqualität insbesondere von zunehmenden Mineralisationen begleitet. Letztere hängen ursächlich meist mit dem Zustrom bzw. der hydraulischen Aktivierung salinarer Grundwässer zusammen. Gleichzeitig steigt die anthropogene Grundwasserbelastung z.B. durch Nitrat aufgrund des ungenügenden Ausbaus sanitärer Versorgung und Abwassermanagement sowie durch landwirtschaftliche Einflüsse. Davon sind auch für die lokale Wasserversorgung wichtige Karst-Quellen betroffenen, deren weitflächige Neubildungsgebiete in den höheren Bereichen der Westbank und des Ostjordanischen Berglands liegen. Aber auch externe Faktoren wie der Syrienkrieg und die damit verbundene hohe

Anzahl zu versorgender Flüchtlinge erhöhen den Druck auf den bereits stark unterversorgten Wassersektor weiter und führten im Fall Jordanien zu verstärkter Förderung auch nicht neugebildeter, fossiler Grundwasserressourcen und zur Erschließung zusätzlicher Brunnenfelder. Durch den stark ansteigenden Wasserbedarf in allen Verbrauchssektoren (Haushalte, Tourismus, Landwirtschaft, Industrie) und die damit verbundenen erforderlichen Investitionen in Infrastruktur und Grundwasserschutz wurde aber auch die große Bedeutung gesetzlicher Rahmenbedingungen und einer fachübergreifenden institutionellen Ausrichtung und Positionierung erkannt. Die Lösung dieses komplexen Ursache-Wirkungs-Geflechts erfordert daher einen ganzheitlichen Wissens-, Technologie- und institutionell basierten Ansatz, der mittel- bis langfristig eine sichere und bedarfsorientierte Wasserversorgung ermöglicht. Um den nötigen qualitativen und quantitativen Sprung in der wirtschaftlich schwachen Projektregion des Unteren Jordantals mit ihrem ausgeprägten Wassermangel zu erreichen, wurden alle Komponenten des Wassersystems im Projekt SMART-MOVE als dritte und letzte SMART-Phase abgebildet. Das Schema in Figure 0-2 zeigt die thematische Aufstellung des Projekts, welche Grundlage der Struktur des vorgelegten Projektabschlussberichtes ist. Die wissenschaftlich-technologischen Fragestellungen und Produktlösungen werden durch die drei Themenschwerpunkte „Monitoring and Local Raw Water Management“, „Implementation of innovative Water Technologies“ und „Integrated Planning Tools for IWRM Implementation“ abgedeckt. Als fach- und projektübergreifende Querschnittsthemen adressieren die Komponenten „Institutional IWRM Implementation“ und „Capacity Development“ die nachhaltige gesellschaftliche und institutionelle Implementierung durch das Verfassen von Leitfäden, Standards, Handbüchern und Empfehlungen, die Förderung interministerieller Zusammenarbeit sowie die Aus- und Weiterbildung auf mehreren Ebenen. Zu letzteren gehören die allgemeine Schulausbildung zu Fragen der Wasserressourcenschonung und des Abwassermanagements, die institutionelle Entwicklung sowohl auf technischer als auch Fachpersonalebene sowie Weiterbildungsangebote für im Wassersektor tätige private Unternehmen.

Das komplexe, interdisziplinäre Arbeitsprogramm wurde durch ein Expertenkonsortium deutscher und regionaler Partner aus Wissenschaft, lokalen Entscheidungs- und Interessenträgern einschließlich Nichtregierungsorganisationen sowie Industriepartnern umgesetzt. Die, durch die verschiedenen Konsortien der drei SMART-Phasen erbrachten, Leistungen umfassen alle nötigen Voraussetzungen für die, auf die Projektregion angepasste, wirtschaftlich und ökologisch nachhaltige Implementierung eines IWRM-Konzepts. Um den integrierten Transfer von Technologien und Managementinstrumenten in die allgemeine Wasserbewirtschaftungspraxis in der Region zu unterstützen, wurden die lokalen Entscheidungsträger und Interessengruppen kontinuierlich konsultiert und in den IWRM-Entwicklungs- und Implementierungsprozess sowie in die Formulierung von Leitlinien einbezogen. Der nachfolgende Überblick stellt die wesentlichen Ergebnisse des Projektes dar.

Monitoring und lokales Rohwassermanagement

Unter der Thematik „Monitoring and Local Raw Water Management“ befassten sich die einzelnen Arbeitspakete mit einer Anzahl von Teilaspekten. Für die grundlegende Charakterisierung des natürlichen Wassersystems wurde in SMART/SMART-MOVE ein kontinuierliches, zeitlich-räumliches Monitoring von Niederschlag und Quellschüttungen durchgeführt, welches im Zusammenhang mit komplementären Oberflächenabflussmessungen und hydrochemischen Untersuchungen die Analyse, Charakterisierung und Bemessung des hydrologischen Systems (Niederschlag, Abfluss, Quellschüttungen), seiner Variabilität sowie der Eintragspfade von Abwasser und dessen Einflüsse auf ausgewählte Quellen erlaubt. Die verwendeten Daten für Temperatur und Niederschlag wurden durch frühere bzw. historische Zeitreihen, wie z.B. der Wetterstation von Jerusalem (104 Jahre) ergänzt. Allein auf Basis dieser wertvollen und essentiellen Datengrundlage konnten empirische und realistische Niederschlags-Abfluss-Modelle sowie typische Niederschlagsszenarien für trockene, durchschnittlich feuchte und feuchte Jahre bzw. Perioden abgeleitet werden. Diese liefern die benötigten hydrologischen Eingangsdaten für die verwendeten hydrogeologischen bzw. Grundwassermodelle, aber auch der Wasserplanungswerkzeuge und ermöglichen sowohl deren Kalibrierung als auch Prognosefähigkeit. Im Rahmen der hier besprochenen Projektkomponente stellen die entwickelten hydrogeologischen Konzeptvorstellungen und numerischen Grundwassermodelle die zweite Säule zur Charakterisierung des natürlichen Wassersystems dar. Ihre Umsetzung und Anwendung erfolgte auf drei Ebenen: (a) als lokale Probleme z.B. zur MAR-Planung (Deir Alla, Jordanien), (b) basierend auf Einzugsgebietsclustern zur Analyse und Planung alternativer MAR- und IWRM-Optionen (Einzugsgebiets-Cluster West (Jericho-Auja), Palästinensische Gebiete) und (c) regional und grenzübergreifend zur Verbesserung des Systemverständnisses des Unteren Jordantals, der Simulation großskaliger Effekte von MAR- und IWRM-Maßnahmen, Wasserplänen bzw. -strategien, der Standortsuche für neue Brunnenfelder sowie der Ableitung lokaler Modelle, Budgets und Flüsse. Auf Grundlage der hydrochemischen Charakterisierung wichtiger Quellen und der Analyse der möglichen Eintragspfade für Abwasser wurden im Rahmen des Projektes mehrere Frühwarnsysteme realisiert. Dies betrifft die Quellen Baqqouria und Hazzir im Wadi Shueib auf jordanischer Seite und die Quelle Ein as-Sultan in Jericho, auf palästinensischer Seite. Die Übertragbarkeit der umgesetzten Konzepte auf weitere Quellen wurde untersucht. Als Voraussetzung für die Leistungsfähigkeit der Frühwarnsysteme wurde eine Dateninfrastruktur entwickelt, welche einerseits grundlegende geographische und Wassersystem-Charakteristika sowie Schnittstellen für die telemetrische und manuelle Aufnahme von Monitoring-Messdaten enthält und andererseits die erforderlichen Algorithmen zur Generierung der mit den lokalen Wasserbehörden vereinbarten Frühwarnsignale aus dem bereitgestellten Datenstrom der angeschlossenen telemetrischen Messstationen implementiert.

Implementierung innovativer Wassertechnologien

Die Schwerpunktgruppe „Implementation of Innovative Water Technologies“ umfasste die Entwicklung und Implementierung innovativer, technologischer Lösungen in den Bereichen (1) optimiertes Wasserspeichermanagement durch Nutzung von Oberflächenreservoiren und künstliche Grundwasseranreicherung (MAR), (2) dezentrales Abwassermanagement im ländlichen und semiurbanen Raum auf jordanischer Seite sowie (3) optimierte und nachhaltige Brackwasserentsalzung. Das optimierte Wasserspeichermanagement basiert dabei maßgeblich auf den Ergebnissen der Charakterisierung und Bemessung des hydrologischen und hydrogeologischen Systems und ist Hauptfaktor für die Robustheit eines bedarfsdeckenden IWRM-Konzeptes in Hinblick auf die kontinuierliche Trinkwasserversorgung der wachsenden Bevölkerung und die Ausschöpfung von Entwicklungspotentialen in Tourismus, Landwirtschaft und Industrie. Zur Ermittlung zusätzlicher Optimierungspotentiale existierender und neu installierter Brackwasserentsalzungsanlagen wurden die lokal am häufigsten installierten Technologien sowie deren Betrieb und Wartung hinsichtlich

Langlebigkeit, Kosten, Effizienz und Effektivität analysiert. Durch minimalen Kostenaufwand lassen sich mittels Designanpassungen Effizienz und Effektivität des Entsalzungsprozesses und damit die Wirtschaftlichkeit der landwirtschaftlichen Produktion erhöhen. Gleichzeitig kann entweder die Grundwasserentnahme verringert oder die bewässerte Fläche ausgeweitet werden. In Hinblick auf die aktuell problematische Praxis der Entsorgung der anfallenden Sole wurden umweltschonende Konzepte entwickelt.

Aufgrund der Komplexität der Einführung eines flächendeckenden und dezentral aufgestellten Abwassermanagements für den ländlichen bis semiurbanen Raum mussten verschiedene Komponenten in einem integrierten Implementierungsansatz zusammengeführt werden. Einerseits wurden im Pilot- (Competence Facility Fuheis) und Realmaßstab (z.B. Nursing Home, Princess Rahmeh College) dezentrale Abwasserbehandlungstechnologien bzw. -anlagen mit lokal anfallenden Abwässern intensiv getestet. Andererseits waren die Definition von Kriterien sowie die Entwicklung der nötigen Planungswerkzeuge zur Beurteilung der Wirtschaftlichkeit von Investitionen in ein dezentrales Abwassermanagement für den ländlichen und suburbanen Raum erforderlich. Exemplarisch wurden die Planungswerkzeuge für die Entwicklung eines Roll-out Investment-Projekts für das Gebiet As Salt und zur konkreten Unterstützung eines realen Investitionsvorhabens für die Stadt Al-Azraq eingesetzt. Als dritte Komponente wurden und werden in einem inter-ministeriellen und sektorübergreifenden Dialog Strategien, Rahmenwerke und technische Normen als Voraussetzung für Planungs- und Rechtssicherheit bei der Implementierung eines integrierten dezentralen Wassersektors umgesetzt. Dazu zählt der Entwurf eines Zertifizierungssystems für Produkte, Hersteller und Betreiber zur Sicherung von Mindeststandards für die Abwasserbehandlung und Wiederverwendung in Jordanien und die „Decentralized Wastewater Management Policy“ als erste ihrer Art im arabischen Raum. Diese wurden in Zusammenarbeit mit dem zur Unterstützung des institutionellen Implementierungsprozesses gegründeten und vom BMBF geförderten interministeriellen und sektorübergreifenden „Nationalen Implementierungskomitees für ein effektives, integriertes Abwassermanagement in Jordanien“ (NICE) umgesetzt. NICE hat eine koordinierende Funktion, ist mit eigenem Büro in Amman dem Ministry for Water and Irrigation (MWI) angegliedert und wirkt als Schnittstelle zum Projekt SMART/SMART-MOVE. Neben der Förderung der institutionellen Entwicklung wurde in SMART der Schwerpunkt Abwassermanagement durch Wissensvermittlungsprogramme auf Schul- und Universitätsebene sowie auf der Ebene von Praktikern im Wassersektor begleitet. Eine wichtige Funktion hat in diesem Zusammenhang die „Competence Facility Fuheis“, für die ein eigenes tragfähiges Aus- und Weiterbildungskonzept entwickelt und die Al-Balqa Applied University als Träger gewonnen wurde.

Integrierte Planung für die IWRM-Implementierung

Im Rahmen der Schwerpunktgruppe „Integrated Planning for IWRM Implementation“ wurden auf Basis der entwickelten Planungswerkzeuge und der umfangreichen Vorarbeiten in SMART-MOVE sowie SMART I/II IWRM-Konzepte unter den Primaten Nachhaltigkeit, Wasserversorgungssicherheit, Resilienz und Wirtschaftlichkeit sowie verbindlicher Entwicklungsziele auf jordanischer und palästinensischer Seite Wasserstrategien erarbeitet. Die Ergebnisse adressieren damit ein weites Spektrum an konkreten Maßnahmen und Konzepten zur Implementierung eines integrierten Wasserressourcenmanagements. Aufgrund der großen Transport-Distanzen und Höhenunterschiede zwischen Jordan-Tal und Amman sowie des nachgewiesenen Abwassereinflusses auf zahlreiche zur

Wasserversorgung genutzte Karstquellen wurde auf jordanischer Seite der Fokus auf die Optimierung der existierenden Gesamtsysteme aus Wasserspeicherung, -verteilung und -behandlung einerseits und auf den Vergleich mit potentiellen, alternativen Wasserinfrastrukturlösungen andererseits gelegt. Primäre Optimierungsziele betrafen die Effizienz von Energieeinsatz, Investitions-, Betriebs- und Wartungskosten sowie die Wasser-Endverbraucherpreise, die Effektivität der Qualitätsverbesserung, Wasser- und Abwasserbereitstellung sowie die Reduktion der unautorisierten Grundwasserentnahme.

Aufgrund weiterhin fehlender Standards für die integrative Entwicklung und Umsetzung von Wasserplänen bzw. -strategien, wurde auf palästinensischer Seite ein allgemeingültiger methodischer Planungsansatz auf Basis eines IWRM-Konzepts entwickelt. Das klar strukturierte und standardisierte Verfahren gewährleistet die Transparenz des Entscheidungsprozesses, z.B. in Bezug auf die Identifizierung und Bewertung alternativer Maßnahmen. Das Planungskonzept ist streng partizipativ und macht eine enge Zusammenarbeit mit den regionalen Interessengruppen und Entscheidungsträgern erforderlich, die im Rahmen der Smart-Vorhaben seit Jahren gegeben ist und die auch im Rahmen des SMART-MOVE Vorhaben erfolgreich fortgeführt wurde. Auf diese Weise konnte die Akzeptanz seitens der Entscheidungsträger gegenüber den erzielten Ergebnissen sichergestellt werden. Die Anwendung des schrittweisen Ansatzes führte zu Empfehlungen zur Implementierung einer IWRM-Strategie für den Systemausbau und die nachhaltige Systembewirtschaftung bzw. der Entwicklung eines Wasserplans Im Untersuchungsgebiet auf palästinensischer Seite. Durch Umsetzung der Empfehlungen kann die Robustheit des Wasserressourcensytems im Cluster West gegenüber der hohen hydrologischen Variabilität und von extremen Dürreperioden unter Berücksichtigung sozialer, ökologischer und wirtschaftlicher Faktoren deutlich verbessert werden. Der ingenieurtechnische Ansatz konzentriert sich prinzipiell auf die Identifizierung und Dimensionierung struktureller wasserwirtschaftlicher Maßnahmen zur Verbesserung der hydrologischen Robustheit des Wasserressourcensystems sowie auf die Umsetzung der Entwicklungsziele im Einzugsgebiet. Mit dem hier entwickelten standardisierten Planungsansatz wurde eine ausgezeichnete Grundlage für die grenzüberschreitende Bewirtschaftung der Wasserressourcen der Region geschaffen.

Eine wesentliche Voraussetzung für die Entwicklung und Umsetzung tragfähiger alternativer und robuster IWRM-Konzepte auf Basis mittel- bis langfristiger Szenarien für die verschiedenen Wassersektoren Haushalt/Tourismus, Landwirtschaft, Industrie, sowie der Bevölkerungs- und sozio-ökonomischen Entwicklung unter verschiedenen Niederschlags-Abfluss-Grundwasserneubildungs-szenarien ist die Bereitstellung und Anwendung von Planungswerkzeugen. Hier wurden in Kooperation mit den lokalen Entscheidungs- und Interessenträgern große Anstrengungen getätigt. Dazu gehören die Entwicklung und Anwendung detaillierter WEAP-Modelle (Water Evaluation and Planning System) sowie die Umsetzung, Optimierung und Anwendung innovativer Planungs- und Entscheidungswerkzeuge, wie das GIS-basierte System ALLOWS (Assessment of Local Lowest-Cost Wastewater Management Solution) zur Konzeption und Planung dezentraler Abwassermanagementlösungen im ländlichen und semiurbanen Raum.

SALAM – Regionale, grenzübergreifende Strategien für die IWRM-Implementierung

Trotz aller Bemühungen, eine optimale, integrierte Wasserbewirtschaftung zu konzipieren, kann allein aus den lokal verfügbaren Ressourcen weder lang- noch mittelfristig eine Deckung der in den verschiedenen Entwicklungsszenarien prognostizierten Wasserbedarfe für das Untere Jordantal erreicht werden. Auch die Erschließung potentiell mobilisierbarer Ressourcen kann an der prinzipiellen, ernsten Mangelsituation nichts Wesentliches ändern. So werden die zu erwartenden Gesamtdefizite an Süßwasser für Jordanien und die Palästinensischen Gebiete von etwa 783 Mio. m^3/a im Jahr 2015 auf etwa 1.680 Mio. m^3/a im Jahr 2035 akkumulieren. Es ist absehbar, dass diese wachsende Versorgungslücke mit einem steigenden Druck sowohl auf die wirtschaftliche bzw. sozioökonomische Entwicklung als auch auf Ökosysteme und Umwelt im Allgemeinen und in deren Folge mit gesellschaftlichen und politischen Spannungen einhergehen dürfte. Die Notwendigkeit von Aktivierung und Import signifikanter, externer Wasserressourcen im Rahmen der regionalen Zusammenarbeit und Strategieentwicklung ist somit evident. Wie eine solche Kooperation umsetzbar sein könnte, ist Thema des Teilvorhabens SALAM in welchem (a) eine sorgfältige, mittelfristige Versorgungs- und Bedarfsanalyse auf Basis von mit den Entscheidungsträgern abgestimmten Entwicklungsszenarien, erarbeitet, (b) realistische Wasserproduktions- und Transferoptionen vorgeschlagen sowie (c) alternative regionale Wasserstrategien auf Basis einer technologischen, sozioökonomischen sowie Kosten-Analyse entwickelt wurden. Trotz bestehender politischer Konflikte, die sich auch auf die Wasserressourcenverteilung beziehen, besteht eine regionale und vertraglich basierte Kooperation zwischen den beteiligten Partnerländern Israel, Jordanien und den Palästinensischen Gebieten in Form von Kompensationsvereinbarungen - sogenannter Water Swap Agreements. Beispielsweise erhält Jordanien Kompensationen aus dem See Genezareth im Gegenzug für die durch Israel durchgeführte Aufstauung und Wasserentnahme und den dadurch verursachten Minimalabfluss. Im Rahmen eines weiteren Water Swaps erhält die israelische Stadt Eilat Wasser aus der Meerwasserentsalzungsanlage Aqaba im Gegenzug für die Erhöhung der Kompensationsleistung aus dem See Genezareth für die Region Amman. Andererseits erscheint gegenwärtig, aufgrund der immensen Kosten, einer langen, prognostizierten Implementierungszeit, sowie Kosten- und Umweltrisiken, die Implementierung des Red Sea-Dead Sea-Projektes nicht kurzfristig realisierbar. Im Rahmen dieser Maßnahme sollten erhebliche Mengen an Meerwasser im Golf von Aqaba entnommen, entsalzt und in Richtung Totes Meer gepumpt werden, mit dem zentralen Ziel der Stabilisierung des Wasserspiegels des Toten Meeres. Dagegen bieten die im Rahmen von SALAM entwickelten Wasserproduktions- und Transfer-Optionen (WPTOs) durch optimale Kombination, kurzfristig realisierbare, wesentlich kostengünstigere und sicherere Alternativen für die zusätzliche Bereitstellung von Frischwasser, allerdings ohne abschließende Lösung des Problems des fallenden Wasserspiegels des Toten Meeres. Durch Kombination mit Wasserkraft lassen sich die Betriebs- und Wartungskosten der Transfer-Komponente der WPTOs wegen des Geländeprofils zwischen Mittelmeer und Jordantal weiter reduzieren. Aufgrund des bestehenden politischen Primats wurden im Rahmen von SALAM und in Absprache mit den institutionellen Partnern weder Empfehlungen ausgesprochen noch Aussagen getroffen, die über die reine technische und wirtschaftliche Machbarkeit hinausgehen.

Executive Summary

As a signatory state, Germany has committed itself for contributing to the Millennium Goals formulated at the United Nations Millennium Summit 2000. The German Federal Ministries for Economic Cooperation and Development (BMZ) and for Education and Research (BMBF) set one of their focuses in the water sector. Here, but also in reference to other international calls and agreements, the BMBF launched the "Integrated Water Resources Management" (IWRM) initiative in 2004 with the goal of exploiting the high potential for a secure supply of drinking water and sanitation, as well as to support environmental protection and rehabilitation and the sustainable economic and social development.

As one of the most important initiatives of the IWRM program BMBF funded the SMART project (Sustainable Management of Available Water Resources with Innovative Technologies) with three phases between 2006 and 2019 focusing on the development and implementation of a comprehensive and sustainable IWRM concept for the Lower Jordan Valley (LJV) with its neighboring countries Jordan, Israel and the Palestinian Territories. With different local focuses, the project area extends from the south of Lake Tiberias to the north of the Dead Sea and reaches up the Eastern and Western mountainous catchment areas of the Jordan River Valley, i.e. the West Bank and the Jordanian valley side.

Due to the hot and dry climate, the project region is characterized by general water scarcity, which is accompanied by a dynamically growing demand for water driven by rapid population growth. Amplifying stress factors include the deterioration of groundwater quality and the reduced flow through the Lower Jordan River due to the large volumes of water abstraction from Lake Tiberias, which is one of the major political water conflicts in the region, despite some compensation from Israel to Jordan.

While groundwater recharge is naturally limited due to the extreme temporal and spatial hydrological variability as a result of the unfavorable distribution of annual precipitation and runoff, increasing groundwater abstraction causes a growing deficit and is locally accompanied by a deterioration of groundwater quality, in particular increasing mineralization. The latter is causally related mostly to the inflow or hydraulic activation of saline groundwater. At the same time, anthropogenic groundwater pollution increases, e.g. by nitrate due to the inadequate extent of proper sanitation and wastewater management as well as agricultural activities. All important karst springs used for local water supply are affected in the same way, because the respective recharge is collected over large areas in the higher parts of the West Bank and the East Bank. However, external factors such as the Syrian war increase the pressure on the water sector even more due to the additionally required water supply for the large number of refugees. In Jordan, this led to increased abstraction of non-renewable, fossil groundwater resources and to the development of additional well fields. The sharply rising water demand in all consumption sectors (households, tourism, agriculture, industry) and the associated necessary investments in infrastructure and groundwater protection increased the level of awareness for the importance of adequate legal frameworks and interdisciplinary institutional orientation and positioning.

The solution to this complex cause-and-effect mechanism therefore requires a holistic knowledge, technology and an institutionally based approach that will enable a demand-oriented and secure medium to long-term water supply. In order to achieve the necessary qualitative and quantitative leap in the economically weak region of the LJV with its pronounced water deficit, all components of the water system were addressed in the SMART-MOVE project as the third and final SMART phase. The scheme in Figure 0-2 shows the coverage of three science and technology based main topics by the project: *"Monitoring and Local Raw Water Management"*, *"Implementation of Innovative Water Technologies"* and *"Integrated Planning Tools for IWRM Implementation"*, which predefine the structure of this final report. As interdisciplinary and cross-sectional linked topics, *"Institutional IWRM Implementation"* and *"Capacity Development"* address the sustainable implementation in relevant institutions and the wider society by guidelines, standards, manuals and recommendations, the promotion of inter-ministerial cooperation as well as education and training at several levels. The latter include general education on water resource protection and wastewater management, institutional development at both technical and expert levels, and the training for companies of the water sector.

The complex, interdisciplinary work program was conducted by an expert consortium of German and regional partners from academia, local decision-makers and stakeholders, including non-governmental organizations and industrial partners. The contributions by the various consortia of the three SMART phases include all the necessary prerequisites for the economically and ecologically sustainable implementation of an IWRM concept adapted to the LJV project region. To support the integrated transfer of technologies and management tools into the local water management practice, local decision-makers and stakeholders have been continuously consulted in the IWRM development and implementation process as well as in the formulation of guidelines and policies. The following overview presents the main results of the project.

Monitoring and local Raw Water Management

Under the topic *"Monitoring and Local Raw Water Management"*, the individual work packages addressed a number of aspects. For the basic characterization of the natural water system SMART / SMART-MOVE implemented a continuous, temporal-spatial monitoring system for precipitation and spring discharges. The major springs that contribute significantly to the water supply system and the hydrological system itself with its variability and various migration paths for wastewater have been studied comprehensively by complementary surface-runoff measurements and the hydrochemical characterization of spring and runoff water. The data used for temperature and precipitation were extracted from available and/or historical time series, e.g. the well-known weather station of Jerusalem with a record of 104 years. Based solely on this valuable and essential data basis, empirical and realistic precipitation-runoff models as well as typical precipitation scenarios for dry, average wet and humid years or periods were derived. These scenarios provide the required hydrological input data for the developed hydrogeological or groundwater models and the water planning tools to allow model calibration and guarantee their sound predictive capability.

The developed hydrogeological concepts and numerical groundwater models constitute the second pillar in the course of the characterization of the natural water system. Their implementation and application was conducted on three levels: (a) as local problems, e.g. for MAR planning (Jericho-Auja, Palestinian Territories, Deir Alla, Jordan), (b) based on catchment clusters for the analysis and planning of alternative MAR and IWRM options (catchment cluster West (Jericho-Auja), Palestinian Territories) and (c) regional and transboundary to improve the understanding of the LJV groundwater system by simulating large-scale effects of MAR and IWRM measures, water plans and strategies, finding sites for new well fields and deriving local models, budgets and fluxes.

Based on the hydrochemical characterization of important springs and the analysis of possible migration paths for wastewater, a number of Early Warning Systems (EWS) were realized within the scope of the project. This refers on the one hand to the Baqqouria and Hazzir springs in Wadi Shueib on the Jordanian side and on the other hand the as-Sultan spring in Jericho, on the Palestinian side. The transferability of the implemented concepts to other springs was examined. As a prerequisite for the adequate performance of the EWS, a data infrastructure was developed, which on the one side contains basic geographical and water system characteristics as well as interfaces for the telemetric and manual recording of monitoring measurement data and on the other side implements the algorithms required to generate the EWS signals that are agreed with the local water authorities from the data stream from the connected telemetric measuring stations.

Implementation of Innovative Water Technologies

The focus topic "Implementation of Innovative Water Technologies" included the development and implementation of innovative technological solutions in the areas of (1) optimized water storage management through the use of surface reservoirs and MAR, (2) decentralized wastewater management in rural and semi-urban areas on the Jordanian side and (3) optimized and sustainable brackish water desalination. The optimized water storage management is mainly based on the results of the assessment of the hydrological and hydrogeological system and is the most significant factor for the robustness of a needs-based IWRM concept with regard to the continuous drinking water supply to the growing population and the exploitation of the development potentials in tourism, agriculture and industry. In order to identify additional optimization potentials of existing and newly installed brackish water desalination plants, the most frequently installed technologies as well as their operation and maintenance procedures were analyzed with regard to durability, costs, efficiency and effectiveness. By minimizing costs, design adjustments can increase efficiency and effectiveness of the desalination process and thus the economics of agricultural production. At the same time either the groundwater extraction can be reduced or the irrigated area can be expanded. In view of the currently problematic practice of disposal of the residual solutions, environmentally friendly concepts have been developed.

Due to the complexity of implementing a decentralized wastewater management system for rural and semi-urban areas, various components had to be brought together in an integrated approach. With regard to the required technologies, pilot scale and real scale decentralized wastewater treatment technologies were intensively tested with local domestic wastewater. The second component required the definition of criteria and the development of the suitable planning tools to assess the economic viability of investments in decentralized wastewater management infrastructures. The planning tools were used to develop a roll-out investment project for the As Salt area and to support the implementation of a real investment project for the city of Al-Azraq. The third component consisted of strategies, frameworks and technical standards developed in an inter-ministerial and cross-sectoral dialogue to promote planning security and legal certainty for the implementation of integrated decentralized solutions. These activities included the development of a certification scheme for products, manufacturers and operators to ensure minimum standards for decentralized wastewater treatment technologies in Jordan, and the preparation of the

"Decentralized Wastewater Management Policy", the first such policy in the Arab world. In this context, the SMART-MOVE project worked closely together with the BMBF-funded "National Implementation Committee for Effective, Integrated Wastewater Management in Jordan" (NICE), which was founded to support the institutional implementation process. In addition, the focus on wastewater management was accompanied by knowledge transfer programs at school and university level and at the level of practitioners in the water sector. In this context, the "Competence Facility Fuheis" plays an important role. Together with the Al-Balqa Applied University, which made a commitment as future site-operator, an education and training concept for decentralized wastewater management has been developed.

Integrated Planning for IWRM Implementation

Under the third topic "Integrated Planning for IWRM Implementation" IWRM concepts were designed in accordance with the binding Jordanian and Palestinian development goals primarily with focus on sustainability, water supply safety, resilience and cost-effectiveness based on the developed planning tools and extensive preparatory work in SMART-MOVE and SMART I/II. The results address a wide spectrum of concrete measures and concepts for IWRM implementation. Due to large transport distances and differences in altitude between the Jordan Valley and Amman and the evident wastewater influence on numerous karst springs used for water supply, the focus on the Jordanian side was on the optimization of the existing systems of water storage, distribution and treatment on the one hand and on the comparison with potential alternative water infrastructure solutions on the other hand. Primary optimization targets included the efficiency of energy use, investment, operating and maintenance costs and end user prices of fresh water, the effectiveness of quality improvement as well as water and sanitation, and the reduction of unauthorized groundwater abstraction.

Due to a lack of standards for the integrative development and implementation of water plans and strategies, a general methodological planning approach based on an IWRM concept was developed on the Palestinian side. The clearly structured and standardized procedure ensures the transparency of the decision-making process, e.g. with regard to the identification and evaluation of alternative measures. It is a strictly participatory planning concept and requires close cooperation with regional stakeholders and decision-makers, which has been part of the SMART I/II projects for many years and which has also been successfully continued within the framework of the SMART-MOVE project. In this way, the acceptance for the achieved results by the decision-makers was ensured. The chosen stepwise approach led to recommendations for the implementation of an IWRM strategy for an upgrade of the system and its management or the development of a water plan in the study area on the Palestinian side, respectively. It is shows that the robustness of the water resource system in Cluster West can be significantly improved by implementing the recommendations in comparison to the high hydrological variability and extreme periods of drought, taking into account social, ecological and economic factors. The engineering approach focuses principally on the identification and dimensioning of structural measures in the water management to improve the hydrological robustness of the water resource system and the implementation of development objectives in the river basin.

In the course of the joint effort for the development of a standardized planning approach an excellent basis for the cross-border management of water resources in the region was created.

The provision and application of planning tools in the context of different precipitation-runoff-groundwater recharge scenarios was the essential prerequisite for the development and implementation of sustainable alternative and robust IWRM concepts based on medium- to long-term scenarios for the different water sectors (domestic/tourism, agriculture, industry), as well as population and socio-economic development. This includes the development and application of detailed Water Evaluation and Planning (WEAP) models, as well as the implementation, optimization and application of innovative planning and decision-making tools such as the GIS-based ALLOWS system (Assessment of Local Lowest-Cost Wastewater Management Solution) for the design and planning of decentralized wastewater management solutions in rural and semi-urban areas.

SALAM – Regional Transboundary Strategies for IWRM-Implementation

Despite all efforts to design optimal, integrated water management systems and strategies, the predictions based on the various development scenarios clearly indicate that the locally available resources in their own neither meet the long-term nor the medium-term water demand in the LJV. Even the development of potentially not yet developed resources cannot essentially improve the serious water deficiency situation. The expected total freshwater deficit for Jordan and the Palestinian Territories will increase from about 783 million m^3/a (MCM/a) in 2015 to about 1,680 MCM/a in 2035. It is foreseeable, that the growing supply gap is likely to be accompanied by rising pressures on both, the socioeconomic and economic development, as well as on ecosystems and the environment in general. As a consequence, growing social and political tensions are conceivable. Thus, the need for the activation and import of significant quantities of fresh water from external sources in the framework of regional cooperation and strategy development is evident.

In how far such a regional, transboundary cooperation could be implemented was the subject of the SALAM sub-project in which (a) a careful medium-term supply and demand analysis is developed based on development scenarios agreed with the decision makers, (b) realistic water production and transfer options are proposed, and (c) alternative regional water strategies based on a technological, socio-economic and cost analysis have been developed. Despite existing political conflicts, which also relate to the distribution of water resources, there is already a regional and contractual cooperation between the participating partner countries Israel, Jordan and the Palestinian territories in the form of compensation agreements or so-called Water Swap Agreements. For example, Jordan receives compensation from the Lake Tiberias in return for the impoundment and abstraction of lake water by Israel and the resulting minimum outflow to the Jordan River. As part of another water swap, the Israeli city of Eilat receives water from the Aqaba seawater desalination plant in return for increasing compensation from Lake Tiberias for the Amman region. On the other hand, the implementation of the Red Sea-Dead Sea project currently does not appear to be implemented in the short-term due to the large costs, a projected long implementation time, as well as risks related to costs and potential environmental problems. Under this measure, significant quantities of seawater from the Gulf of Aqaba were to be extracted and desalinated. The residual brines as well as untreated seawater were to be pumped towards the Dead Sea, with the central objective of stabilizing the Dead Sea level. In contrast, the water production and transfer options (WPTOs) proposed by the SALAM team of experts provide an optimal combination of short-term and cheaper and safer alternatives for additional provision of fresh water, but without the ultimate solution to the problem of the decreasing Dead Sea water level. Combined with hydropower, the operating and maintenance costs of the transfer component of the alternative WPTOs can be further reduced due to the topographic profile between the Mediterranean and the Jordan Valley, with a negative gradient towards the LJV. Because of the primacy of politics, no recommendations or statements that go beyond the mere technical and economic feasibility were made in the framework of the SALAM project and in agreement with the institutional partners.

0 Introduction to the SMART-MOVE – Project

0.1 Background

With different local foci the project region of the Lower Jordan Valley (LJV) extents from south of Lake Tiberias to the northern coast of the Dead Sea and reaches into the right- and left-hand side upstream wadi catchments in the mountainous areas of the West and East Bank, respectively (Figure 0-1). 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 climate 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 outside of the LJV in the upstream river catchments that are feeding Lake Tiberias could affect the fragile water situation in the project region.

A regional conflict like the Syrian war is a worst-case scenario and has created a tremendous jump in water and infrastructural demand in the whole northern governorates Mafraq, Irbid, Zarqa, and Amman 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. Therefore, the German Federal Institute for Geosciences and Natural Resources (BGR), cooperating for decades in the water sector with a number of countries in the Near and Middle East, has launched a special program in 2015 to support the Jordan water authorities and affected communities with the development of new well fields on the one hand and vulnerability analyses on the other hand. Groundwater vulnerability and pollution have further increased to major problem for water suppliers due to overstrained sewer networks and wastewater plants and the uncontrolled expansion of domestic and industrial areas. Groundwater recharge areas that are sensitive to pollution are insufficiently mapped and measures for groundwater protection are not adequately implemented.

Also in the Palestinian Territories Germany has a long standing as a partner country for the development of the water sector, where similar problems 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.

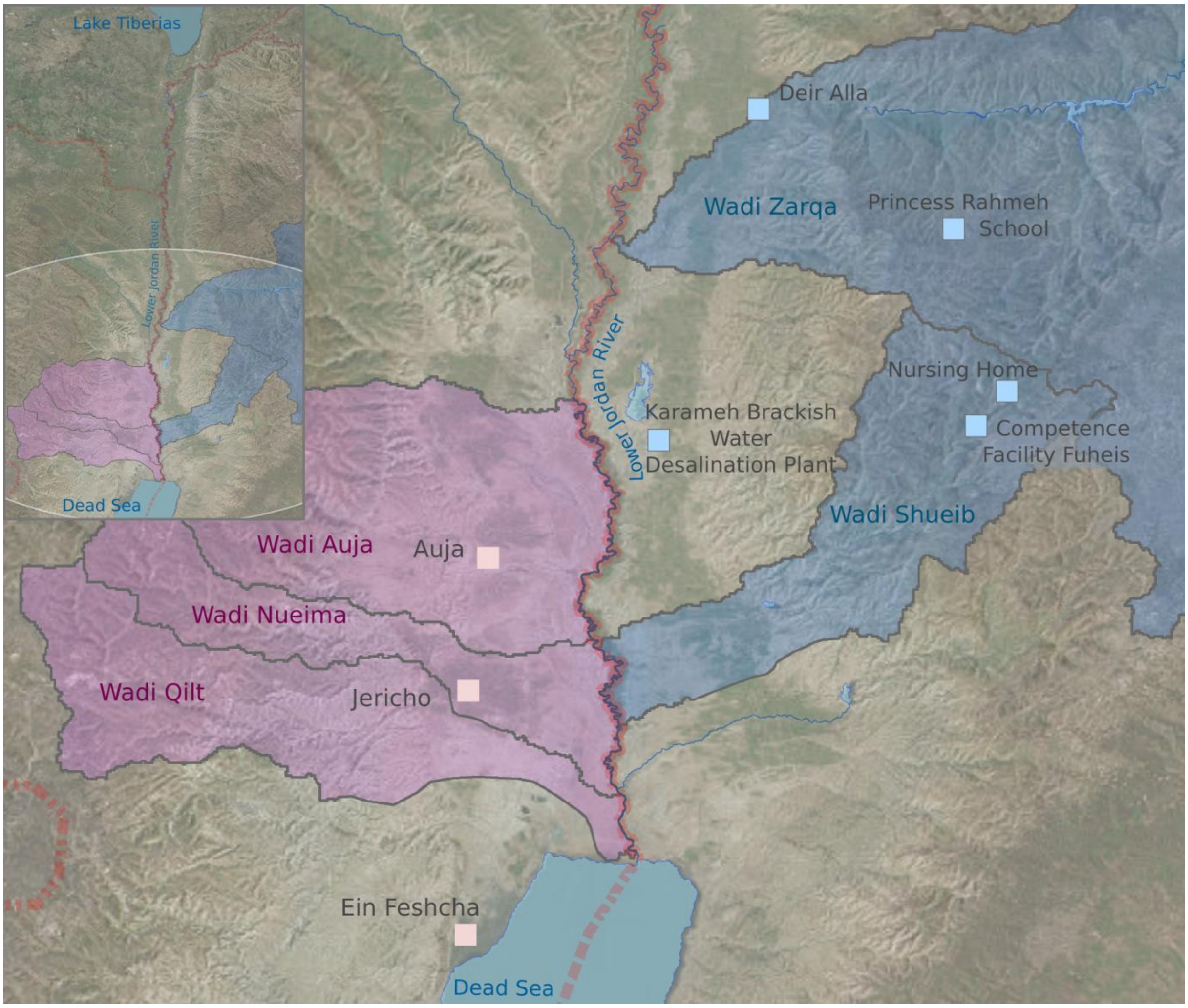

Figure 0-1: Overview map of the SMART-MOVE project region in the Lower Jordan Valley, the western and eastern catchment clusters and a selection of focus sites.

Lake Tiberias, the most important natural surface water storage reservoir in the area, 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 in the last two decades. This causes occasionally strong reductions of water withdrawal to a minimum and even to zero, when the lake levels fall below the so-called 'red' and 'black' alarm lines. The latter is the elevation of the intake of the pipe system. While changing climate conditions were believed to be the major factor for the decreasing water inflow to the lake, recent research indicates more complex causes. In fact, increasing groundwater abstraction in the groundwater basin since the 1950s seems to be the dominant impact factor not only on the water level but also on salinity. 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 efforts undertaken since the early plans for large scale commercial sea water desalination in 1999 fully reshaped the national strategy for water resources management in Israel. The dynamic development parallel to the three SMART project phases emphasized the potential of sea water desalination as one of the key technology solutions besides wastewater treatment and brackish groundwater desalination to fill the water gap in the project region. Although limited water swap contracts already exist, the difficult political process needs to continue before joint efforts for alternative, regional, and transboundary IWRM strategies can be successfully arranged. The voices for practical solutions become more pronounced with time and the necessity is being increasingly realized in the three neighboring partner countries.

Like all countries of the Near East region, except for Israel, Jordan and the Palestinian Territories are at the OECD-DAC list of development countries with a high percentage of young people. Due to generally weak national economic performances the younger generation faces multiple challenges especially with regard to their professional education and career perspectives easily leading to social discontent. Therefore, the comprehensive strategic orientation of the water sector plays a key role to improve the concrete socio-economic situation and perspectives of the people and to prepare the ground for predictable development potentials of all economic sectors with a focus on agriculture, industry, tourism, and service activities.

In addition, institutional development, professional and technical training and school education programs need to keep pace with the technological and methodological innovations in the water sector and the regulatory requirements for the implementation process of the national water strategies and sustainable IWRM concepts, respectively.

Without question, the partner countries made noticeable progress with respect to the overall situation in their national water sectors. However, only Israel as a highly industrialized country had the necessary resources to fully implement a comprehensive national water strategy for a long-term stable and sufficient water supply. More regional and international cooperation would not only help Jordan and the Palestinians to upgrade and strengthen their water sectors for the future as well, it would induce additional economic potential and optimism for better life perspectives for the local communities.

0.2 Objectives

The central goal of the SMART-MOVE 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.

For its achievement, a generalized concept for IWRM implementation was to be developed on the basis of catchment clusters on both sides of the Lower Jordan River. The western catchment cluster refers to the Jericho-Auja area with the upstream catchments of Wadi Qilt, Wadi Nueima and Wadi Auja. On the Jordanian side, the eastern cluster consists of Wadi Zarqa and Wadi Shueib. Following the implementation concept, integrated water plans on cluster level will be established, taking the social, economic and environmental policy strategies of the individual states into account. The 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 in this conflict-prone region.

For this purpose, the 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 is to be expanded into overall strategies, and work already started on the development of prototypes (e.g. brackish water desalination) had to be completed.

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.

0.3 SMART-MOVE project organization and overall strategy

SMART-MOVE has been organized as the implementation phase of the three SMART project phases and involves 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 *(A) Monitoring and local Raw Water Management*, *(B) Implementation of innovative Water Technologies* and *(C) Integrated Planning Tools for IWRM Implementation*, which are cross-sectional 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 0-2).

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 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 suited and adjusted to the local requirements to implement all technologically-based components of the comprehensive IWRM concept, like 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 account for the rising water gaps due to a fast-increasing water demand, driven by high population growth rates and groundwater deterioration.

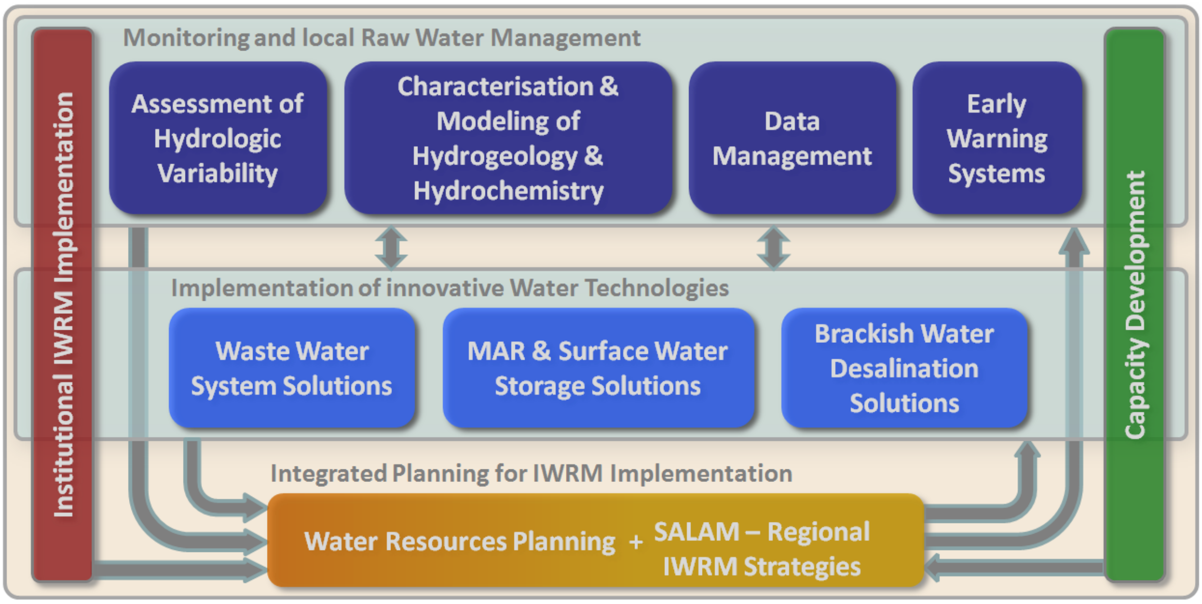

Figure 0-2: Schematic of the SMART IWRM Research Concept.

All work and goals are closely coordinated together with the local partners especially with the decision makers and stakeholders for the development and implementation of the IWRM concepts and guidelines. Formulated as cross-sectional tasks under each of the three main topics, a broad spectrum of Institutional Implementation concepts as well as Knowledge Transfer and Capacity Development measures like the DWWT Competence Facility Fuheis supports and strengthens the implementation process and ensures its sustainability.

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PART II

A Monitoring and Local Raw Water Management

A.1 Hydrological data acquisition, variability scenarios, and modeling for water resources planning – Jericho-Auja

Contributing partners	UGOE, PWA, MEK, SEBA, HEC
Contributing authors	Sebastian Schmidt, Torsten Lange, Martin Sauter
Key words	Hydrological monitoring network, precipitation-runoff model, long-term precipitation time series

A.1.1 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.

A.1.2 Starting point, objectives, approaches

Starting point 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 in 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). Hereby, groundwater resources are difficult to predict because of the 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.

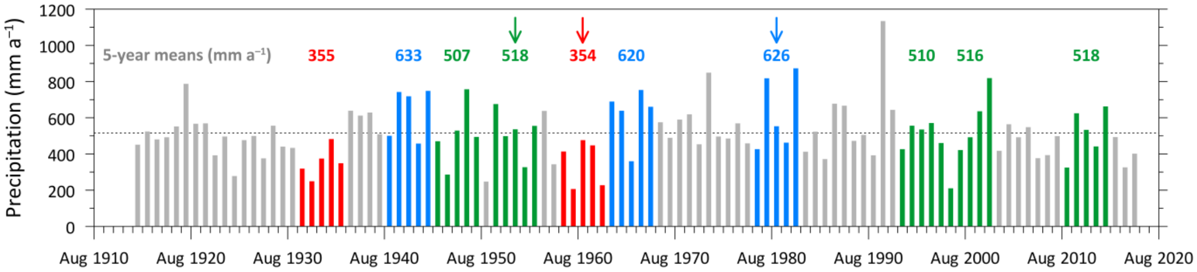

Figure A.1-1: Representative 5-year drought, medium and wet periods selected from the long-term precipitation record (rain gauge at Jerusalem). The selected periods employed for the construction of the 20-year scenario combinations are indicated by arrows.

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 from the hydrological 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 (Figure A.1-1).

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).

A.1.3 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 against variable and especially low supplies. Figure A.1-2 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.

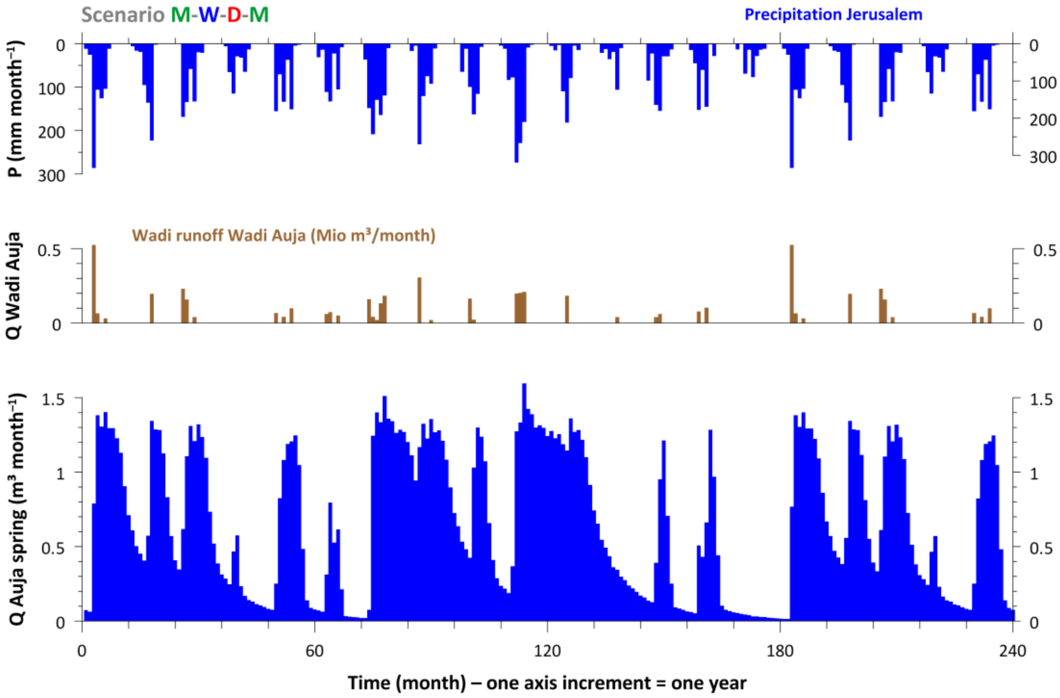

Figure A.1-2: Calculated hydrological time series for the 20-year scenario combination Mean-Wet-Drought-Mean for Wadi Auja. Wadi flow (calculated for a surface catchment area of 55 km²) is of minor importance compared to spring discharge from Auja spring. Due to the high interannual variability even 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).

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.

Project publications

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A.1.4 References

SMIATEK, G., KEIS, F., CHWALA, C., FERSCH, B. H. KUNSTMANN (2017): Potential of commercial microwave link network derived rainfall for river runoff simulations. Environ. Res. Lett. 12 (2017) 034026 https://doi.org/10.1088/1748-9326/aa5f46

A.2 Groundwater Model of the Shallow Aquifer of Jericho-Auja

Contributing partners	HEC, UGOE, PWA, RWC
Contributing authors	Muath Abu Sadah, Amer Marei, Torsten Lange, Sebastian Schmidt, Florian Walter, Bernd Rusteberg, Martin Sauter
Key words	Precipitation measurement network, precipitation-runoff model, long-time precipitation time series

A.2.1 Key findings

A transient numerical flow model of the Shallow Aquifer of 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 Mm³ for the period of 2000-2014 with ca. 6 Mm³ through lateral inflow from the Cretaceous limestone formations of the Mountain Aquifer and ca. 3 Mm³ 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.

A.2.2 Starting point, objectives, approaches

Starting point and objectives

The groundwater model for 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 on monthly time series data for the time period 2000 to 2014.

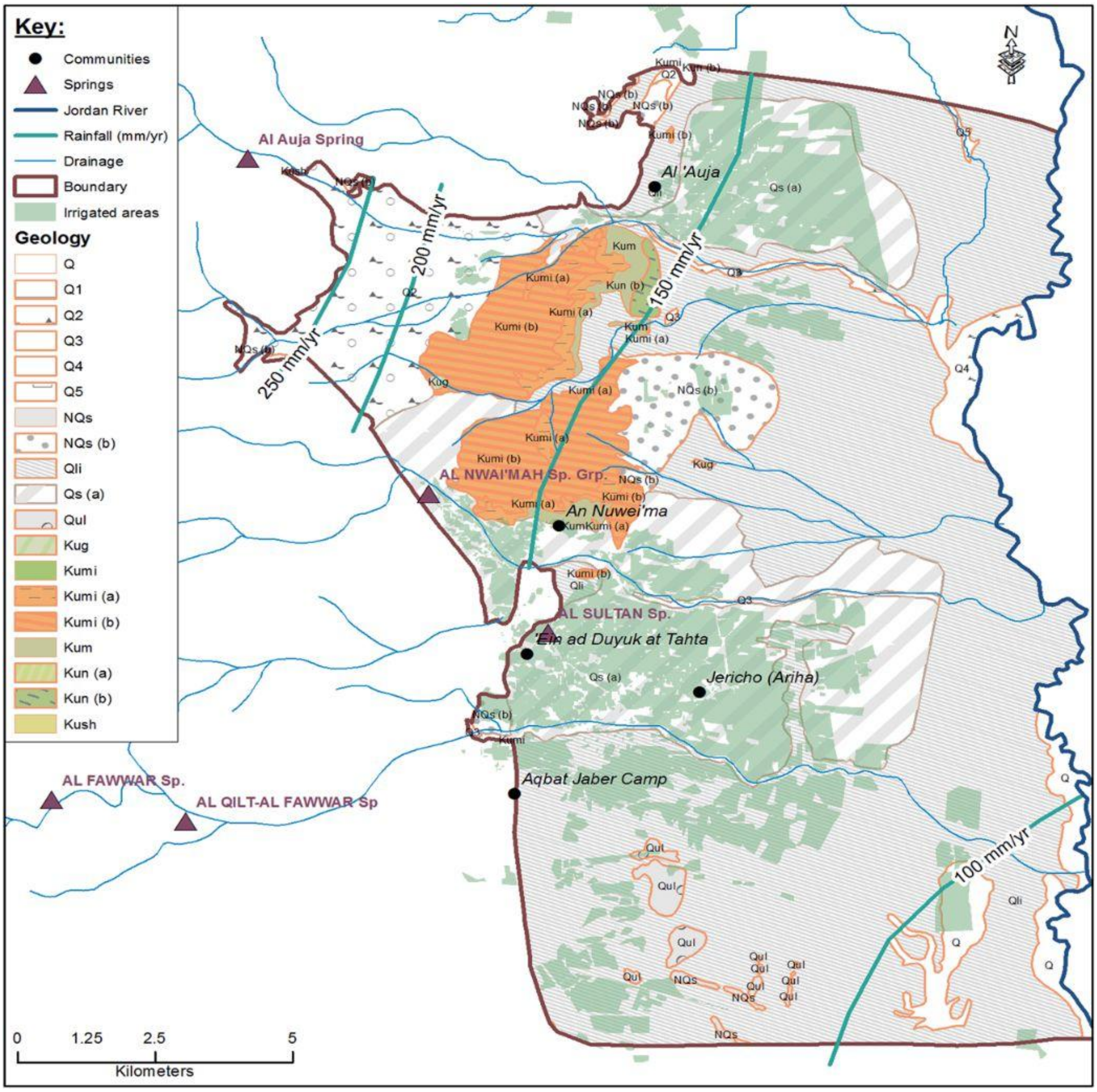

Figure A.2-1: Overview map of the study area: geology, precipitation, irrigation areas, springs and model boundary.

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.

A.2.3 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.

Capacity Development

The model was developed by Dr. Muath Abu Sadah, who did is PhD 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

Publications

ABU SADAH, M., T. LANGE, A. MAREI, S. SCHMIDT, F. WALTER & M. SAUTER (in prep.): Managing Stressed Water Resources in the Lower Jordan Valley - Reference Groundwater Model for the Alluvial System of Jericho-Al Auja.

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A.2.4 References

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KHAYAT, S.K. (2005): Hydrochemistry and Isotope Hydrogeology in the Jericho Area/Palestine. – Dissertation, University of Karlsruhe, Germany, December 2005.

A.3 The Marsaba-Feshcha groundwater basin and Ein Feshcha spring group: vulnerabilities, risks, water resources potential

Contributing partners	HEC, Mekorot, TAU
Contributing authors	Jawad H. Shoqeir, Joseph Guttman, Anat Yellin-Dror
Key words	Brackish groundwater, groundwater vulnerability, pumping strategies

A.3.1 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 Mm^3/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.

A.3.2 Starting point, objectives, approaches

Starting point and objectives

The Marsaba-Feshcha (M-F) groundwater basin is considered as one of the most 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 identified 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.

Figure A.3-1: Overview photograph of the Feshcha spring area at the NW Dead Sea shore.

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.

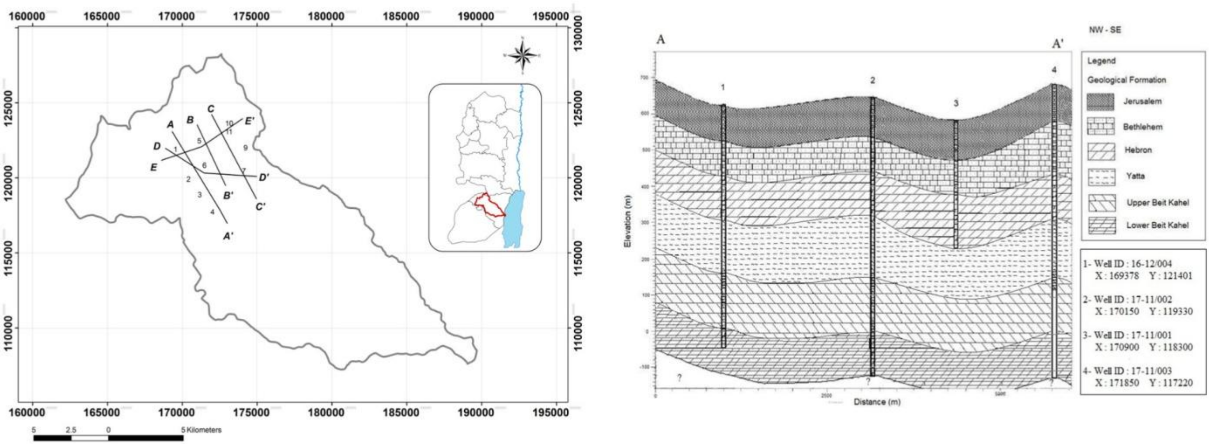

Figure A.3-2: Left: Location of geological cross section in the Daraja catchment from Bethlehem to the Dead Sea; Right: Example of the geological cross section A-A' between the wells Herodion 1, 2, 3 and Hundaza.

As a result, new hydrogeological cross sections were constructed (Figure A.3-2) 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 fields is abstracted from the lower aquifer before the mixing happens. 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 actions plans. The site is believed to be well-suited for capturing the fresh water before salinity increases significantly southward.

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 helps in identifying existing and potential point and non-point pollution sources.

Figure A.3-3: Göttingen University and Hydro-Engineering Consultancy team installing water quality sensors.

The elements of synthesis of this convergence process are vulnerability and risks maps, 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.

A.3.3 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 A.3-4) 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.

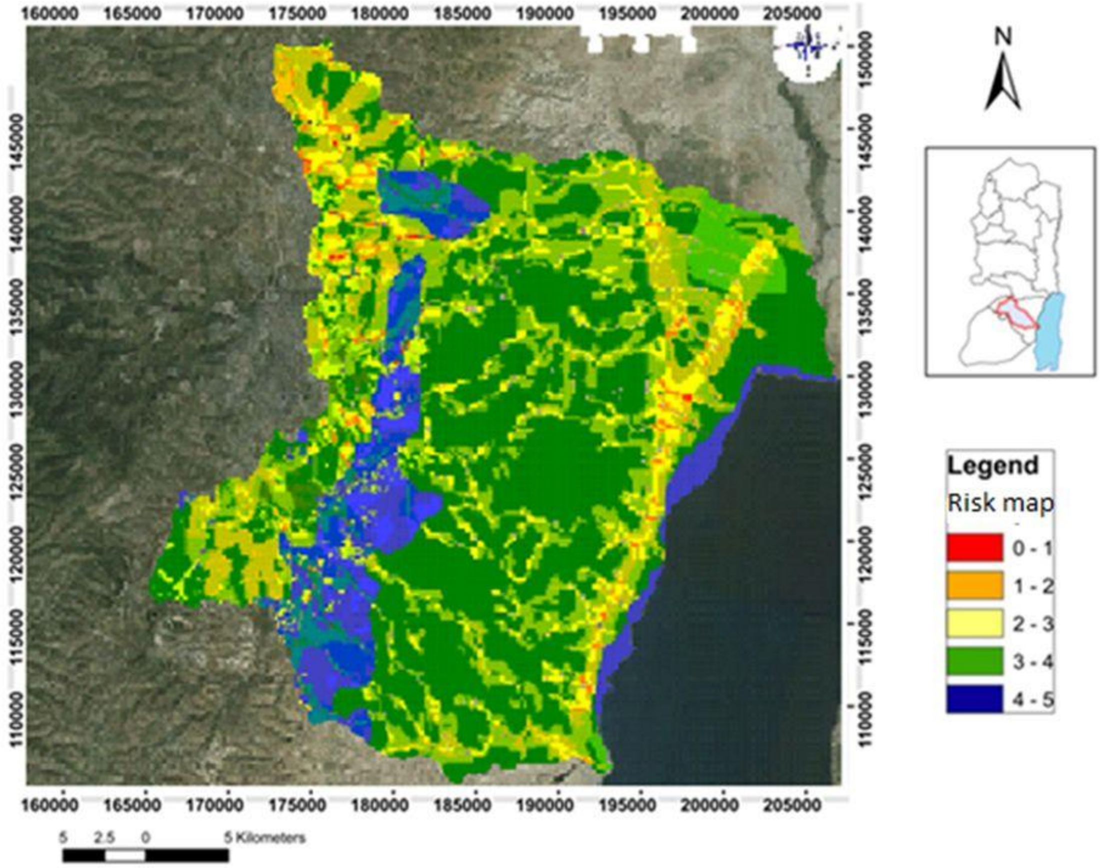

Figure A.3-4: Risk Map of M-F Basin using my-Observatory (NEED TO BE EXPLAINED).

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.

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 low levels of the Dad Sea.

A.3.4 References

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PALESTINIAN WATER AUTHORITY (2011): Annual Status Report on Water Resources, Water Supply, and Wastewater in the Occupied State Of Palestine.

SHOQEIR, J. (2014): Tracing groundwater in a karstic aquifer: IWRM components implications and challenges. - 1st Edition. Lambert Academic Publishing, ISBN: 978-3-659-27211-0.

A.4 Quantification of the water fluxes in the recharge zones of the Wadi Shueib springs

Contributing partners	KIT, SEBA, DISY, MWI
Contributing authors	Felix Grimmeisen, Julian Xanke, Tanja Liesch, Nico Goldscheider
Key words	Karst aquifer, stable water isotopes, fresh water, waste water, water import

A.4.1 Key findings

- Environmental isotopes were used to study urban water source partitioning and mixing.
- Nitrate $\delta^{15}N$ and $\delta^{18}O$ isotope data of groundwater in Jordan are presented.
- Endmember mixing calculations revealed significant contributions of urban effluents to groundwater flow.
- Leaky networks and sewers contribute between 32% and 71% to polluted groundwater.

A.4.2 Starting point, objectives, approaches

Starting point and objectives

Water supply in developing countries is often vulnerable to large water losses due to leaky distribution networks and leaky canals, which affect groundwater quality and quantity in urban areas and can lead to complex mixed underground dynamics. The objective was to quantify the proportions of the individual water source components in the water cycle of Wadi Shueib.

Methodology

The study in Wadi Shueib used a stable isotope approach to investigate spatio-temporal variations in the distribution and mixing of surface and subsurface water sources and to assess nitrogen (N) contamination in the urban water cycle of As-Salt. The water import from King-Abdullah Canal (KAC), tap water from the distribution network and wastewater can be characterized by distinct isotope signatures that allowed quantifying the influx of urban wastewater into the phreatic zone. Temporal variations in isotope signatures of polluted groundwater are explained by seasonally fluctuating inflows and dilutions from fresh water from Lake Tiberias that enters the urban water cycle via the KAC.

A.4.3 Results

Isotope analyses (N and O) and the comparison between nitrate concentrations of groundwater and tap water, water imports and waste water confirmed that the input from leaking sewers is the main factor for nitrate pollution. The nitrate of heavily contaminated groundwater was characterized by the highest $\delta^{15}N_{NO3}$ values (13,3±1,8‰), while the lowest $\delta^{15}N_{NO3}$ values were measured in unpolluted groundwater (6,9‰). Similarly, nitrate concentration and isotope ratios were used to distinguish the different sources and qualitatively confirmed by δD_{H2O} and $\delta^{18}O_{H2O}$ based estimates. Calculations using a two-component mixing model for water isotopes indicate that urban wastewater from leaky networks and canals contribute 30-64% to heavily polluted groundwater. Ternary mixing calculations, which also include chloride, showed that 5 - 18% of the polluted groundwater can be attributed to wastewater. Up to two thirds of the groundwater originates from the network, which indicates excessive water loss from the network and requires improved water supply management (Grimmeisen et al. 2017).

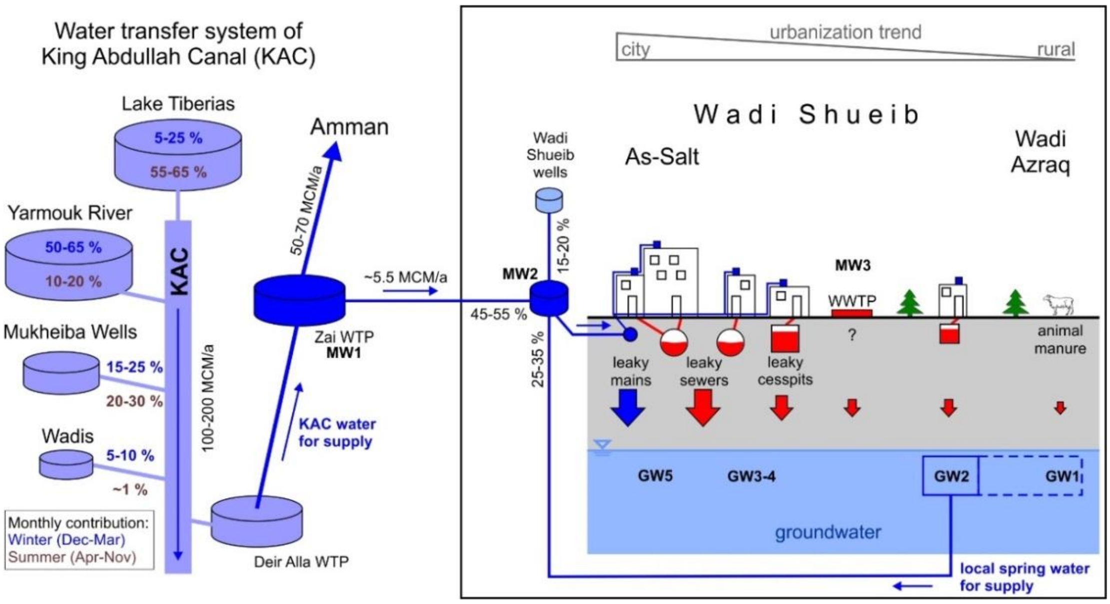

Figure A.4-1: **Schematic representation of the water supply and the urban water cycle of As-Salt. The sampling locations GW1-GW5 are karst sources, MW1-MW3 are mixed water resources. The figures are based on unpublished data from the Jordanian water authority; MCM/a stands for millions of cubic metres per year (Grimmeisen et al. 2017).**

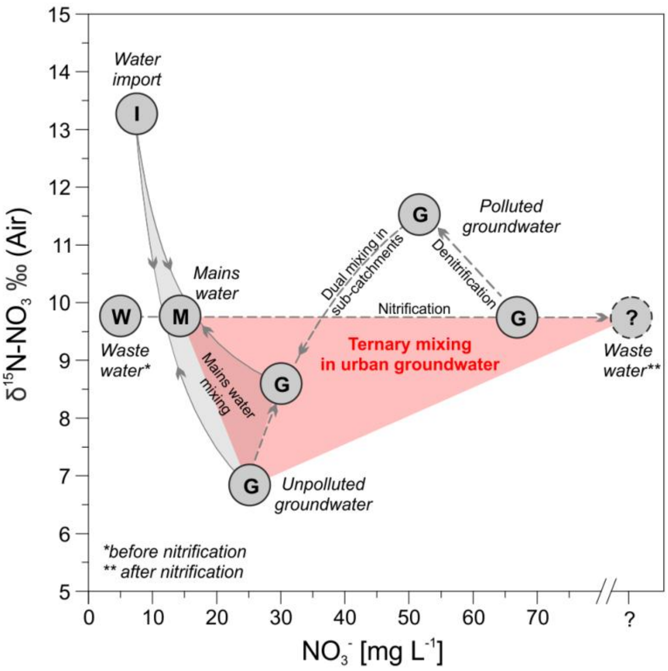

Figure A.4-2: Ternary mixing model with the different water components in Wadi Shueib (GRIMMEISEN et al. 2017).

Further Research Needs

This study provides evidence for urban effluent contamination / artificial recharge qualitatively consistent with the presented mixing models. However, the limited data set is still ambiguous with regards to the mixing and fate of contaminant nitrogen sources (nitrification/denitrification) and therefore needs further detailed research.

Capacity Development

This study was carried out in close cooperation with the MWI which allowed access to unpublished data. Furthermore, the laboratory analyses were performed with the help of the Institute for Isotope Biogeochemistry at the University of Basel, Switzerland.

Publications

GRIMMEISEN, F., LEHMANN, M. F., LIESCH, T., GOEPPERT, N., KLINGER, J., ZOPFI, J., & GOLDSCHEIDER, N. (2017). Isotopic constraints on water source mixing, network leakage and contamination in an urban groundwater system. Science of the Total Environment, 583, 202-213.References

A.4.4 References

GRIMMEISEN, F., LEHMANN, M. F., LIESCH, T., GOEPPERT, N., KLINGER, J., ZOPFI, J., & GOLDSCHEIDER, N. (2017). Isotopic constraints on water source mixing, network leakage and contamination in an urban groundwater system. Science of the Total Environment, 583, 202-213.

A.5 Early Warning System for spring water contamination in Wadi Shueib

Contributing partners	KIT, SEBA, DISY, MWI
Contributing authors	Felix Grimmeisen, David Riepl, Nico Goldscheider, Julian Xanke
Key words	Early warning system for spring water contamination, Wadi Shueib, Karst

A.5.1 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).

A.5.2 Starting point, objectives, approaches

Starting point and objectives

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.

Methodology

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.

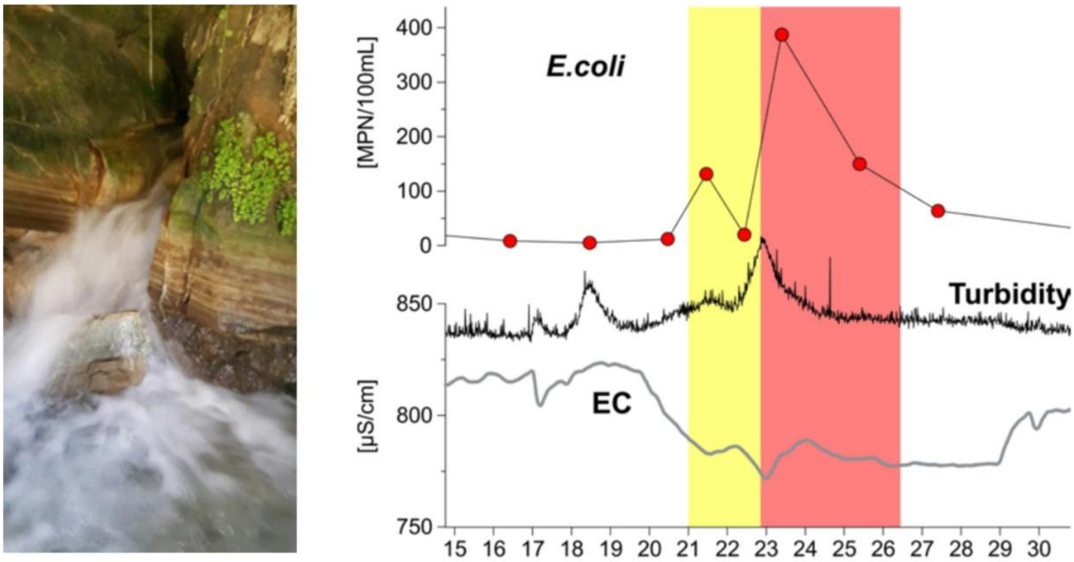

Figure A.5-1: Discharge at Baqqouria spring (left) and relation between E. coli, Turbidity and electrical conductivity (EC) (right).

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.

A.5.3 Results

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 A.5-1), which forms the basis of the EWS as illustrated in Figure A.5-3.

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.

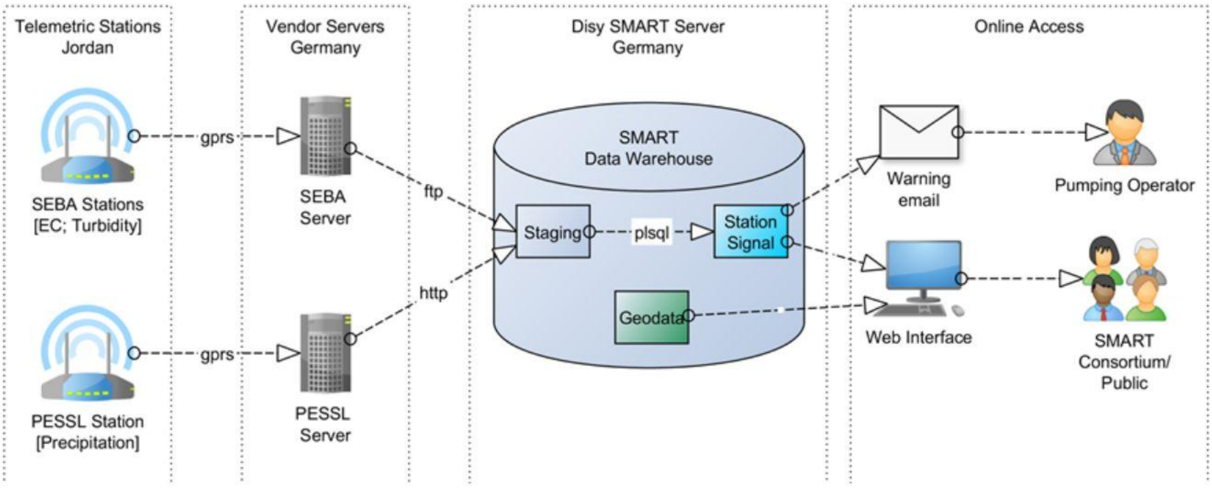

Figure A.5-2: Schematic illustration of the Early Warning System components.

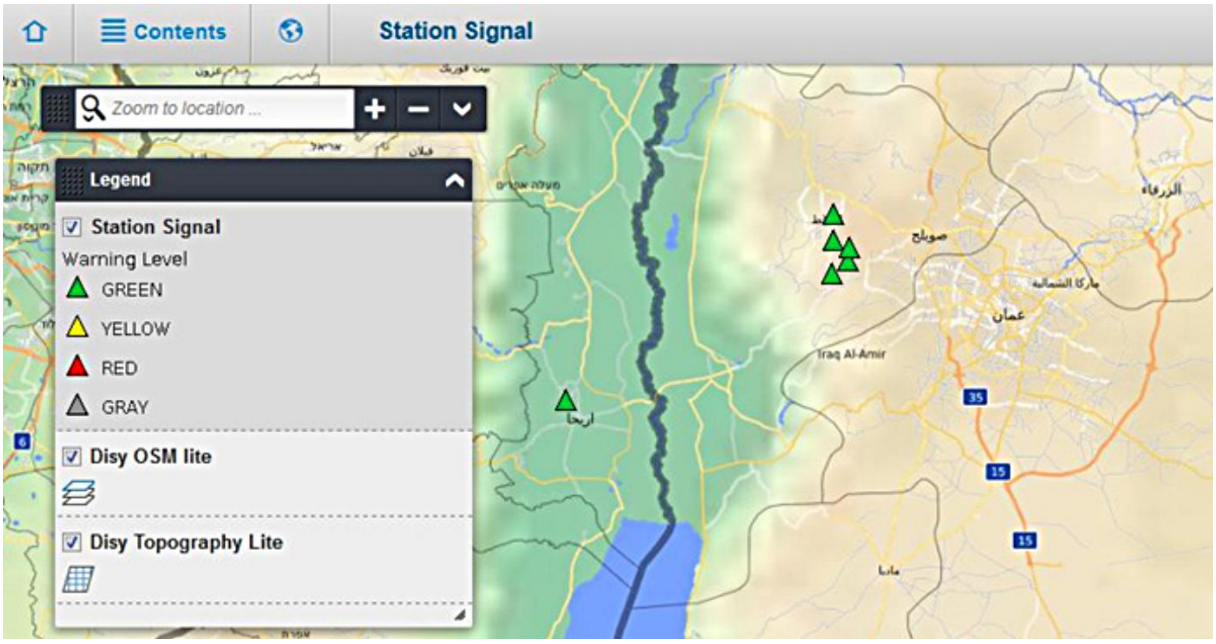

Figure A.5-3: Example for the visualization of the station signal including background geo-data of the project region.

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 held for employees of Jordanian and Palestinian water authorities and water suppliers.

Further Research Needs

The Early Warning System (EWS) concept is based on a detailed analysis of the local characteristics of the aquifer and the problems to be addressed. For this purpose, a differentiated monitoring of different parameters and their correlations is important to understand the dynamic variations. A further detailed evaluation of the hydraulic and hydrogeochemical data, the integration of new measurement methods and the assessment of the transferability of this system to other sites are necessary to further improve this approach.

Capacity Development

Staff from the Ministry of Water and Irrigation (MWI) and local authorities were involved in the planning, installation, data collection and development of the EWS and trained on site. In addition, a workshop was held together with partners from Palestine in which both the equipment and the concept of the EWS were presented and instructed. The preparation of a handbook on the scientific approach and the technical set-up of the system will enable the authorities to maintain the EWS and, if necessary, establish it at other sites.

Publications

GRIMMEISEN, F., D. RIEPL, S. SCHMIDT, J. XANKE, N. GOLDSCHEIDER (2018): Set-up of an early warning system for an improved raw water management of karst groundwater resources in the semi-arid side Wadis of the Jordan Valley. – Geophysical Research Abstracts, Vol. 20, EGU2018-16731, EGU General Assembly 2018

GRIMMEISEN, F., SCHMIDT, S., KLINGER, J., GOLDSCHEIDER, N. (2017): Konzeption und Aufbau eines online Grundwasserqualitäts-Monitoring zur Ermittlung von Kontaminationsereignissen in einem jordanischen Karstgebiet. – Zbl. Geol. Paläont. Teil I, Jg. 2017, Heft 1, 119–125.

SCHMIDT, S., GRIMMEISEN, F., RIES, F., GOLDSCHEIDER, N., SAUTER, M. (2018): Hochauflösendes Monitoring von Karst-Grundwasserressourcen beiderseits des Jordangrabens – Konzepte und Anwendungsbeispiele. – Grundwasser, 23, 59-72.

A.6 Vulnerability and risk mapping to strengthen the link between wastewater treatment and groundwater protection in the hot spot area Wadi Shueib

Contributing partners	KIT-HYD, UFZ, MWI
Contributing authors	Julian Xanke, Anna Ender, Tanja Liesch, Nico Goldscheider
Key words	Vulnerability mapping, karst aquifer, Wadi Shueib, reuse of treated waste water for irrigation

A.6.1 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.

A.6.2 Starting point, objectives, approaches

Starting point and objectives

To improve the groundwater and spring water quality in Wadi Shueib, it is important to implement protection zones, reduce pollution and detect 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 the type of porosity. In large conduits, flow velocities can reach tens to hundreds of meters per hour, whereas the flow velocity generated from matrix porosity is typically in the range of centimeters per day.

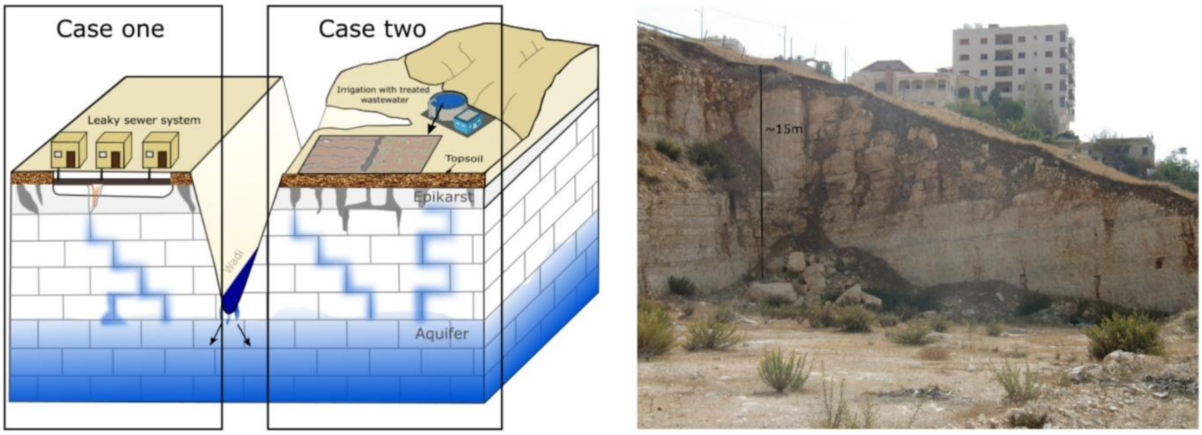

Figure A.6-1: ***Left:*** **Schematic overview of the potential contamination risks of leaky sewer pipes and irrigation with TWW.** ***Right:*** **Wadi as Sir Formation with Epikarst and thin topsoil layer in the northeastern part of Salt.**

Methodology

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 A.6-1 - left) considering the hazard potential of wastewater infiltration into the underground:

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 groundwater or spring water, respectively. 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).

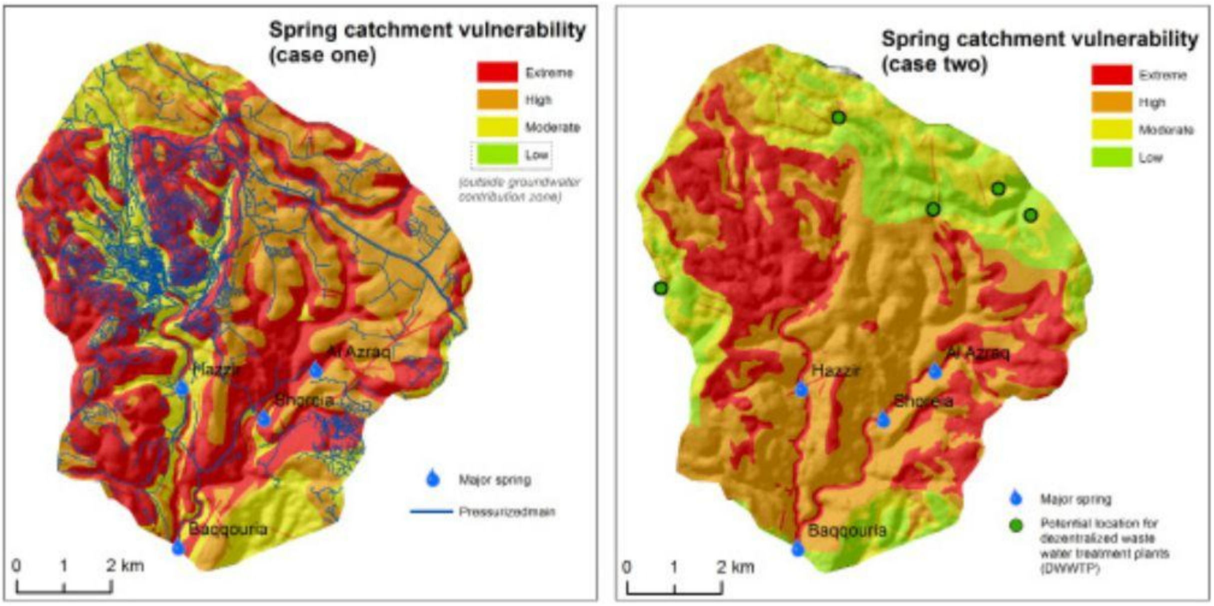

Figure A.6-2: *Left:* Rehabilitation concept for the sewer systems in the upper Wadi Shueib based on vulnerability assessment. *Right:* Impact of irrigation with treated wastewater on groundwater based on vulnerability assessment.

A.6.3 Results

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 A.6-2 - 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 A.6-2 - 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 seen to be less critical.

Further Research Needs

The further development of the reuse maps for treated wastewater for irrigation purposes requires additional detailed studies on different scales. On a smaller scale, field tests on pilot sites can be useful to investigate e.g. soil properties and infiltration under different conditions. On a larger scale, new satellite data (e.g. on vegetation cover, soil composition and soil moisture) could be evaluated in order to improve the applicability of this approach. Additionally, there is a need for further harmonization of the planning of decentralized waste water treatment plants (DWWTP; e.g. in terms of the treatment level) and its reuse (for irrigation) as the classification of the reuse potential on the maps not only depends on geological or geographical conditions but also the intensity of treatment and the remaining substances in the water.

Capacity Development

The application of vulnerability mapping is a common and globally used approach, also in Jordan. Since there are a variety of mapping approaches, it was important for the MWI to pursue an approach that was as consistent as possible with the mapping approach commonly used in Jordan's water sector. Therefore, this study discussed with the MWI and the BGR, which also works intensively with vulnerability mapping in their water projects in Jordan.

Publications

XANKE, J., T. LIESCH, N. GOEPPERT, J. KLINGER, N. GASSEN, N. GOLDSCHEIDER (2017): Contamination risk and drinking water protection for a large-scale managed aquifer recharge site in a semi-arid karst region, Jordan. – Hydrogeology Journal, 25, 6, pp. 1795-1809.

A.6.4 References

HOPPE, N., J. XANKE, J. KLINGER, N. GOLDSCHEIDER (2018): Vulnerability and risk mapping to strengthen the link between waste water treatment and groundwater protection in the hot spot area Wadi Shueib. – SMART Move project report.

A.7 Transboundary Hydrogeological Model of the Lower Jordan Valley

Contributing partners	EWRE, MEKOROT, KIT, Julia Sahawneh
Contributing authors	Jacob Bensabat, Julia Sahawneh, Heinz Hötzl, Joseph Guttmann
Key words	Regional 3D groundwater flow model, Lower Jordan Valley, Transboundary model

A.7.1 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.

A.7.2 Starting point, objectives, approaches

Starting point 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 map 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).
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. Guttmann in the west and J. Sawahneh in the east). Despites 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 going 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.

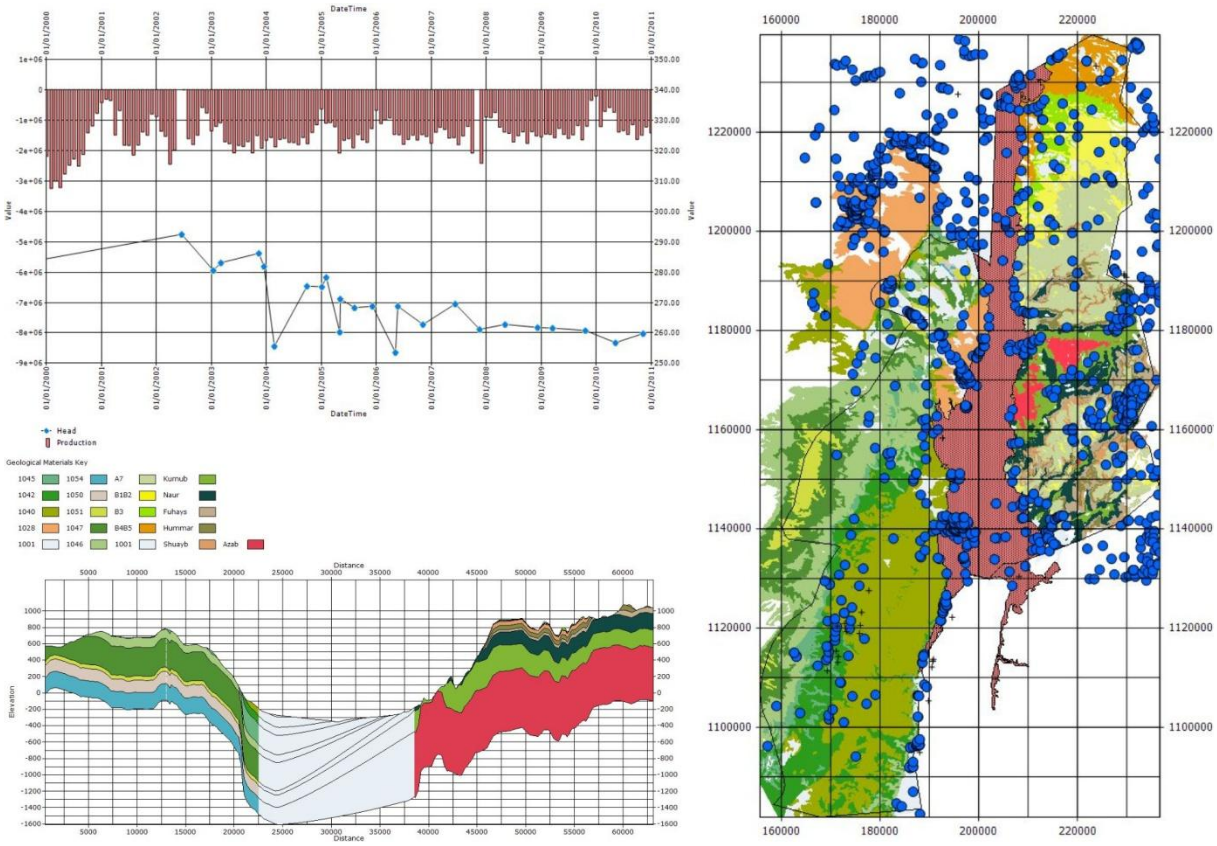

Figure A.7-1: Integrated database of the Transboundary Hydro-Geological Model of the LJV. *Upper left:* Herodion-2 well head elevation and water production time series. *Right:* Map representation of the 3D hydrogeological model of the LJV and well locations. *Lower left:* Arbitrary W-E-cross section through the model area.

A.7.3 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.

A.7.4 References

SAHAWNEH, J. (2011): Structural Control of Hydrology, Hydrogeology and Hydrochemistry along the Eastern Escarpment of the Jordan Rift Valley, JORDAN. – Dissertation, Karlsruher Institut für Technologie, 2011.

B Implementation of Innovative Water Technologies

B.1 Managed aquifer recharge (MAR) planning for the Jericho-Auja area

Contributing partners	RWC, HEC, PHG, UGOE
Contributing authors	Florian Walter, Bernd Rusteberg, Muath Abu Sadah, Abdelrahman Tamimi, Torsten Lange, Martin Sauter
Key words	Managed Aquifer Recharge, MAR, IWRM, Middle East, Groundwater Simulation

B.1.1 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 enable 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.

B.1.2 Starting point, objectives, approaches

Starting point 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 on 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 B.1-1). 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 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.

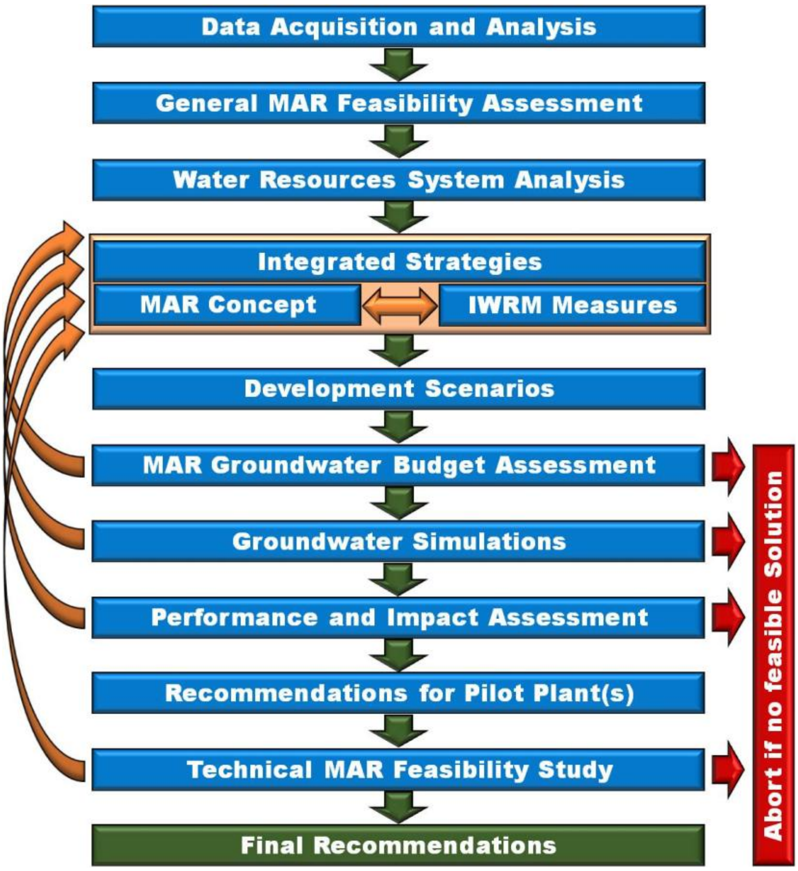

Figure B.1-1: Illustrated overview of suggested integrated MAR planning approach (Walter, 2018).

B.1.3 Results

Three suitable locations were identified: one at Auja village and further two at the City of Jericho (Figure B.1-2). For each location the implementation of new hydro-infrastructure is required. It is suggested to use spring discharge and surface runoff as source of MAR. Since the existing water transport and distribution network presents high losses of water, modernization measures are required in the first place. 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.

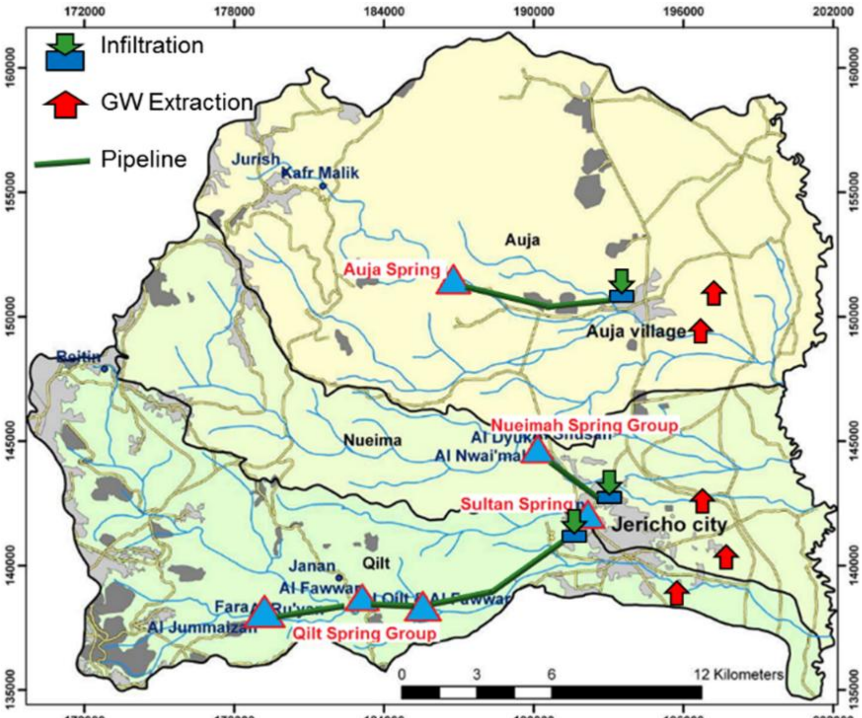

Figure B.1-2: Schematic of suggested MAR locations in the Jericho-Auja Wadi Cluster.

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 B.1-1 presents different strategies for MAR planning and management. 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. Also the reuse of treated waste water contributes significantly to the resilience of the water resources system against high hydrological variability.

Table B.1-1: 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

Figure B.1-3 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 enormous 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.

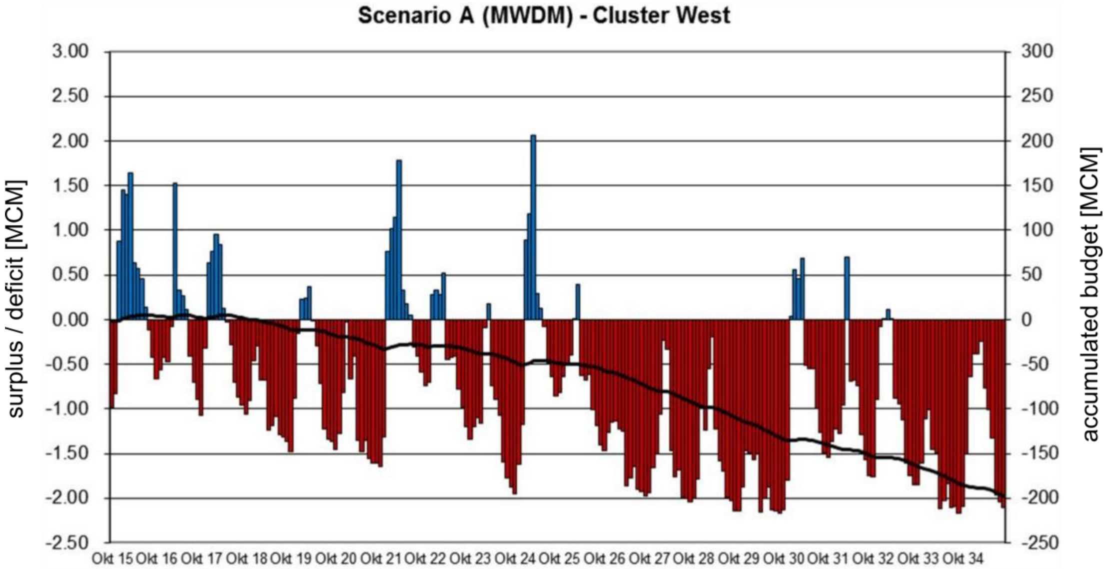

Figure B.1-3: Water budget assessment for MAR strategy A for the upcoming 20 years under the assumption of moderate climate conditions.

The remaining water deficits would have to be covered by shallow wells and other local water resources to ensure irrigation development. Figure B.1-4 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 local water resources should be activated to cover or minimize water deficits. The results show the need for an integrated water management approach.

Figure B.1-4 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.

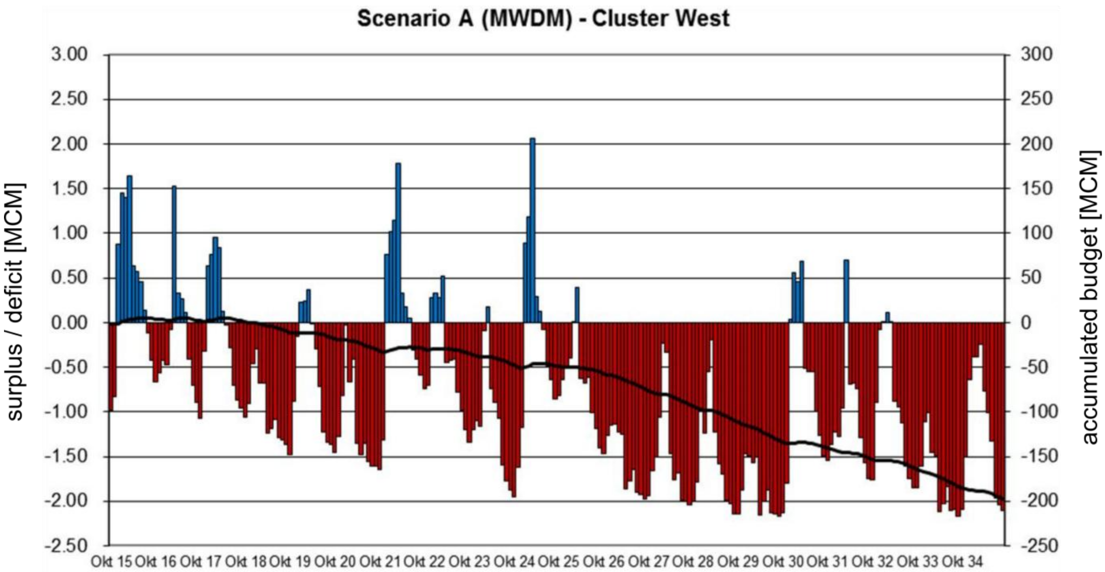

Figure B.1-4: Water budget assessment for MAR strategy F for the upcoming 20 years under the assumption of dry climate conditions.

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 B.1-2) could be optimized.

Figure B.1-5 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 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 drawdown can be reduced by more than half.

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.

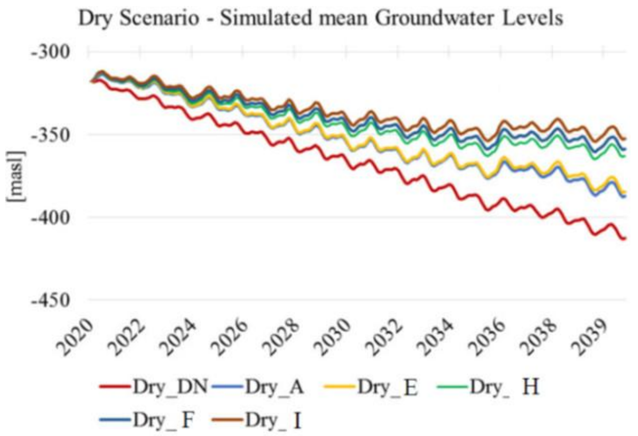

Figure B.1-5: Simulation of mean groundwater levels for all three MAR sites under extreme climatic scenario with agricultural extension for all developed strategies (Walter, 2018).

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.

Publications

WALTER, F. (2018): Conceptual Planning of Managed Aquifer Recharge in the Context of Integrated Water Resources Management for a semi-arid and a tropical Case Study in Palestine and Brazil: A new Integrated MAR Planning Approach. - PhD Thesis. Georg-August-Universität Göttingen.

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B.1.4 References

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RUSTEBERG, B., BENSABAT, J., WALTER, F., RIEPL, D., GUTTMAN, Y., TAMIMI, A. R., SAUTER, M. (2014): *IWRM Strategies at local sub-basin level, sensitivity analysis and performance assessment*. Unpublished report, Deliverable D803-804-805, SMART II project. Georg-August-Unviersity Göttingen.

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RUSTEBERG, B., WALTER, F., XANKE, J., KLINGER, J., SADAH, M. A., MAREI, A., SALAMEH, E., GUTTMAN, Y. AND TAMIMI, A. R. (2014b): Development, Evaluation and Ranking of Managed Aquifer Recharge (MAR) Planning Options in Case Study Areas of the Lower Jordan Valley. Unpublished report, Project Deliverable D318-320, SMART II project. Georg-August-University Göttingen.

B.2 Managed aquifer recharge (MAR) along the eastern lower Jordan Valley - General Potential and Deir Alla Test Site

Contributing partners	JUA, KIT-HYD, ATEEC
Contributing authors	Amer Salman, Elias Salameh, Julian Xanke, Tanja Liesch
Key words	Managed aquifer recharge, Jordan Valley, unconsolidated porous aquifer, socio-economic benefit

B.2.1 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 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.

B.2.2 Starting point, objectives, approaches

Starting point and objectives

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.

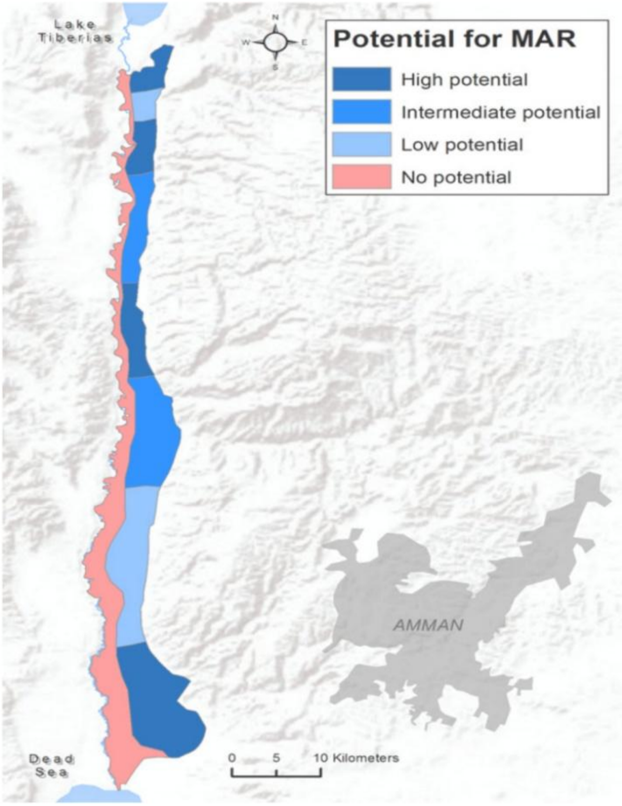

Figure B.2-1: *Left:* Groundwater fountain by pressure rotary drilling from borehole in Deir Alla. *Right:* Potential for Managed aquifer recharge in the Jordan Valley.

Methodology

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 B.2-1) 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.

B.2.3 Results

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.

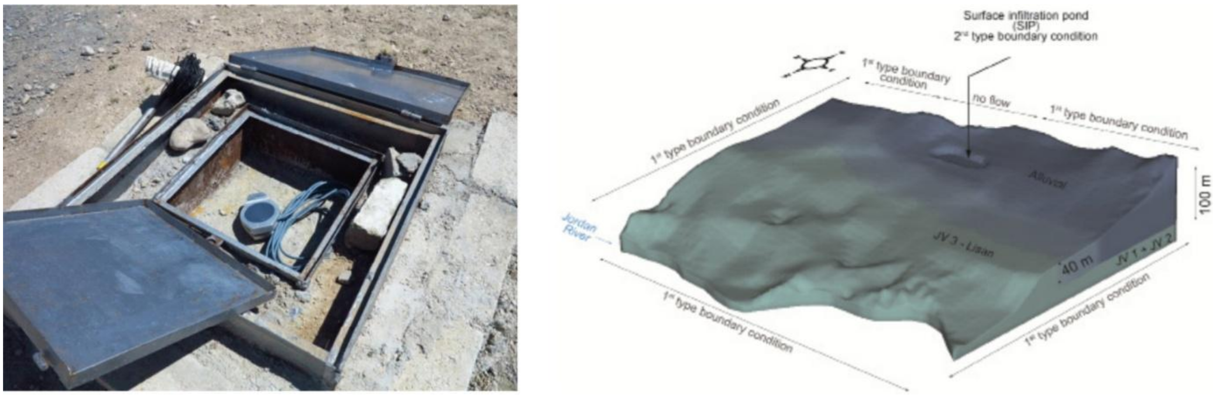

Figure B.2-2: ***Left*: Observation well in the Jordan Valley. *Right*: Numerical model of the test site in Deir Alla.**

Further calculations recommend that 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 m², the maximum possible annual infiltration volume is about 1 MCM.

A further assessment using a numerical groundwater model (Figure B.2-2) 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 about 7 months.
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.

Further Research Needs

Further investigations on the finer discretization of the subsurface as well as large-scale infiltration experiments are necessary to better understand the geological structure and the hydraulic behavior of the aquifer during surface water infiltration.

In addition, studies could be carried out on the potential transferability of the MAR approach to the whole Jordan Valley, as MAR can play an important role in the water management of the area. In particular, subsurface storage of treated waste water for the rehabilitation of overexploited aquifers and for later reuse for irrigation purposes is of interest.

Capacity Development

The University of Jordan and the Ministry of Water and Irrigation (MWI) were involved in field experiments. In this context, the different technical challenges of the individual MAR components were discussed. In addition, the socio-economic assessment of the MAR implementation and its potential benefits also included discussion with the local population (farmers), which may lead to greater acceptance of this concept.

Publications

XANKE, J., A. SALMAN, E. AL-KARABLIEH, E. SALAMEH, L. LIESCH & N. GOLDSCHEIDER (2018): Hydrogeological site investigation in the Jordan Valley and economic evaluation to assess the potential and profitability of Managed Aquifer Recharge (under preparation)

B.2.4 References

SALMAN, A. (2017): Socio-economic assessment of MAR in Jordan. – SMART Move project report.

XANKE J, E. SALAMEH (2017): Assessment of the IWRM implementation site Deir Alla. – SMART Move project report

XANKE J., E. SALAMEH (2017): Planning of MAR-facilities at SMART Move implementation site in Jordan: Deir Alla and along the eastern Lower Jordan Valley. – SMART Move project report

B.3 A Handbook on Brackish Water Usage in Water-Scarce Regions – The Jordan Valley

Contributing partners	EBI, HEC, MWI
Contributing authors	Oliver Jung, Florencia Saravia, Gudrun Abbt-Braun, Harald Horn, Amer Marei
Key words	brackish water treatment, desalination, membrane technology, handbook

B.3.1 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.

B.3.2 Starting point, objectives, approaches

Starting point and objectives

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.

Methodology

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 B.3-1) 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

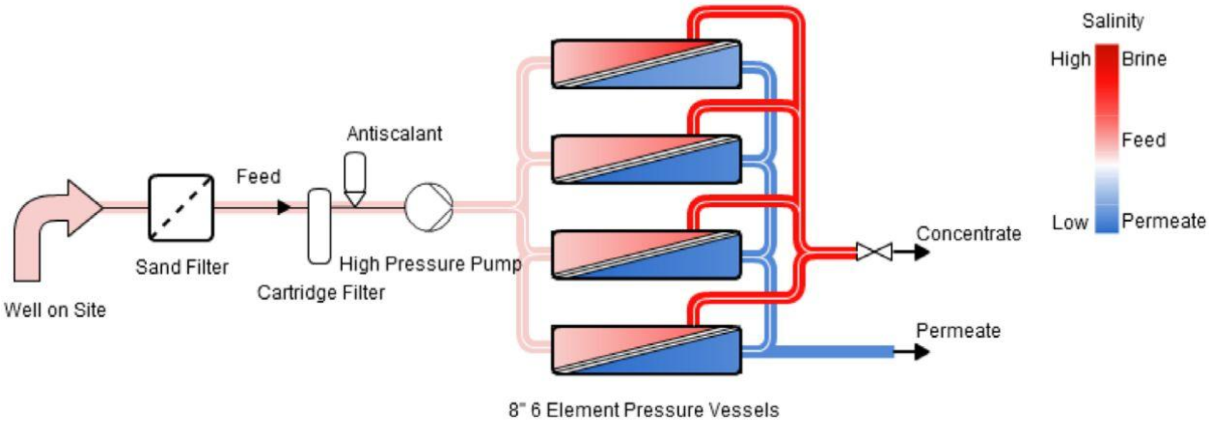

Figure B.3-1: General layout of a typical RO-unit on a farm in Jordan.

Table B.3-1: Desalination systems on farms in the Lower Jordan Valley.

n = 64	unit	min	max	mean
Capacity	[m³/h]	15	100	42
Product Capacity	[m³/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

Figure B.3-2: 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).

B.3.3 Results

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.

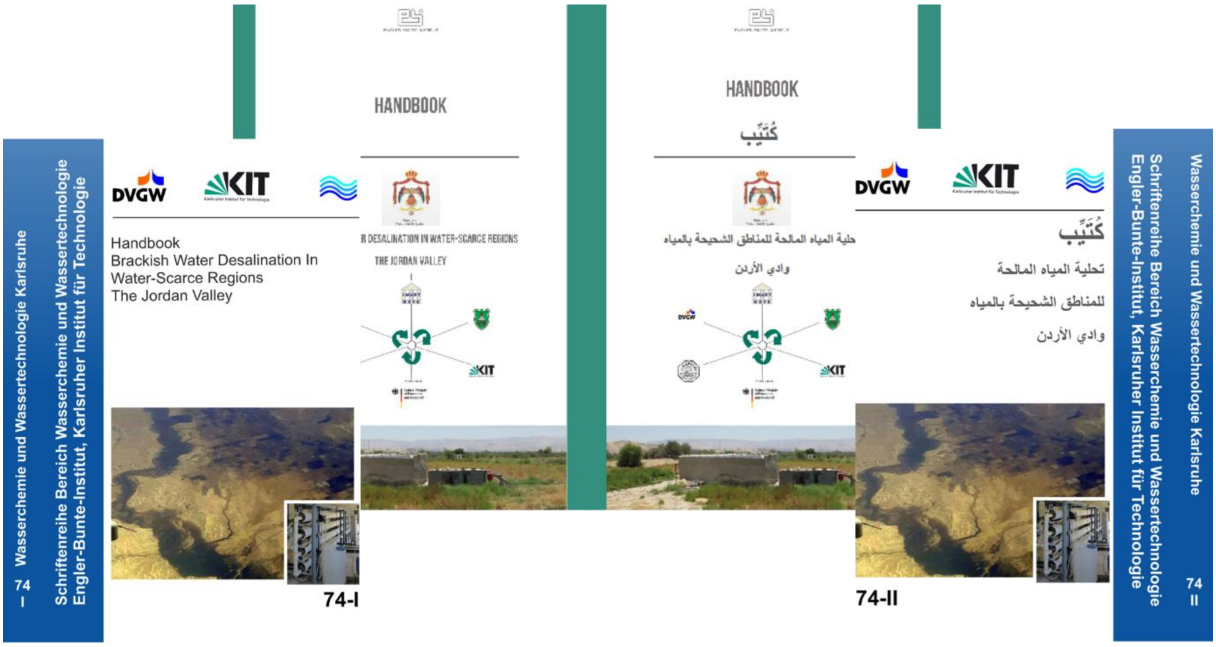

Figure B.3-3: Front cover of the Handbook on Brackish Water Usage in Water-Scarce Regions – The Jordan Valley (English and Arabic) - center/back: online edition; ambient/front: print edition

Further Research Needs

A persistent and unsolved problem of brackish water desalination in the region and worldwide is the management of brine. Zero liquid discharge is an innovative research field with the aim of establishing technical solutions for brine treatment. The region would also profit from more robust membrane desalination systems, which maximize recovery, but with a designated focus on easy operation and automation.

Capacity Development

In addition to the Handbook, the authors have met with project partners in Jordan to discuss the requirements and challenges inherent in the operation of small-scale desalination plants in the region, based on the experience with the pilot plant near Karameh. These meetings also included a short report with a technical and an economic assessment of operation.

Publications

O. Jung, F. Saravia, H. Horn, E. Al-Karablieh, M. Shadfan, A. Marei (2018): Handbook on Brackish Water Usage in Water-Scarce Regions – The Jordan Valley. – https://wasserchemie.ebi.kit.edu/english/918_3174.php

B.4 Treatment performance and suitability of EU-Certified DWWT-technologies treating wastewater representative for Jordan

Contributing partners	UFZ, PIA
Contributing authors	Khaja Z. Rahman, Elmar Dorgeloh, Peter Mosig, Marc Breulmann, Manfred van Afferden
Key words	Certification, decentralized wastewater treatment (DWWT), treatment performance

B.4.1 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 (class 1: 20 BSB- 30 TSS - 20 TN)
- 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

- Training for O&M personnel
- Declaration of O&M parameters in Arabic

B.4.2 Starting point, objectives, approaches

Starting point and objectives

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 ‘strong’ (e.g. BOD_5 > 500 mg/L) which is due to water scarcity and thereby low water consumption (ca. 40-70 L/capita/day). EU-certified smaller treatment systems are not automatically designed and tested to purify such strong wastewater containing high concentrations of BOD_5, ammonium, phosphorus etc.

Methodology

This study compared the treatment performance and suitability of conventional DWWT-technologies treating wastewater representative for 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 B.4-1 - 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 B.4-1 - left).

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.

Figure B.4-1: *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.

B.4.3 Results

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 BOD_5 and COD removal of 99% and 97%, respectively (Figure B.4-3).

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 B.4-2 - right).

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

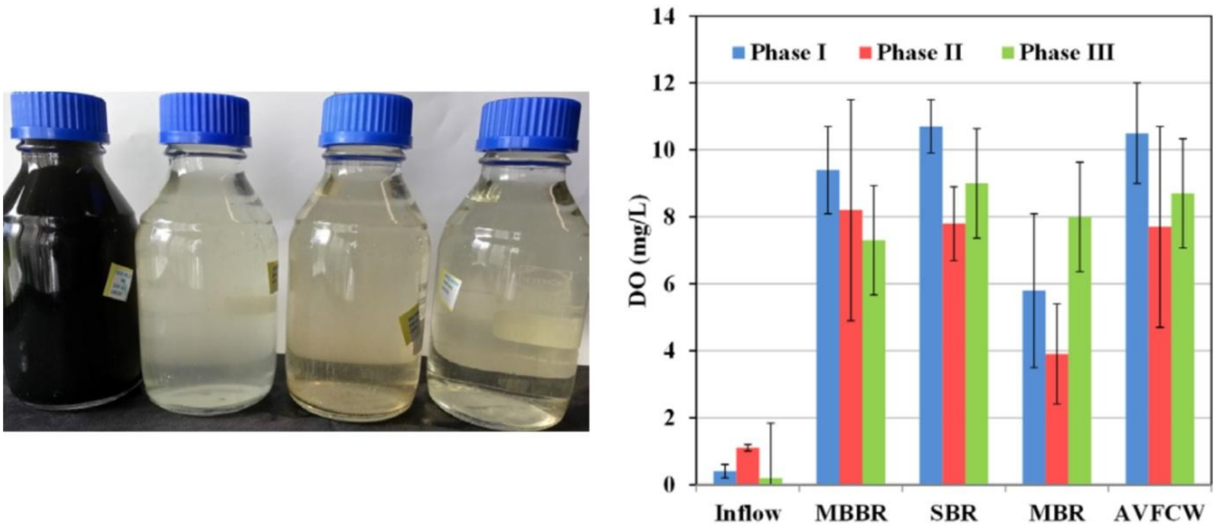

Figure B.4-2: *Left:* High strength wastewater influent (extreme left) and finally treated effluents collected from selected DWWT-technologies. *Right:* DO inflow and outflow concentrations for different treatment systems in three experimental phases.

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 certification system should also include the organizational framework as well as the certification of the O&M personnel.

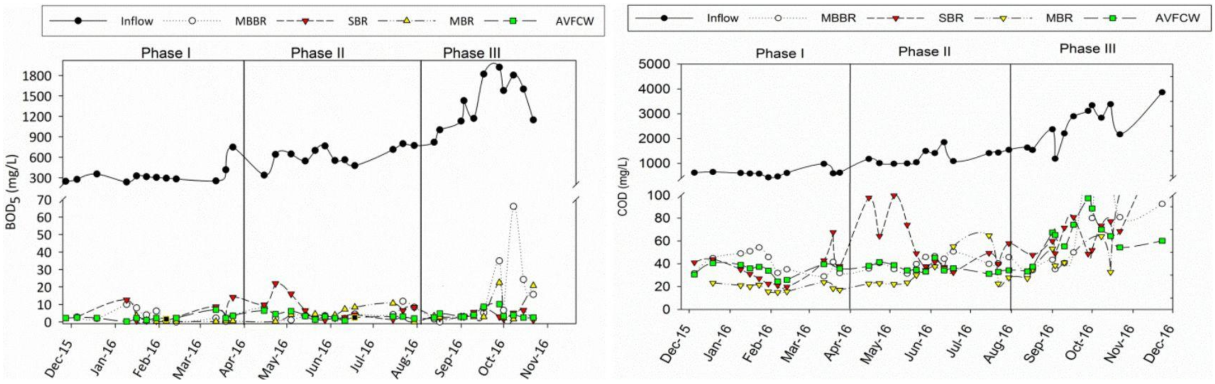

Figure B.4-3: Mean inflow and outflow concentrations of BOD_5 (left) and COD (right) that were observed for different technologies in three experimental phases.

Further Research Needs

The two main future research needs are:

1. Definition of the Jordanian post-certification process for EU-certified DWWT-technologies (<50PE),
2. Proposal of a Jordanian certification process for engineered DWWTPs for up to 500 PE.

Capacity Development

The “9th NICE Steering Committee Meeting” on certification of DWWT-technologies was organized in Jordan on 06th November, 2016.

A meeting with GIZ, BORDA and UFZ on the future of DWWM in Jordan with a special focus on certification systems was coordinated.

Publications

Al-Saadi S., K.Z. Rahman, P. Mosig, M. van Afferden, R.A. Müller (2017): A study on the effects of different organic loads (BOD_5) on treatment performance of four selected small wastewater treatment plants. – International IWA Conference on Sustainable Solutions for Small Water and Wastewater Treatment Systems (S2SMALL), Nantes, October 24, 2017.

Al-Saadi S., K.Z. Rahman, P. Mosig, M. van Afferden, R.A. Müller (2018): The Effect of Influent Characteristics on the Performance of Vertical Flow Constructed Wetland. – IWA Specialist Conference on Wetland Systems for Water Pollution Control. 30 September – 4 October 2018, UPV, Valencia, Spain.

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MASSOUD, M.A., A. TARHINI, J.A. NASR (2009): Decentralized approaches to wastewater treatment and management: Applicability in developing countries. – Journal of Environmental Management, 90, pp. 652-659.

B.5 Research Activities on DWWT-systems at pilot scale

Contributing partners	ATB, Bauer, NAW, BAU, UFZ
Contributing authors	Jaime Nivala, Johannes Boog, Manfred van Afferden, Nabil Wakileh, Thomas Gester, Bassim Abbassi, Naser Almanaseer, Stephane Prigent, Roland A. Müller
Key words	Aerated treatment wetland, French-type wetland, treatment performance, DWWT

B.5.1 Key findings

Pilot studies on the optimization of decentralized wastewater treatment technologies were carried out in Germany (research infrastructure: Langenreichenbach) and Jordan (research infrastructure: Fuheis). The main products are briefly presented below.

- Construction of four treatment systems in Jordan: 1) actively aerated horizontal filter, 2) raw wastewater filter + vertical filter (French system), 3) raw wastewater filter + actively aerated horizontal filter, 4) load controlled SBR (Puroo);
- High removal rate of nitrogen and pathogens;
- Significant reduction of sludge (zero-sludge);
- Integration of two aerated filter systems (developed in Germany and tested in Jordan) into the new German standard DWA-A 262: "Principles for dimensioning, construction and operation of sewage treatment plants with planted and unplanted filters for treatment of domestic and municipal wastewater";
- The scientific results on process understanding, design and optimization of ecotechnologies in Langenreichenbach have been published in more than 30 publications.

B.5.2 Starting point, objectives, approaches

Starting point and objectives

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 2010 a “Research and Demonstration Site” started its operation in Fuheis, Jordan. At the multifunctional site, 13 different pilot-scale treatment systems are operated with real wastewater. Safe reuse of treated wastewater is optimized and demonstrated in agricultural and garden plots. Furthermore, the site serves as a center for hands-on education at university level, and capacity development for technicians, planners and decision makers.

In addition to the site in Jordan, extensive research activities for developing new eco-technologies for wastewater treatment have been carried out at the UFZ research infrastructure in Langenreichenbach. The research facility counts with installations for 15 different pilot plants operated with real domestic wastewater and enables a comparison of treatment efficiencies from different treatment technologies.

Aerated Treatment Wetland (UFZ)

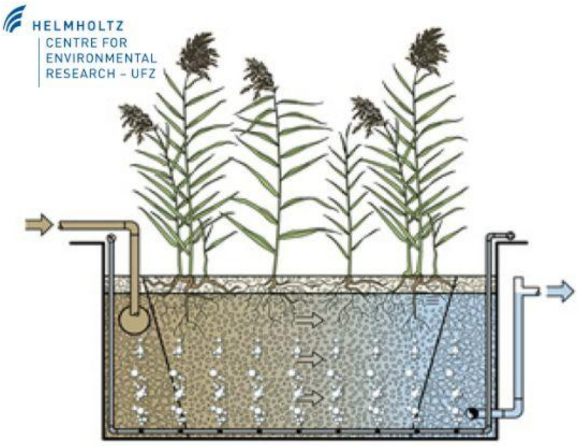


Figure B.5-1: Aerated Treatment Wasteland (UFZ)

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

Modified septic tank (WAKILEH)

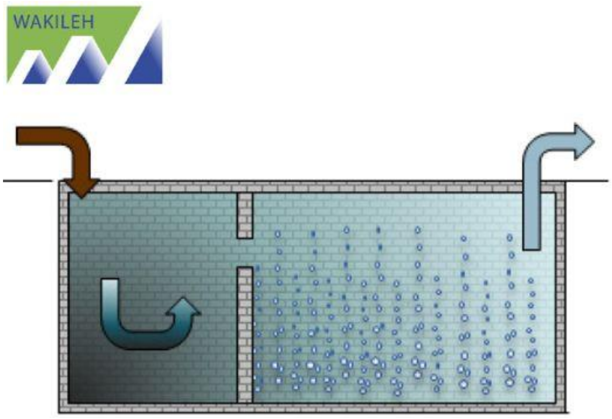
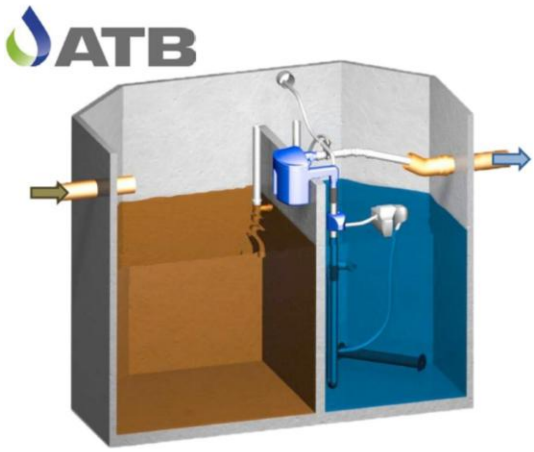
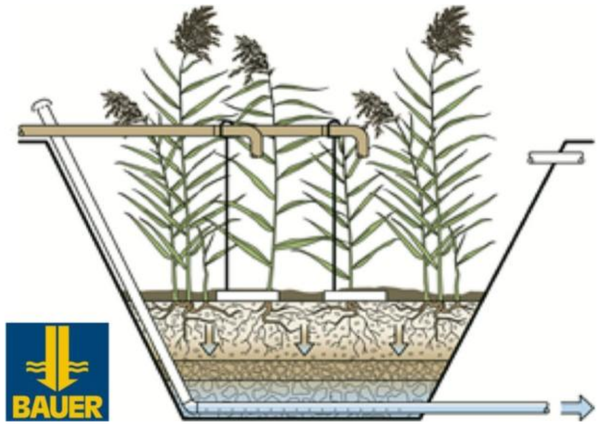


Figure B.5-2: Modified Septic Tank (WAKILEH)

- Combined anaerobic and aerobic treatment
- Low operation and maintenance requirements
- Compact design

The objective within the SMART-MOVE project phase was to design, construct and optimize pilot-scale aerated and French-type wetlands as well as sequencing batch reactors (SBR PUROO, ATB) with the intension to develop DWWT systems that efficiently remove organic carbon, total nitrogen and pathogens while on-site managing produced sludge. Furthermore, monitoring of already existing treatment systems was continued. Within SMART-MOVE the conducted research focused on the treatment systems as depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.** Figure B.5-4.

Load-controlled SBR (PUROO, ATB)	**French-type Treatment Wetland**
 Figure B.5-3: Load-Controlled SBR (ATB)	 Figure B.5-4: Raw Wastewater Filter (BAUER)
• Combined secondary treatment & disinfection • Compact & energy efficient design • Simple installation	• Combined sludge & wastewater treatment • Robust and resilient treatment • Alternating operation allows sludge to turn into compost

The wastewater treatment systems at the Jordanian and German research sites include the following technologies:

- Sequencing- (SBR) and Continuous-Batch Reactors (CBR) and load driven SBR (PUROO),
- Modified Septic Tanks (activated sludge and fixed bed type),
- Membrane Bioreactor (MBR),
- Sludge Dewatering Reed Bed and Anaerobic Bioreactor,
- Eco-technologies: Vertical flow, horizontal flow, aerated and not aerated, planted and without plants, with recirculation and without recirculation, Raw Wastewater Filter.

Overall, the research conducted at the facilities focused on:

(i) technology optimization & adaptation,
(ii) nutrient recycling,
(iii) pathogen removal,
(iv) wastewater reuse,
(v) sludge management,
(vi) groundwater recharge,
(vii) resilience of carbon and nitrogen removal,
(viii) oxygen transfer in aerated treatment wetlands.

B.5.3 Results

The SBR with load-driven operation cycles (SBR-PUROO) and the ecotechnologies (Aerated and French-type treatment wetland) were built in cooperation of the German companies ATB Water GmbH (ATB), Bauer Resources (Bauer) and the Jordanian company Wakileh & Contracting (NAW).

The newly built and monitored SBR and ecotechnologies exhibit comparable treatment performance to studies from temperate climates and show that aerated and French-type treatment wetlands, as well as demand-driven SBR systems, are suitable technologies for decentralized wastewater treatment in arid and semi-arid regions such as Jordan. The ecotechnologies have been proven as more robust as the SBR, which requires consistent maintenance (sludge level management) for a reliable operation. However, the robustness comes at the cost of a larger land area requirement compared to the SBR. The treatment performance of the new systems is summarized below and in Figure B.5-5:

SBR-PUROO

- Effluent re-use for a) Discharge to wadis, streams or water bodies and b) Reuse class B Irrigation of fruit trees, sides of roads outside city limits, and landscape
- Consistent maintenance necessary
- Optimization potential for NH4-N removal
- Compact design favors use if land availability is critical

Aerated Treatment Wetland

- Effluent re-use for a) Discharge to wadis, streams or water bodies and b) Irrigation of fruit trees, sides of roads outside city limits, and landscape
- Aeration scheme should be adapted to improve NO_3-N removal
- High process robustness
- Low operation and maintenance requirements

French-type + Aerated Wetland

- Complies to Jordanian Standards for a) Discharge to wadis, streams or water bodies and b) Reuse Class B for irrigation of fruit trees, sides of roads outside city limits, and landscape
- Includes on-site sludge management by production of compost from sludge accumulated on the first stage (raw wastewater filter)
- Optimization potential of the aeration scheme for the second stage (aerated wetland) to improve NO3-N removal
- High process robustness
- Low operation and maintenance requirements

French-type Treatment Wetland

- Does not fully comply with the Jordanian Discharge and Reuse class B - Standards because of elevated E-coli concentrations in the effluent of the second stage.
- Includes on-site sludge management by production of compost from sludge accumulated on the first stage (raw wastewater filter)

- Optimization potential regarding E-coli removal
- High process robustness
- Low operation and maintenance requirements

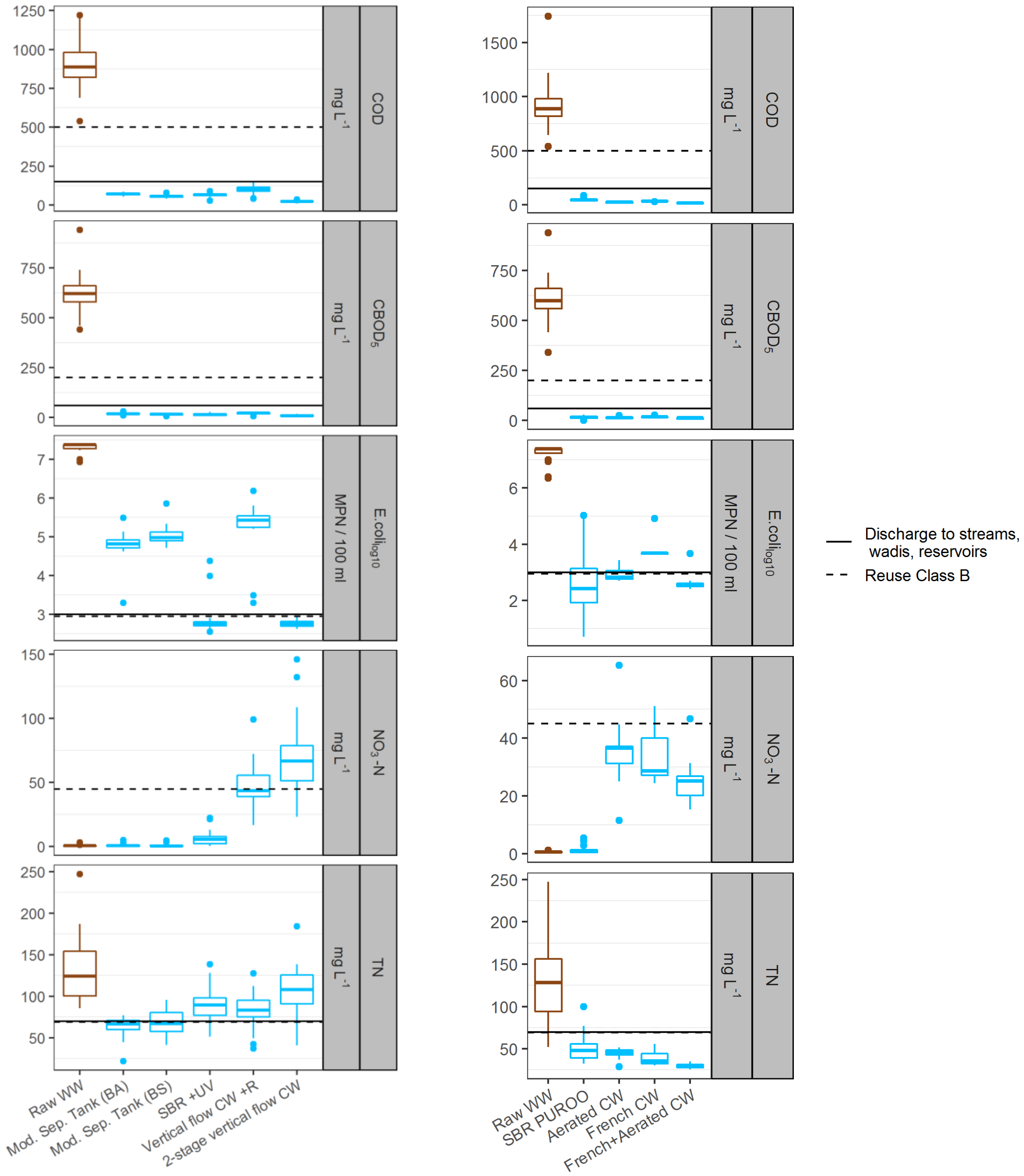


Figure B.5-5: Influent (Raw WW) and effluent concentrations of pilot-scale treatment systems at the "Research and Demonstration Site" in Fuheis compared to the Jordanian reuse standards: a) Discharge to wadis, streams or water bodies; b) Reuse class B (Irrigation of fruit trees, sides of roads outside city limits, and landscape) (EEA 2014). *Left:* Pilot-scale treatment systems constructed in the first phase of the SMART Project. *Right:* Newly built treatment systems

Two technologies developed at the research site in Langenreichenbach and tested in Jordan (Figure B.5-6 - right) were integrated into a new German standard (DWA-A 262, Figure B.5-6 - left) for the design of ecotechnologies for (DWWT). The new standard defines state of the art technologies and can be used as a basis for authorities to implement DWWT systems.

Further research has been conducted on process understanding, design and optimization of ecotechnologies at Langenreichenbach. The related scientific results have been published in more than 30 publications as indicated in the section *Publications*.

Further Research Needs

Future research should focus on investigating the flexibility of selected treatment technologies for providing defined water qualities for different reuse options (e.g. high and low nutrient concentrations).

With perspective to upcoming guidelines for wastewater reuse, the treatment performance of selected technologies should be characterized and optimized for the removal of micropollutants and the reduction of negative toxic effects for direct reuse of the effluent.

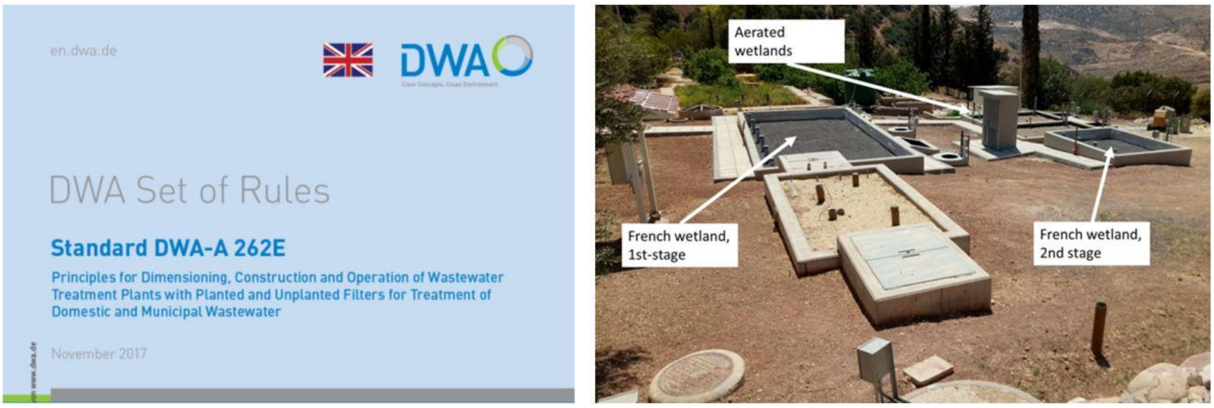


Figure B.5-6: ***Left:*** **English version of the new DWA-Standard DWA-A-262E.** ***Right:*** **Construction of new DWWT-systems at Fuheis.**

Capacity Development

The new German Standard DWA-A 262 was translated into English in order to improve its impact at international level.

Publications

The scientific results of the SMART-MOVE projects on DWWT-systems at pilot scale have been published in or submitted to the following scientific journals:

ISI-indexed publications

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NOWAK J., VAN AFFERDEN M., ALBOLD A., BERNHARD K., FEHR G., GALANDER C., HASSELBACH R., HEISE B., KÜHN V., KUNST S., LANGERGRABER G., MOLLE P., NIVALA J., RUSTIGE H., STOCKBAUER M. (2016): The new draft German constructed wetland guideline for treatment of domestic and municipal wastewater. In: Gajewska, M., Matej-Lukowicz, K., Wojciechowska, E. (Eds.), Proceedings of the 15th IWA Specialized Group Conference on Wetland systems for Water Pollution Control. – Conference Proceedings Volume 2, 4-9 September 2016, Gdansk, Poland, pp.745-746; ISBN: 83-60261-14-8.

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B.6 Real-Scale Implementation of Decentralized Wastewater Treatment and Reuse Systems

Contributing partners	ATB, Bauer, NAW, BAU, UFZ
Contributing authors	Nabil Wakileh, Thomas Gester, Jaime Nivala, Johannes Boog, Manfred van Afferden, Bassim Abbassi, Naser Almanaseer, Stephane Prigent, Roland A. Müller
Key words	real scale DWWTPs, operation and maintenance, reuse

B.6.1 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.

B.6.2 Starting point, objectives, approaches

Starting point and objectives

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 Resource 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.

Methodology

The SMART-Projects have 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 B.6-1.

The installed technologies include:

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

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.

Figure B.6-1: ***Left:*** **Construction of a Modified Septic Tank (Aerated Fixed Bed Reactor).** ***Right:*** **Load-controlled SBR (PUROO).**

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.

Figure B.6-2: ***Left:*** **Subsurface irrigation system for treated wastewater.** ***Right:*** **Wastewater treatment plant at Princess Rahmeh College (Aerated Horizontal Filter).**

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 B.6-2 - right).

The reuse of treated wastewater for some of the full-scale systems is accomplished by subsurface irrigation systems (Figure B.6-2 - left), or, if the treatment system was equipped with an additional disinfection unit, the treated effluent could be directly used for unrestricted surface irrigation.

B.6.3 Results

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 (Figure B.6-3).

In general, decentralized wastewater treatment technologies have been demonstrated to be an appropriate solution for 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
- Real-scale DWWTP require regulated and regular O&M activities
- Privately owned DWWTP require a considerable co-operation of the private site-owner
- Private owners may not be aware of the critical situation of water scarcity and the relationship to wastewater treatment
- Private owners may not be aware of 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

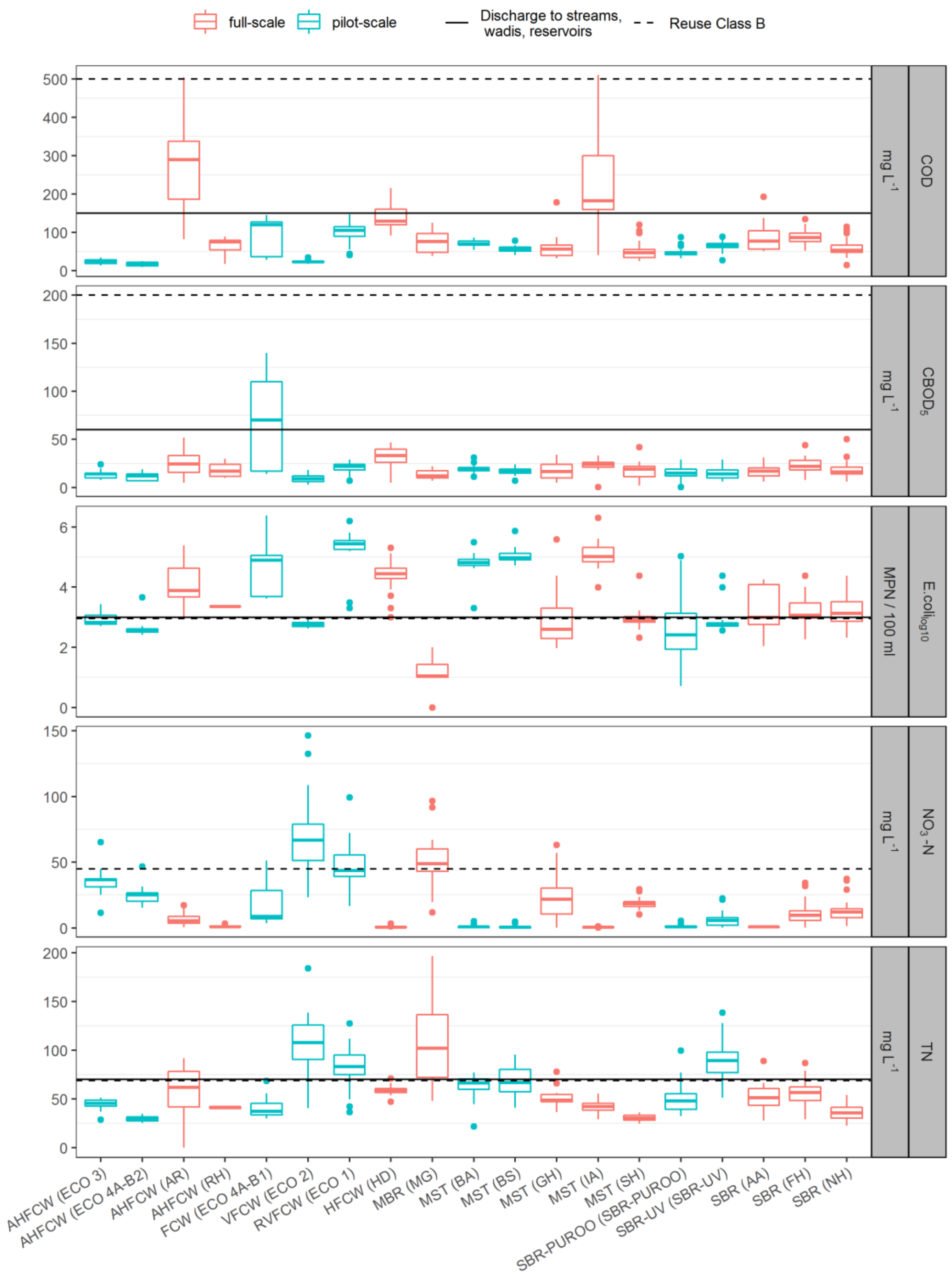

Figure B.6-3: Effluent concentrations of pilot and real-scale treatment systems during June 2016 to June 2018. Jordanian reuse standards: a) discharge to wadis, streams or water bodies; b) Reuse class B (Irrigation of fruit trees, sides of roads outside city limits, and landscape) (EEA 2014).

Further Research Needs

In Jordan reuse regulations are still limited to large reuse schemes for an indirect reuse of "mixed water" that depends on mixing from effluents of centralized WWTPs with surface water. One of the main bottlenecks related to the direct reuse of treated wastewater from DWWTPs is the institutional fragmentation of responsibilities.

For further promoting acceptance and implementation of DWWTPs integrated management concepts for direct reuse and sanitation safety planning should be included for the whole food chain: DWWTP, reuse system, farm handling, marketing and consumer.

Capacity Development

For the implemented real-scale treatment technologies the involved companies conducted a Capacity Development Program addressing a) owners, b) O&M company and c) authorities (WAJ, MWI). Owners of the new systems were trained in routine control measures and practical operation for both the wastewater treatment and reuse system. With the support of the German "technology providers" a Jordanian company established a specific O&M scheme for each of the new technologies. The authorities have been informed in detail on the installed systems and treatment performance.

B.6.4 References

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Klinger, J., N. Goldscheider, N. & H. Hötzl (2015): SMART-IWRM-Sustainable Management of Available Water Resources with Innovative Technologies-Integrated Water Resources Management in the Lower Jordan Rift Valley: Final Report Phase II, KIT Scientific Publishing.

B.7 Competence Facility for Decentralized Wastewater Management

Contributing partners	BDZ, BAU, UFZ
Contributing authors	Alena Lepilova, Marcela Muñoz Escobar, Ruth Goedert, Daniel Gieseler, Naser Almaneseer, Manfred van Afferden
Key words	training concept, education concept, competence facility, DWWM

B.7.1 Key findings

- A detailed SWOT analysis (Strengths, Weakness, Opportunities, Threats) has been conducted as the core element of the Competence Facility for Decentralized Wastewater Management.
- The organizational design and a funding strategy have been defined for the Competence Facility.
- An educational concept for hands-on education at university level is proposed.
- A capacity development program for technicians, planners and decision makers was developed.

B.7.2 Starting point, objectives, approaches

Starting point and objectives

With the objective to promote Decentralized Wastewater Treatment and Reuse systems in Jordan, the "SMART – Research Facility" was constructed in Fuheis near Amman. The site was funded by the German SMART project for a Sustainable Management of Available Water Resources with Innovative Technologies and started operation in 2010.

Different wastewater treatment technologies are operated at the site and special focus is put on ecotechnologies as a suitable technology for decentralized wastewater treatment. In addition sequencing batch reactors, extended aeration systems and sludge treatment technologies are operated with real wastewater.

In the frame of the SMART-MOVE project, it was aimed to transform the site from a research-oriented project site to a national Competence Facility for DWWM providing educational and research opportunities for the region.

Methodology

A SWOT analysis (strengths, weakness, opportunities and threats) was used in order to get an impression of the current situation of the site and to formulate realistic strategies for its future successful operation. Furthermore, the SWOT analysis allowed delivering insights that helped to formulate a clear vision and mission for the planned Fuheis Competence Facility (Figure B.7-1) for DWWM.

Based on the SWOT analysis and in cooperation with the national stakeholders an organizational structure, a funding strategy and an educational concept was developed.

Figure B.7-1: ***Left:*** **Competence Facility for DWWM in Fuheis.** ***Right:*** **Site sketch of the Competence Facility for DWWM in Fuheis.**

B.7.3 Results

The results of the SWOT analysis showed that the current situation of the Competence Facility for DWWM Fuheis requires a clear formulation of strategies in organization, funding and education in order to guarantee a successful operation in the future.

The proposed organizational design for the Competence Facility for DWWM Fuheis includes the coordination of capacity development (CD), operation and maintenance, as well as the coordination of the research activities. With respect to CD measures, the organizational design was combined with a group of internal and external experts to create a pool of professionals on the topic of DWWM that can conduct the trainings and workshops planned for the Competence Facility for DWWM Fuheis.

With respect to the identified financial requirements, a step- by- step implementation of the new organizational structure was recommended and potential revenues from courses and other activities over a horizon of five years were calculated. Based on the calculations of the future costs and revenue sources, a combination of funding sources was identified as the most feasible option for the financial sustainability of the Competence Facility for DWWM Fuheis. Firstly, a basic funding for operation and maintenance (O&M) and the current personnel of the site is needed. This can be best achieved if the Competence Facility will be integrated into the Al-Balqa Applied University campus, and the O&M and personal costs of the site are covered by BAU. Secondly, a complementary funding source can be composed of international research programs and funding derived from capacity development activities to which fees can be charged (training courses, guided tours, renting the site for training activities).

The educational training concept highlighted the identification of the training needs in DWWM in Jordan (regulatory, managerial and technical aspects) which could be covered by training activities at the Competence Facility for DWWM Fuheis. Based on these training needs an outline for technical training modules was developed. The content and duration of this outline can be adapted according to the target groups for the respective trainings. In addition, the strategy included the identification of the relevant target groups. The educational concept was further elaborated in the activity "development of an educational concept for technical experts", based on a theoretical-didactic framework in capacity development for DWWM.

The educational concept for technical experts was developed by using exemplary training materials. As complementary material of the educational strategy of the concept for sustainable implementation of the Competence Facility for Decentralized Wastewater Management Fuheis the topics for two specific training components were agreed between BDZ and Al-Balqa University. The components were designed and written based on BDZ expertise and the existing DWWT technologies at the Competence Facility for DWWM in Fuheis:

- Component I: Operation of Decentralized Wastewater Treatment Technologies (DWWT)
- Component II: Maintenance and Monitoring of DWWT

Both components consist of several modules, case studies and practical exercises, which elaborate in detail each topic and incentive an analytical approach and apply technical solution skills for a real problem.

Figure B.7-2: Impressions from the Capacity Development program at DWWT Competence Facility Fuheis: (a) routine analysis, (b) training on correct sampling techniques, (c) training on O&M, (d) handing over of attendance certificates.

Further Research Needs

- Currently the land of Fuheis site belongs to the Water Authority of Jordan (WAJ) and a transfer of the property to the Al-Balqa University is crucial. Once this step is achieved, it would be more feasible for the University to cover the financial costs of the Fuheis site as part of running the campus.
- Accreditation of the Competence Facility for training on DWWM by MWI
- Definition of a basic package of services is recommended (defined annual technical training courses of 2 or 3 days, guided tours)
- Certifying of training courses to be offered
- It is recommended to design and implement a concrete marketing strategy that promotes CD-activities in Jordan and the region - e.g. online advertisement, cooperation with other Universities, distributing brochures of Fuheis at water sector events, etc.
- Networking and public relations

Capacity Development

The proposed teaching components based on various CD and training courses that have been organized and conducted at the Competence Facility in Fuheis by Al-Balqa Applied University (Table B.7-1).

Table B.7-1: Capacity Development and training courses at the Competence Facility for DWWT in Fuheis.

Date	Organization	Participants
03.03.2015	Public security management buildings	10
2015	Students of Al-Balqa Applied University	11
15.11.2015	GIZ-Group	15
2016	Arava Institute for Environmental Studies (Israel)	4
13.11.2016	GIZ-Group: Decentralized Wastewater Management for Adaptation to Climate Change in Jordan (ACC Project)	6
17.05.2017	Omani group (Haya Water and Government)	10
07.10.2017	Students of Al-Balqa Applied University	7
20.01.2018	MWI operators training	25
12.02.2018	Technical training course on DWWT Solutions	22

B.8 National Implementation Committee for Effective Integrated Wastewater Management in Jordan – NICE

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-MOVE project to sustainably implement IWRM approaches with a special focus on DWWM. Since the NICE project is still running, the results presented here should be considered as a preliminary overview. Detailed results can be found in the specific NICE project reports.

Contributing partners	UFZ, MWI
Contributing authors	Mi-Yong Becker (née Lee), Manfred van Afferden, Marc Breulmann, Anwar Al-Subeh, Ali Subah, Roland A. Müller
Key words	Policy advice, participation, transdisciplinary, DWWM

B.8.1 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 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 proposed:
  - Hot spots of groundwater contamination from 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.

B.8.2 Starting point, objectives, approaches

Starting point and objectives

The Ministry of Water and Irrigation (MWI) and the SMART joint research project, funded by the German Ministry of Education and Research (BMBF) jointly prepared and support the implementation process of integrated wastewater management systems across rural and urban settlement areas.

In 2013, the Ministry of Water and Irrigation had 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.

Methodology

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 B.8-1 depicts the structure 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.

Figure B.8-1: Members of the NICE Steering Committee.

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.

B.8.3 Results

These contributions have 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 B.8-2). While being a milestone for Jordan, it is the first policy for decentralized wastewater management in the Arab world.

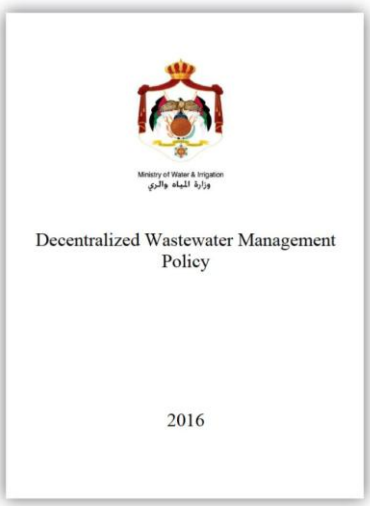


Figure B.8-2: Cover page of the Jordanian DWWM Policy from 2016.

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

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:

- development of a framework for certification of wastewater treatment plants (≤ 5000 PE) and for O&M personnel for integrated wastewater systems in Jordan.
- recommendations for the use of integrated wastewater management concepts towards implementing the SDG 6 reuse target for Jordan.
- development of a draft directive on the use of IWRM concepts in rural and suburban settlements with refugee influx (host communities).

Further Research Needs

Based on the National Policy on Decentralized Wastewater Management, an Action Plan for implementation should be defined that clearly defines and schedules required actions to be taken on legal and administrative provisions, institutions and governance and most important actions concerning future capital investment in decentralized wastewater management infrastructure.

Due to the institutional fragmentation of responsibilities supplementing research has to be conducted on the implementation requirement of directly reusing treated wastewater in DWWT systems.

Capacity Development

Table B.8-1: Various Capacity Development events.

Date	Event	Location
14.05.2017	Coordination Meeting with GIZ, BORDA and UFZ	Amman
24. - 27.07.17	WHO - Regional Training Workshop on Sanitation/ Wastewater Safety Planning	Amman
12.09.2017	DESERVE Consortium Meeting: Das Tote Meer: Umweltforschung am Rande der Extreme; Deutsche Akademie der Naturforscher Leopoldina - Nationale Akademie der Wissenschaften	Halle (Saale)
20.09.2017	Multi Stakeholder Consultation on "Valuing Water" - High Level Panel on Water	Amman
08. - 09.11.2017	Capacity development planning workshop ACC- Project (GIZ)	Amman
06.12.2017	Kick-Off Meeting of the Project: Sanitation solutions for underserved communities in Jordan (BORDA)	Amman
07.12.2017	Coordination Meeting at SESAME: potential connection of SESAME to the wastewater treatment (WWTP) at Princess Rahmeh College	SESAME Balqa
14.01.2017	Wastewater treatment and reuse to reduce scarcity and protection of the Environment in Jordan; Desalination, Diplomacy and Water Reuse in the Middle East (SCARCE)	Amman
06.02.2018	Coordination Meeting with Deputy Head of Development Cooperation; German Embassy	Amman
07.02.2018	Strengthening Capacities for Wastewater Management (CWWM) Planning Workshop (GIZ)	Amman
28.02.2018	Groundwater Vulnerability to Contamination at Landfill Sites in Jordan; Final Workshop	Amman
29.03.2018	Expert Stakeholders Consultation Meeting: Initiative of Establishing a Regional Platform for Excellence in Wastewater Management	As-Salt

Publications

Presentation of the NICE-Project:

LEE, M.Y. (2016): The Way Forward, International Water Conference in Arid Areas. – 13-16 March, 2016, Muscat, Oman.

LEE M.Y. (2015): Decentralized Wastewater Management for Effective Water Resources Protection under Extreme Water Scarcity. – IWA Water and Development Congress & Exhibition, 18 – 22 October 2015, Amman, Jordan.

BREULMANN M., LEE M.-Y., VAN AFFERDEN M., MÜLLER R. (2017): Brief overview of the scope of the NICE Office. – 4th SMART-Move Consortium Meeting, Dead Sea, Jordan.

BREULMANN M., LEE M.-Y. (2018): National Water Strategy and Decentralized Wastewater Management Policy. – Technical Training Course on Decentralized Wastewater Management organized by BDZ and Al Balqa University, Sadeen Hotel Amman, 12th February, 2018, Jordan.

BREULMANN M., LEE M.-Y. (2018): Sludge Management and Reuse. – Technical Training Course on Decentralized Wastewater Management organized by BDZ and Al Balqa University, Sadeen Hotel Amman, 12th February, 2018, Jordan.

BREULMANN M., MÜLLER R.A., LEE M.-Y. (2018): Integrated Wastewater Management in Jordan. – 1st Water Research Forum: Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas, Middle East Desalination Research Centre (MEDRC) Geneva Hotel, Amman, Jordan.

B.8.4 References

MWI (JORDANIAN MINISTRY OF WATER AND IRRIGATION) (2016): The Decentralized Wastewater Management Policy and Summary of the National Framework for Decentralized Wastewater Management in Jordan. – www.mwi.gov.jo.

MWI (JORDANIAN MINISTRY OF WATER AND IRRIGATION) (2016): Summary of the National Framework for Decentralized Wastewater Management in Jordan. – www.mwi.gov.jo.

B.9 Water Fun – hands, minds and hearts on Water for Life!

The results presented here mainly belong to the second 2 phase of the BMBF-funded SMART-Project: “Integrated Water Resources Management in the Lower Jordan Rift Valley” (Funding number: 02WM1080), UFZ-project leader: Prof. Roland A. Müller. Within the third phase of the SMART project (SMART-MOVE), activities related to training and supervision of teachers in Jordan have been continued on a voluntary basis.

Contributing partners	BDZ, UFZ
Contributing authors	Ruth Goedert, Jaime Cardona, Manfred van Afferden
Key words	School education, awareness rising, DWWT, water reuse, hands-on experience

B.9.1 Key findings

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:

- 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

B.9.2 Starting point, objectives, approaches

Starting point and objectives

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 have been 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.

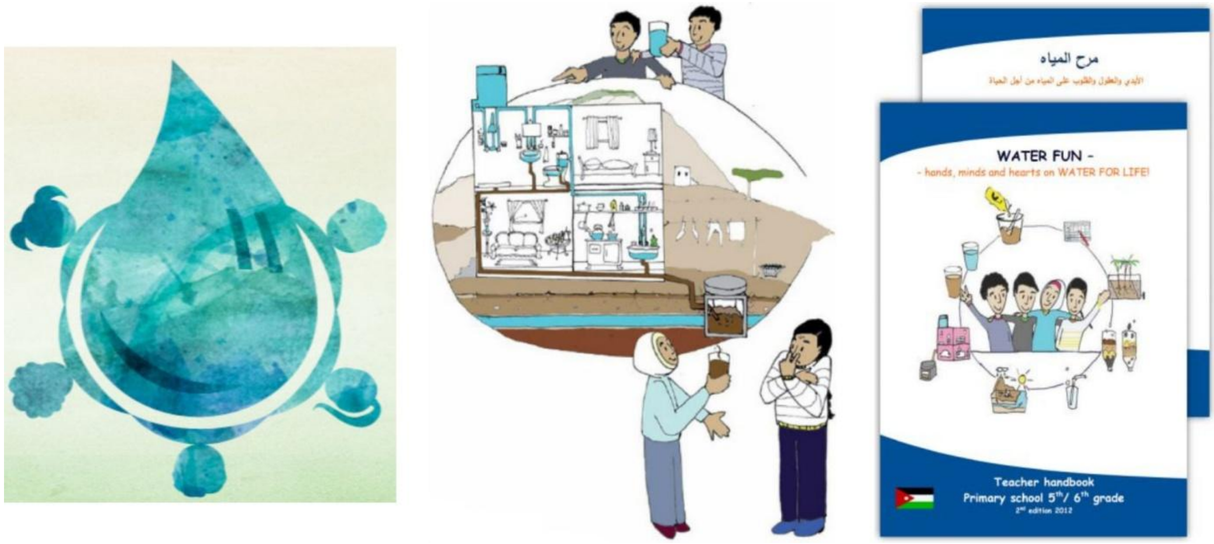


Figure B.9-1: Water fun education program for waste water treatment – *left:* from the Website “http://www.waterfunforlife.de, *middle:* sketch of the urban water circle from the Water Fun teachers handbook (*right*).

Methodology

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.

Figure B.9-2: Conceptual sketches from the teacher's handbook for the practical execution of the proposed experiments.

B.9.3 Results

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.

Figure B.9-3: Class room experiments *left:* water quality testing, *middle:* reuse and *right:* training course for teachers.

Capacity Development

- Training for Jordanian teachers (14) on the teaching unit “Water Fun” at the Demonstration and reuse site on DWWT in Fuheis on the 07 and 08.05.2015
- Communication with teachers that attended the training courses in the second Phase of the SMART-project.

B.9.4 References

Website “Water Fun – hands, minds and hearts on Water for Life!”. – http://www.waterfunforlife.de

GOEDERT, R. et al. (2012): Capacity Development in IWRM: experiences and lessons learned. - World Water Week 2012: Water and Food Security. 27.-31. August 2012, Stockholm, Sweden.

GOEDERT R., J. CARDONA, M. VAN AFFERDEN, B. ABASSI, S. SAMHAN, W. ALI, R. DAOUD, A.R. TAMIMI, A.A. ULEIMAT, R.A. MÜLLER (2012): Water Fun – hands, minds and hearts on Water for Life! Teacher handbook Primary School 5th/6th grade. Leipzig, Germany

C Integrated Planning for IWRM Implementation

C.1 IWRM Concept and WEAP-Application, Cluster West

Contributing partners	RWC, HEC, PHG
Contributing authors	Bernd Rusteberg, Muath Abu Sadah, Abdel Rahman Tamimi
Key words	Water Resources Planning, IWRM Implementation, WEAP, System Resilience

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).

C.1.1 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 to Ramallah;
- In spite of all efforts, significant future water imports into the study area will be required to ensure sustainable development.

C.1.2 Starting point, objectives, approaches

Starting point and objectives

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 C.1-2). The difference in elevation between the lower and upper parts is around 1,000 m. All water sectors present significant and increasing water deficits. The water resources need to be further developed and the 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 in 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 Integrated Management of Water Resources (IWRM).

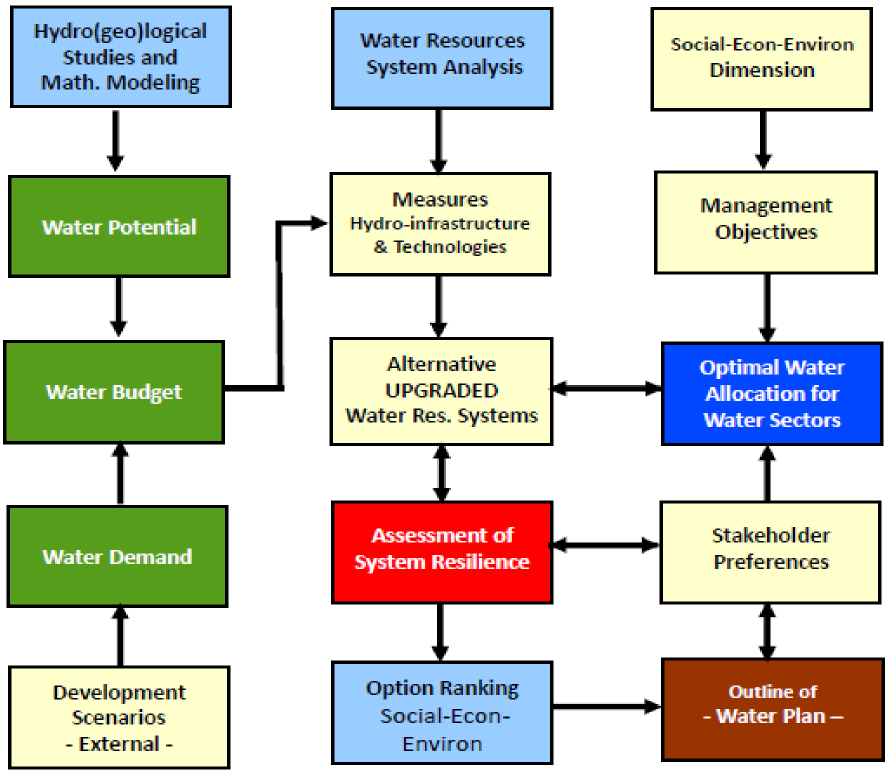


Figure C.1-1: Water Resources Planning Approach (Rusteberg, 2018a)

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 C.1-1 presents a flow chart of the water resources planning approach. The approach has been built on 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.

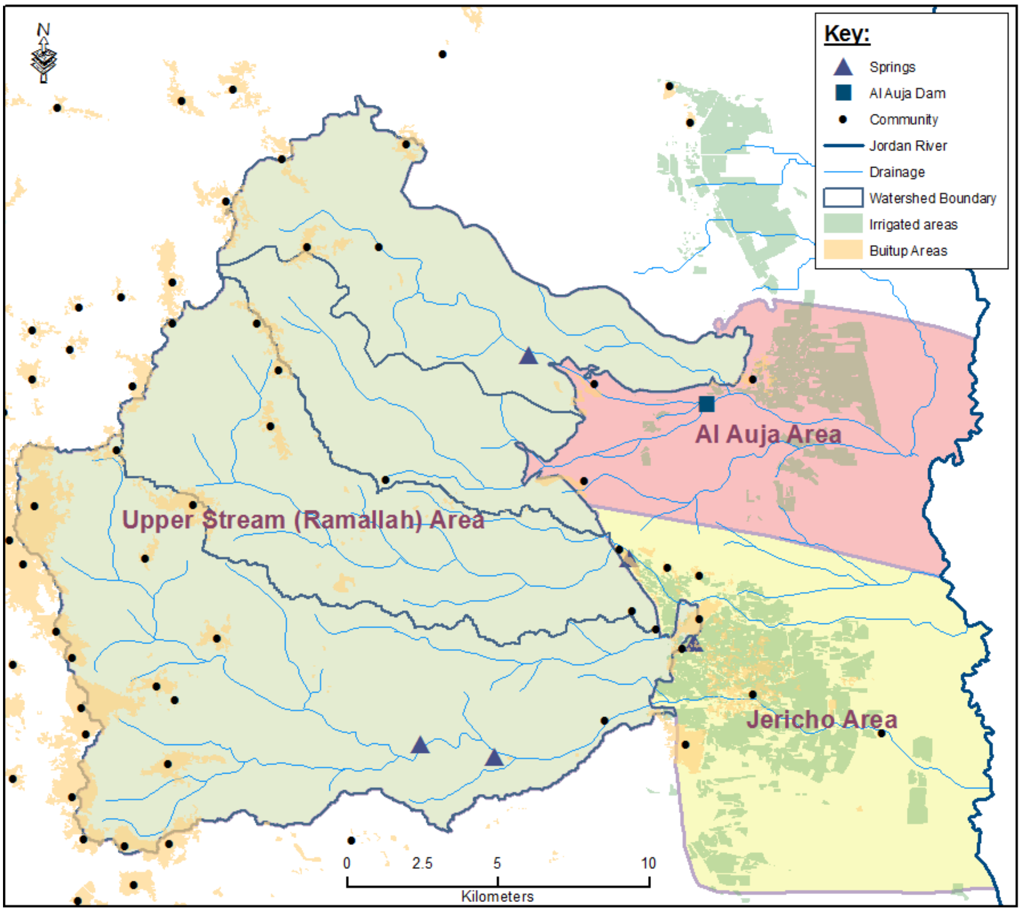


Figure C.1-2: Division of Cluster West in Budget Zones.

Alternative IWRM-strategies are being defined as 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 C.1-2 illustrates the division into the so-called Auja Area, the Jericho Area and Ramallah (East) Area.

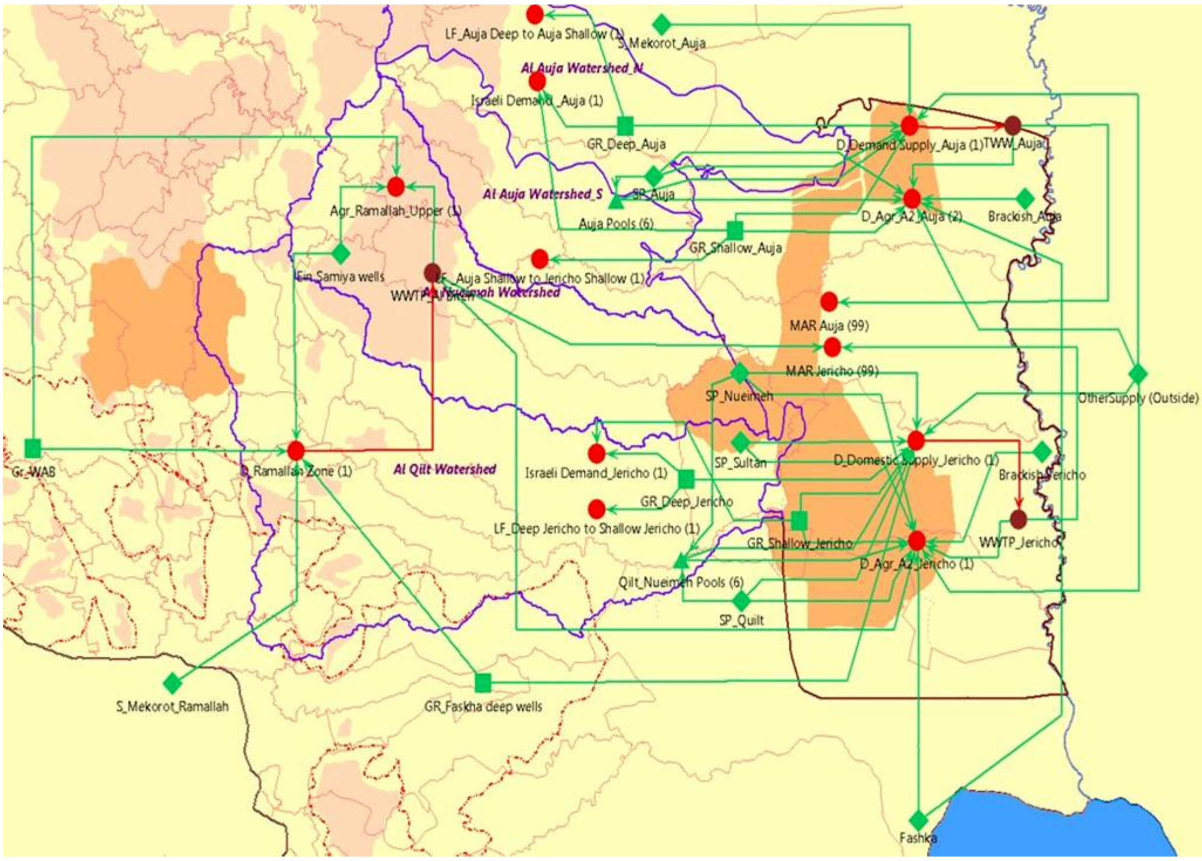


Figure C.1-3: Representation of the Water Resources System at Cluster West with the WEAP model.

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 C.1-3. It already includes the different potential measures for system upgrade according to Table C.1-1.

The identification and dimensioning of the IWRM measures was done in close collaboration with the project partners, as well as with Palestinian stakeholders and decision makers. Table C.1-1 defines a set of alternative IWRM strategies as combined structural measures, with the individual measures 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. Also 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 on the further extension of the irrigated land in the valley around Jericho-Auja to the maximum irrigable area with the next 10 years (RUSTEBERG, 2018a).

Table C.1-1: 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 installations (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

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 the system resilience, taking a moderate and a dry climate scenario into account. The following water supply indicators were considered: Total water supply delivered, un-met 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).

C.1.3 Results

Table C.1-2 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.

Table C.1-2: Average Incremental Cost of structural measures as part of integrated strategies.

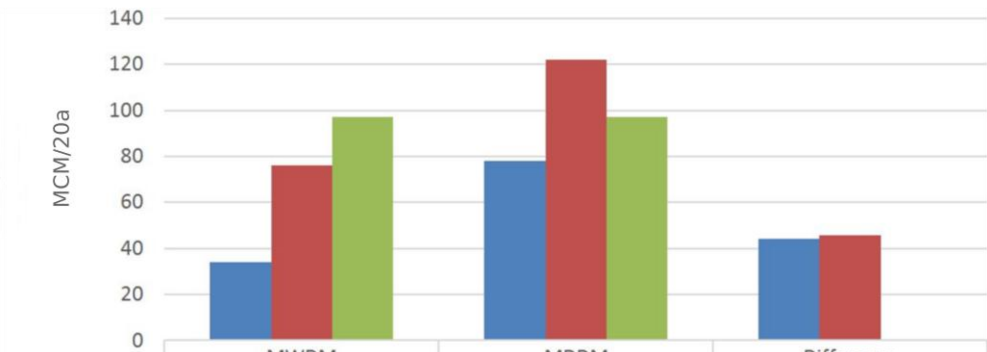
Average Increm. Cost	**IWRM-Measures as part of Integrated Strategies**						
	GW recharge with spring water surpluses	Flood Water Retention to enhance GW recharge	Deep wells in the area	Treated effluent reuse from Jericho WWTP for direct irrigation	Treated effluent import from El-Bireh	Deep Wells at Feshcha and transfer to Ramallah East	Brackish water imports from Feshcha springs *(extra cost for desalination in brackets)*
USD/m³	**0.07**	**0.27**	**0.41**	**0.49**	**0.45**	**0.87**	**0.35** *(0.39)*

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/m³. 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 sub-area 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 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 covered, so that additional water imports into the study area will be necessary to enable sustainable development. According to Figure C.1-4, depending on the climatic conditions, an average of 10 to 15 million m³ (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 C.1-3), 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.



	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 C.1-4: 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.

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 strengthening 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 area around Jerusalem, 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.

Publications

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RUSTEBERG, B., BENSABAT, J., TAMIMI, A., SALMAN, A., AL-KARABLIEH, E., SALAMEH, E., WALTER, F., LANGE, T. & M. SAUTER (2018c): The SALAM Initiative: Concepts and Approaches for the Resolution of the Water Deficit Problem in the Middle East at Regional Scale, SALAM Policy Brief, iwrm-smart-move.de.

RUSTEBERG, B., TAMIMI, A., SADDAH, M. A., WALTER, F., SCHMIDT, S., SAMHAN, S., NOFAL, I., GUTTMAN, Y., LANGE, T. & M. SAUTER (2018d): Comparison of alternative water development and planning options towards sustainable IWRM implementation in the Lower Jordan Valley based on indicator assessment. Conference presentation and abstract, EGU 2018, Vienna.

C.2 Socio-economic and political context of Integrated Water Resources Management in the Lower Jordan Valley

Contributing partners	PHG, RWC, PWA, MoA, HEC, UGOE
Contributing authors	Abdelrahman Tamimi, Bernd Rusteberg, Subhi Samhan, Hazem Kittani, Issam Nofal, Muath Abu Sadah, Torsten Lange
Key words	socioeconomics, institutional IWRM implementation, interministerial IWRM implementation committee

C.2.1 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 and 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 huge 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.

C.2.2 Starting point, objectives, approaches

Starting point and objectives

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.

Identifying the importance of the Lower Jordan Valley 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).

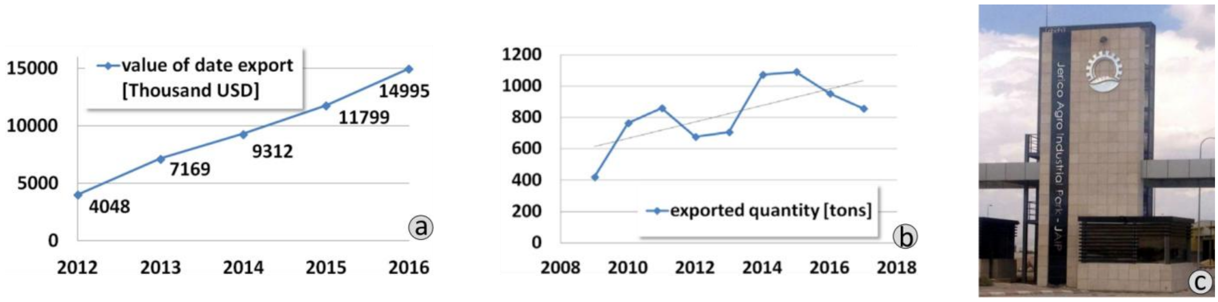

Figure C.2-1: Realized annual exports of agricultural products from the Jordan Valley: (a) value of date exports 2012-2016, (b) quantity of exported agricultural products in tons 2008-2017, (c) Jericho agro-industrial park.

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.

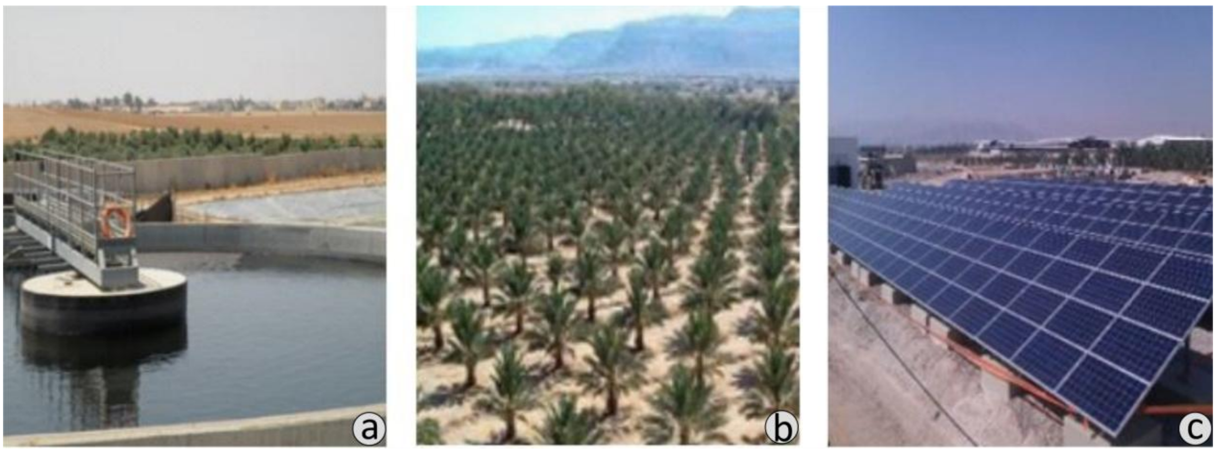

Figure C.2-2: Recent and continuous optimization and intensification of land use and agriculture in the Jericho area, Lower Jordan Valley: (a) Jericho wastewater treatment plant, (b) dates farm, (c) solar energy farm installation of the Jerusalem District Electricity Company in Jericho.

Diagnosis of the situation

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

Methodology

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.

C.2.3 Results

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 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). If implemented, 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.

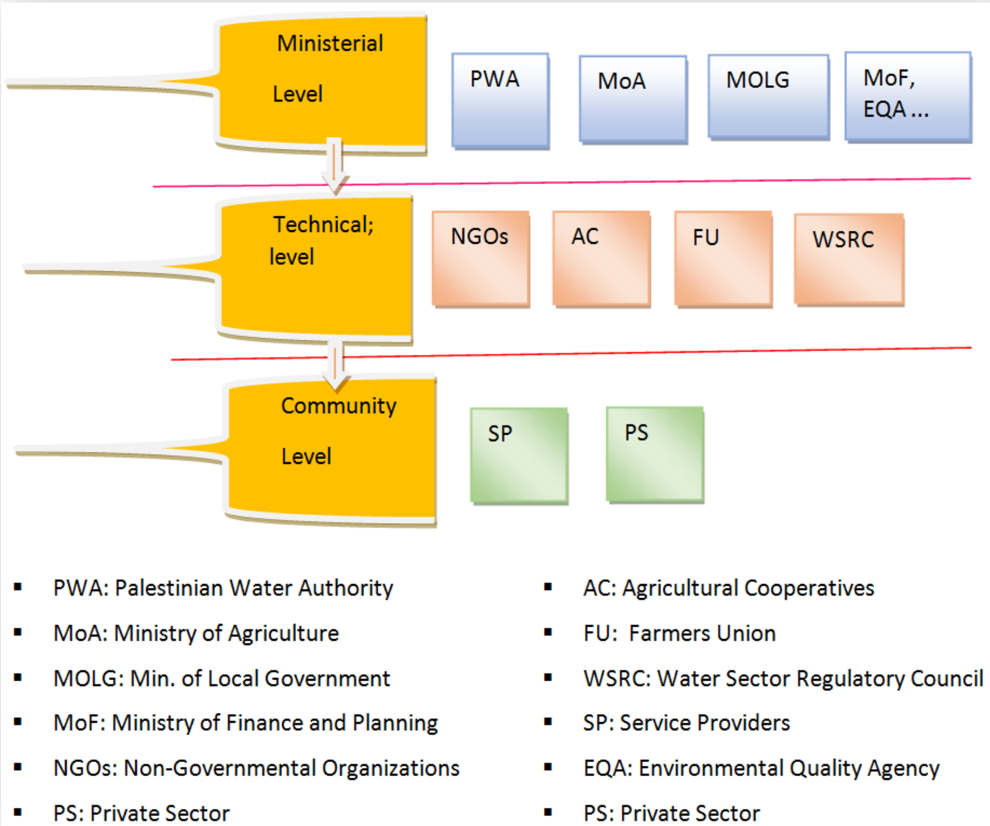

Figure C.2-3 Suggested Structure for the IWRM Implementation Committee in the Palestinian Territories

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.

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.

C.3 Economic assessment of alternative water plans in Jordan

Contributing partners	KIT-HYD, HPW
Contributing authors	Heinz-Peter Wolff, Patrik Frick, Julian Xanke, Jochen Klinger
Key words	Socio economic assessment, water distribution system, Wadi Shueib

C.3.1 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.

C.3.2 Starting point, objectives, approaches

Starting point and objectives

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.

Methodology

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.

C.3.3 Results

Economic assessment of the cost structure of the pumping system for the sections between Deir Alla, Zai WTP and the Dabouq Reservoir

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 C.3-1, 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.

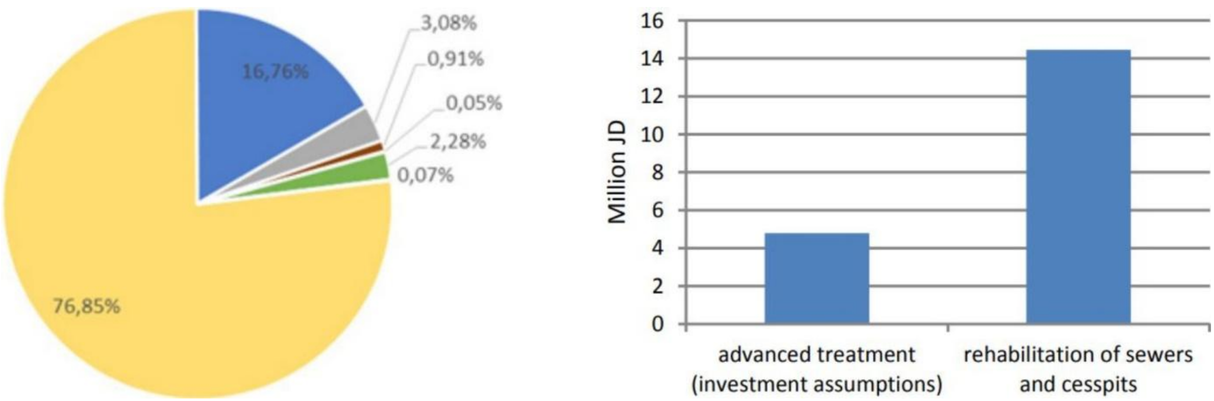

Figure C.3-1: Economic assessment of an alternative and optimized water infrastructure as a water planning component in Jordan – *left:* cost structure of the Deir Alla - Zai WTP pumping system, *right:* cost differences between status quo and alternative solutions.

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 the 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.

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 charges 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 C.3-1, 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.

Further Research Needs

The economic assessment and its accuracy always depend on the quality and availability of the data. In both cases, the calculations were based on a limited data set and therefore further studies would require more detailed surveys in the cost structures, e.g. of water treatment plants or water distribution systems, and take also non-economic aspects into account.

Capacity Development

The collection and evaluation of the relevant data and indicators for the assessment of the results was carried out in exchange with representatives of the Ministry of Water and Irrigation. The methods and results of the studies were presented and handed over to the representatives of the authorities.

Publications

FRICK, P. (2017): Economic Assessment of an adapted water distribution strategy in Jordan. - SMART Move project report.

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

C.4 Water management scenarios for Wadi Shueib using WEAP and MODFLOW models

Contributing partners	KIT-HYD
Contributing authors	Paulina Alfaro, Tanja Liesch, Julian Xanke, Nico Goldscheider
Key words	Numerical modeling, Coupling WEAP-MODFLOW, Irrigation, groundwater over-exploitation

C.4.1 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.

C.4.2 Starting point, objectives, approaches

Starting point and objectives

In order to optimize and strengthen the water system 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.

Methodology

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.

C.4.3 Results

Results show that hydrological conditions (Figure C.4-1), 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%.

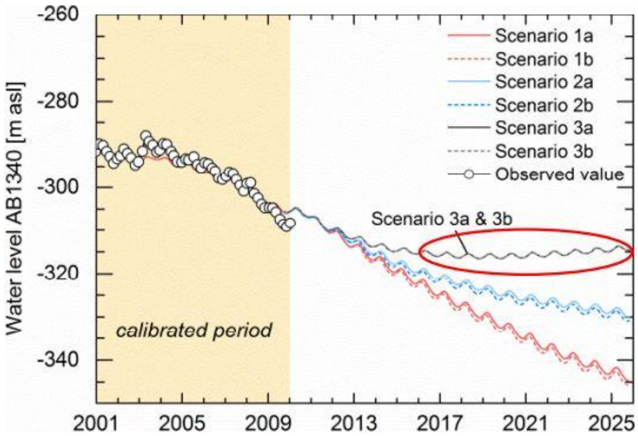

Figure C.4-1: The results of the different hydrological scenarios combined with different agricultural development show that stabilization of the groundwater table can be achieved if irrigation decreases by at least 40% (Alfaro 2017).

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 C.4-2). 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.

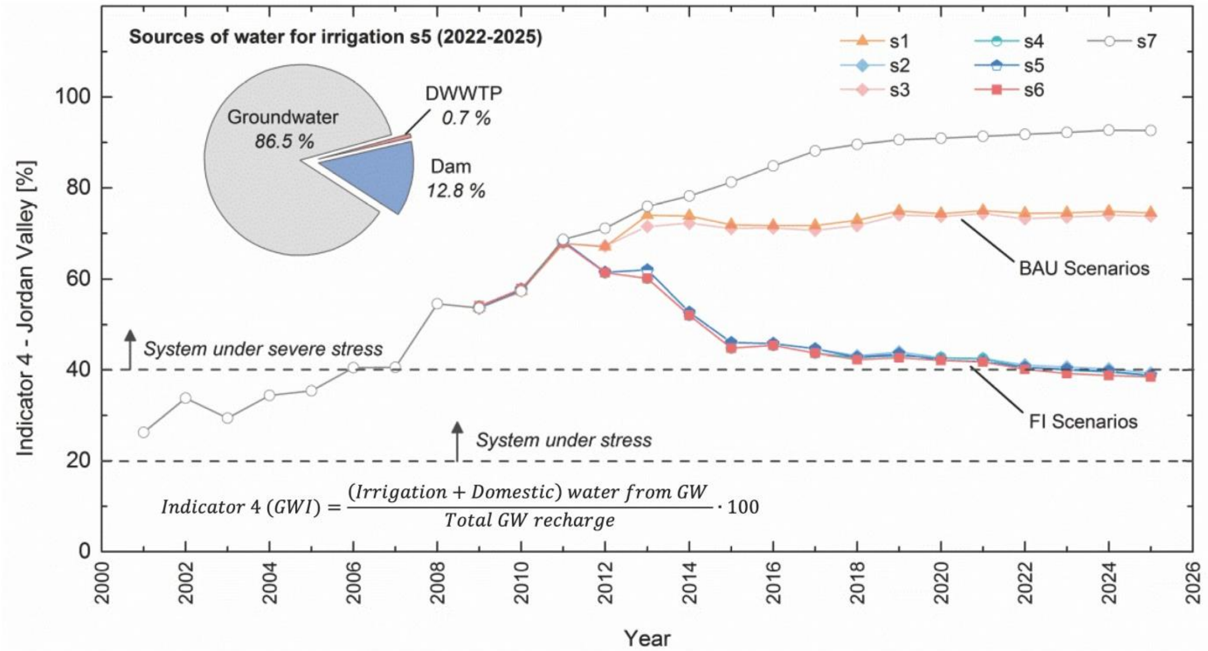

Figure C.4-2: The JV falls under the severe stress line by 2022 through the reduction of groundwater withdrawals with the full implementation scenario plus (full implementation plus scenario; Alfaro 2017).

Further Research Needs

Further research could focus on creating a larger network of hydrogeological monitoring systems and improving the overall hydrogeological understanding of the test site. More detailed data on water use and groundwater abstraction are needed to reduce uncertainties in water modelling.

Further scenario models should also better integrate climate change. It is recommended to include also the influence of other sectors such as energy, climate security and food on the water strategy, which implies moving from an IWRM to a nexus approach (Alfaro 2017).

Capacity Development

The two model applications WEAP and MODFLOW were submitted together with the reports to the MWI for further use. The dataset was also forwarded to the GIZ office in Amman, where WEAP is also used for water resources planning.

Publications

ALFARO, P., T. LIESCH, N. GOLDSCHEIDER (2017): Modelling groundwater over-extraction in the southern Jordan Valley with scarce data. - Hydrogeology Journal, 1–22, doi: 10.1007/s10040-017-1535-y.

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C.4.4 References

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C.5 GIS-based decision support: Assessment of Local Lowest-Cost Wastewater Management Solution (ALLOWS)

Contributing partners	UFZ, BDZ, MWI
Contributing authors	Ganbaatar Khurelbaatar, Mi-Yong Becker (née Lee), Jaime Cardona, Manfred van Afferden, Roland A. Müller
Key words	Decision support, life cycle cost assessment, DWWM, cluster solution, urban development

C.5.1 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, has been extended:

- 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.

C.5.2 Starting point, objectives, approaches

Starting point and objectives

Currently around 40% of the total population of Jordan is not connected to wastewater collection and wastewater treatment and disposal relies on cesspits, which are often managed poorly. 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.

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.

Methodology

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 C.5-1).

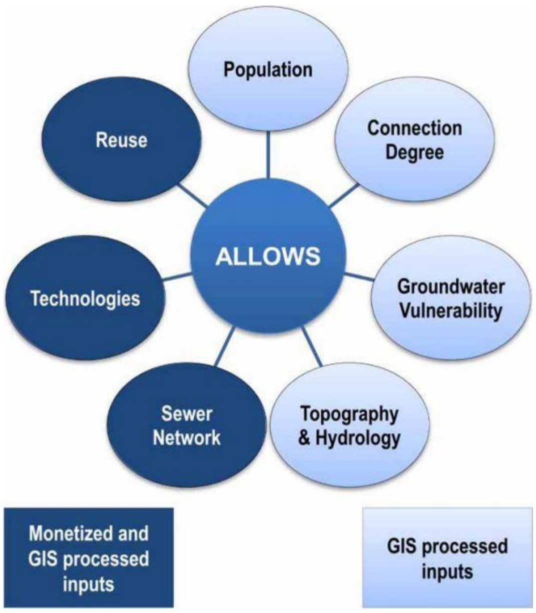
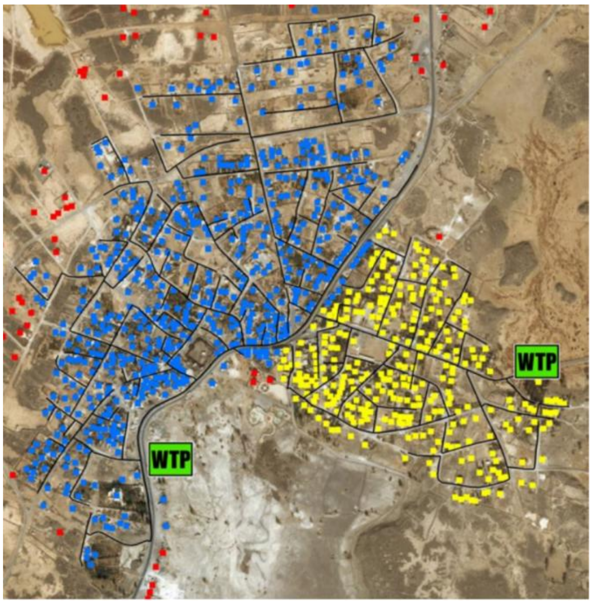


Figure C.5-1: Component scheme of the GIS-based ALLOWS modeling process.

A spatial analysis enables high precision assessment of the current wastewater situation and facilitates the development of possible management scenarios under real conditions (Figure C.5-2). These scenarios are based on hydrology, 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 decision making towards investment in local wastewater solutions.



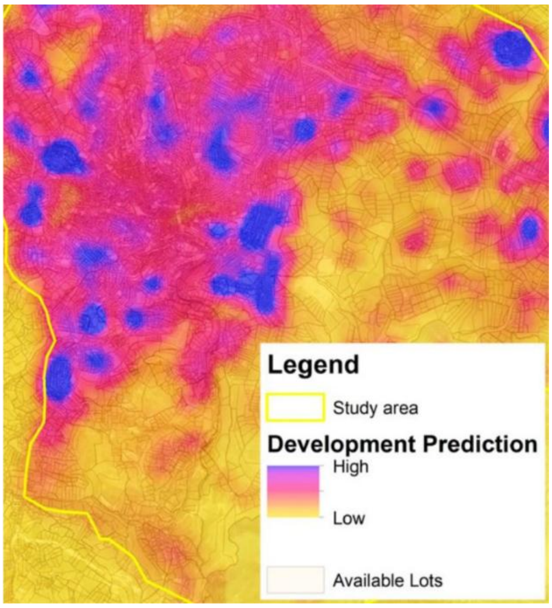


Figure C.5-2: GIS-based decision support for cost optimized waste water infrastructure planning – *left:* spatial classification of waste water network connectivity in Al-Azraq, *right:* scenario of temporal-spatial urban development prediction in Wadi Shueib.

C.5.3 Results

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.

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 long-term (Figure A.5-2 - left).

Further Research Needs

Future research should focus on a scale change for applying ALLOWS nationwide. This should imply to reduce the required local input data (field data) and replace them by suitable new indicators.

Capacity Development

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- AFFERDEN, M. VAN, M.-Y. LEE, R. A. MÜLLER (2017): Implementing Decentralized Wastewater Management in Jordan. – UNEP/UNESCO/BMU International Course on "Environmental Management for Developing and Emerging Countries (EM40)", July 06th, 2017, Leipzig.

Publications

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C.6 The SALAM Initiative: Concepts and Approaches for the Resolution of the Water Deficit Problem in the Middle East at Regional Scale

Contributing partners	RWC, EWRE, PHG, ATEEC, UGOE, MWI, MEKOROT, PWA
Contributing authors	Bernd Rusteberg, Jacob Bensabat, Abdel Rahman Tamimi, Amer Salman, Emad Al-Karablieh, Elias Salameh, Florian Walter, Torsten Lange, Martin Sauter
Key words	water transfer, transboundary water management, seawater desalination, water deficit, Middle East

C.6.1 Key findings

The steadily increasing water demand in Jordan and the Palestinian Territories during the next two decades, all sectors included, cannot be covered by the available water resources, which are limited. According to Figure C.6-1, in 2015, both countries already faced a total annual freshwater deficit of about 783 Million m³ (MCM/a). According to SALAM forecasts, both countries will need additional freshwater resources of approximately 1,680 MCM/a by 2035. These amounts of water are not available in the region. To resolve the water deficit problem, the mobilization of substantial amounts of external water resources as well as large-scale regional cooperation is required. According to SALAM, the enormous amounts of water required can be produced by seawater desalination (SWD) only. The solution developed by SALAM for the imminent water crisis in the Middle East is based on these conclusions.

SALAM Water Production and transport Options (WPOs) are suggested to provide the additionally required water resources to the region in an economically sustainable manner and within a reasonable time horizon.

Due to the geographical characteristics of the region, transboundary cooperation and water trading (SWAP) agreements between Israel, Jordan and the Palestinian Autonomous Territories are essential to resolve the water deficit problem.

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

Significant water cost reduction (USD/m³) could be achieved by employing hydropower generation along the water transport routes, large scale solutions and the integration of other low-cost renewable energy production schemes (e.g. solar energy).

An integrated regional water development strategy may consist of a combination of SALAM WPOs and SWAP schemes in an appropriate manner.

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

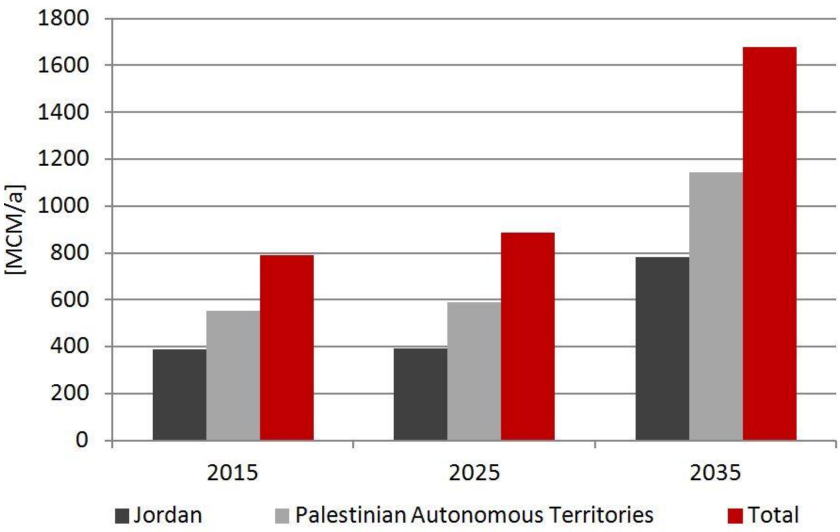

Figure C.6-1: Additional required freshwater resources in 2015, 2025 and 2035

C.6.2 Starting point, objectives, approaches

Starting point and objectives

The SALAM initiative was funded by the German Federal Ministry of Education and Research in the context of the SMART-MOVE IWRM project (BMBF, FKZ: 02WM1355A). SALAM quantified the present water deficit as well as the additionally required water resources during the next two decades in Israel, Jordan, and the Palestinian Autonomous Territories and delineates five so-called Water Production and Transport Options (SALAM WPOs) to resolve 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 centers in the region. The group of experts from the region worked 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 and large-scale reuse of treated effluent in irrigated agriculture. These two measures dramatically improved the water supply situation in Israel and will ensure the matching of the Israeli water demand for the next decades, independently of the prevailing climatic conditions.

Jordan invested all possible efforts to develop its water resources, including conventional and non-conventional sources of water. However, the country increasingly suffers 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 decrease, seriously reducing the water available for abstraction. The Palestinian Territories, despite all efforts, suffer from similar problems.

SALAM claims that seawater desalination (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 water level needs to be stabilized for environmental, water resources and geotechnical reasons. The Lower Jordan River, lacking of base flow for decades with adverse effects on local groundwater flow and the ecosystem in the alluvial plain has to have a minimum of flow.

Methodology

In order to resolve the problem, the SALAM initiative investigates 5 water production and transport options which are shown on a map in Figure C.6-2 and listed below.

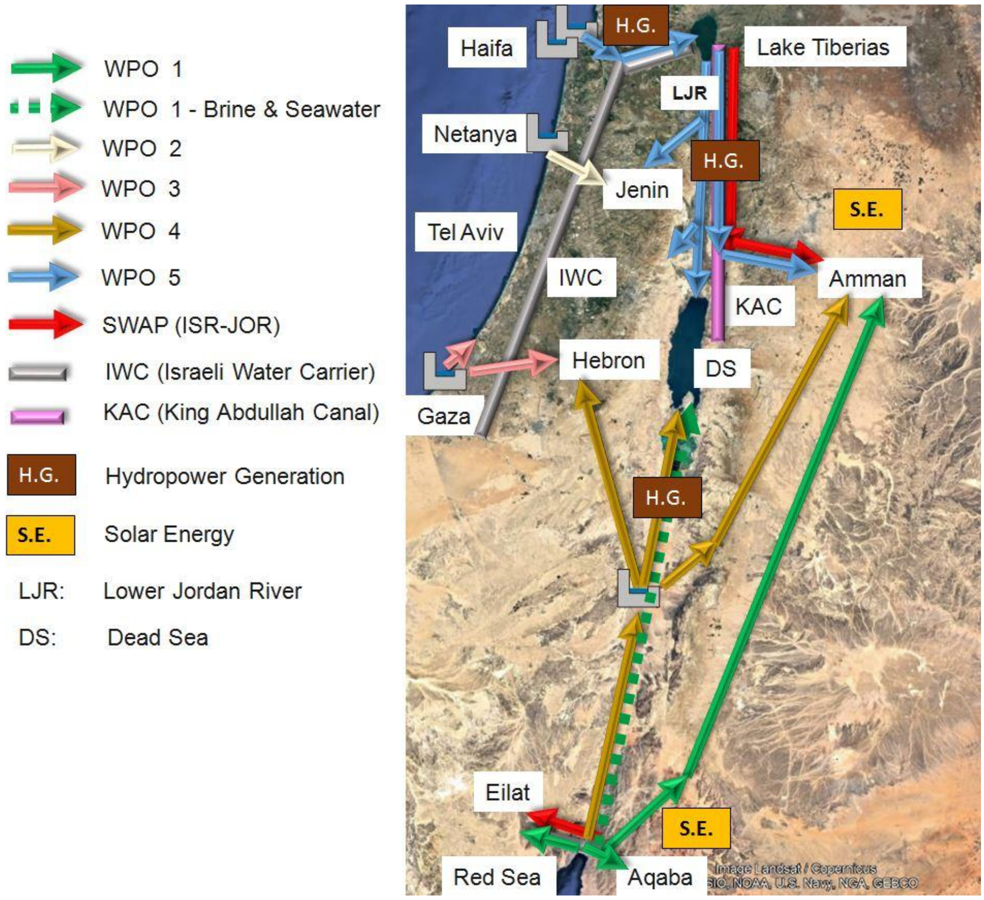

Figure C.6-2: Schematic map for SALAM Water Production and Transport Options (WPOs).

According to Table C.6-1, SALAM WPO 1 and 5 further consider 3 different levels of water production by SWD, given in million m³ per year (MCM/a). The SALAM WPOs are characterized as follows:

SALAM WPO 1:

WPO 1 represents a variant of the original RSDS project (WPO4), which avoids the construction of a canal. The option envisages a gradual expansion of SWD units at the Red Sea near Aqaba to supply water first to the cities of Aqaba and Eilat, Israel (Table C.6-1: WPO 1-0), then to Amman and Central Jordan respectively (WPO 1-1, 1-2). This would allow Jordan to extend the Water-SWAP agreement with Israel (Figure C.6-2: red arrows) and to draw additional water from the Sea of Galilee. Depending on the desalination technique, 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 (dashed green line). The difference in level between the red and the dead sea could at the same time used for hydropower generation. To reduce costs, the desalination plants could be operated with solar energy. However, such studies were not part of the SALAM preliminary study.

SALAM WPO 2:

Seawater desalination 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 the Palestinian Territories (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 C.1-2), alternative water SWAP options between Israel and the Palestinian Autonomous Territories could be more appropriate.

SALAM WPO 4:

This option refers to the so-called Red-Sea-Dead-Sea (RSDS) Canal Project as long-term solution with a time frame for project implementation of about 50 years. It involves the construction of a large canal between the Red and Dead Seas with the main objectives to stabilize the Dead Sea, providing hydropower for SWD, and to transfer substantial amounts of drinking water to the area. In addition to high costs, the option is also characterized by potential ecological risks. The project idea was further examined by the World Bank (Coyne & Bellier, 2012).

SALAM WPO 5:

This solution consists in SWD at the Mediterranean Coast, near the city of Haifa, water transport to the Lake Tiberias for storage and from there, transport to Jordan and the Palestinian Territories. Part of the freshwater stored in the Lake Tiberias could be discharged directly into the Lower Jordan River (LJR), which nowadays has been reduced to a trickle, discharging mainly brackish water and sewage. In this way, the water transfer would contribute to the sustainable development of irrigated agriculture in the LJV as well as to the "historical" and "country-connecting" rehabilitation of the LJR. 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 water cost of the tunnel solution has been studied in more detail (Table

C.1-2). This option could result in the production of considerable amounts of water, far larger than the already existing water SWAP between Israel and Jordan of 50 MCM/a (Figure C.6-2, red arrows).

C.6.3 Results

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 USD/m³ is considered. The water cost of each WPO, estimated for a planning horizon of 20 years, is presented in Table C.6-1. With regards to SALAM WPOs 1 and 5, different levels of yearly freshwater production have been studied.

- Five feasible engineering solutions (SALAM WPOs) were 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 delivered directly to the LJR, contributing to socioeconomic development in the Lower Jordan Valley, being a particularly attractive water transfer solution due to its low water cost, especially in the case of large scale SWD (WPO 5-2).
- SALAM WPO 1, 4 and 5 would directly contribute to the stabilization of the Dead Sea, which is a key concern of the neighboring countries.
- An integrated regional water development 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 effluent (reuse) and brackish groundwater into account.
- Finally, it should be stated that, depending on the regional development objectives as well as the political and economic constraints, including the financing of construction works, a set of alternative regional water strategies need to be developed to be able to offer implementable solutions in accordance with the current political and economic priorities. For example, in order to protect the Dead Sea additional water will be required. The feasibility of such solutions, in addition to environmental considerations, will depend on current economic and political objectives as well as the willingness of the international community to support such a regional development goal.
- We, therefore, recommend a modular implementation concept, which enables a gradual expansion of the required water infrastructure in order to adapt to new political priorities and development goals, if necessary.

Table C.6-1: Water Cost of SALAM WPOs as Average Incremental Cost (AIC) in USD/m³.

SALAM-WPO	1-0	1-1	1-2	2	3	4	5-0	5-1	5-2
Water Production [MCM/year]	80	230	500	50	50	850	250	500	1,000
Water Cost [USD/m³]	[0.64/0.80]*	[1.57/1.61]*	[1.36/1.38]*	0.73	2.16	-**	0.79	0.67	0.61

* Cost with brine disposal in the [Red Sea / Dead Sea, mixed with seawater].
** RSDS-canal project studied by the World Bank (COYNE ET BELLIER, 2012).

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 the Palestinian Territories seem to be a promising concept instead of water transfer from Gaza to Hebron and surrounding cities by pipeline.
- More detailed impact and performance assessment of SALAM WPOs, based on quantitative assessments for environmental, social and political indicators.
- More detailed water budget studies on the spatial distribution of existing and further expected water deficits in Jordan and the Palestinian Territories as a basis for the development of water allocation schemes, which are required for the development of integrated water strategies for the region.
- 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.
- Further research is required in the wastewater sector. Due to the drinking water supply, substantial amounts of waste water will be produced. A special challenge consists in the combination of centralized and decentralized solutions to promote water reuse. Innovative water management strategies are also needed to strengthen the sustainable development of irrigated agriculture in the LJV.
- Scientific challenges are also related to the multi-purpose management of the Lake Tiberias as a central regional water storage reservoir, taking ecological objectives, such as the rehabilitation of the LJV, into consideration.
- 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 Israel, Jordan and the

Palestinian Autonomous Territories and as basis for water strategy implementation, supported by the international community.

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Main Project Coordination:
Prof. Dr. Martin Sauter
Georg-August-University Göttingen
Geoscience Center, Department Applied Geology
Goldschmidtstraße 3
37077 Göttingen
Germany
martin.sauter@geo.uni-goettingen.de

GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN