Water scarcity versus agricultural production
– a new way for an optimal and sustainable management
of resources under arid conditions –

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Outline

1 Motivation & Objectives

2 A new Tool for sustainable Management of Resources
   • Structure & Modules
   • Water Resources
   • Agriculture
   • Management

3 Implementation

4 Summary, Conclusion

Motivation & Objectives

A new Tool for sustainable Management of Resources

• Structure & Modules
• Water Resources
• Agriculture
• Management

Implementation

Summary, Conclusion

Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –
**1 Motivation & Objectives**

**Batinah Region of Oman**

- excessive groundwater abstraction due to irrigated agriculture
- Inversion of groundwater’s natural gradient (flow direction)
  - Marine saltwater intrusion
- Saline irrigation water and thus – saline soils
- Destruction of agricultural resources
- Decreasing farm income & abandoned farms
- impacts the food security of the country

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Saline intrusion in coastal areas

Wadis Bani Kharus, Ma‘awil, Taww
1 Motivation & Objectives

Objectives
• Optimal integrated water management and long-term planning system for water quality and quantity
• Sustainable management of water and soils
• Balancing water demand and availability
• Improvement of water use efficiency in irrigated agriculture by novel irrigation techniques

Challenges
• Coupled dynamic agricultural - coastal aquifer system
• Climate and global change
2. A Tool for sustainable IWRM in arid Regions: Structure and Submodules

**Appm**

- **Prognosis**: Future Climate Scenarios

**Assessment**

- Water Resources Availability
  - Surface and Subsurface Water Module
  - Groundwater Module

**Management**

- Optimal and sustainable management strategies of water resources
- Operative optimal control of the technical system

**Planning**

- Evaluating the effects of planning scenarios for a most beneficial policy

**Water Demand**

- Agriculture
  - Potential and actual water use

**Water Supply**

- Irrigation Module
  - Water Productivity of Agriculture

**Decision Making**

- Objectives, Management Options, Constraints, etc.

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Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –

IWAS OMAN
Water scarcity versus agricultural production
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Assessment Tools for Water Resources - Groundwater Modelling -

- Three-dimensional density driven groundwater flow model for simulating the aquifer behavior inclusive salt water intrusion phenomena based on OpenGeoSys (OGS) Kolditz et al. 2012
- Development of a hydrogeological model of the coastal aquifer for the pilot area
- Steady state calibration

Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –
Assessment Tools for Water Resources - Groundwater Recharge -

Hadjar mountain

P(x,y,t)

rainfall

surface runoff

Subsurface Runoff
Recharge at the mountain front

Wadi channel routing with infiltration

Recharge dam simulation

Wadi channel routing with infiltration; free lower boundary

Q(t)

Q(t)

Q(t)

Q(t)

Subsurface Runoff and Infiltration

ET

ET

Dam inflow

Dam outflow

irrigated agriculture (most important)

recharge dam for artificial ground-water recharge

infiltration

Q_{w,d}

Q_{w}\n
Q_{a}

Q_{inf}

Q_{o}

Q_{lo}

Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –
Assessment Tools for Water Resources - Groundwater Recharge -

1. Boundary Conditions for the Groundwater Model
2. Uncertain subsurface catchment divide due to geological characteristics

Contour plot of oxygen isotopes ($\delta^{18}O$) (Weyhenmeyer et al., 2002)

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Assessment Tools for Water Resources - Groundwater Recharge -

- Boundary Conditions for the Groundwater-Model
- Uncertain subsurface catchment divide due to geological characteristics

GIS-based approach for spatially distributed recharge-rates in % of annual areal precipitation based on geomorphologic variables (height, slope, lithology, soils)
GIS-based approach for spatially distributed recharge-rates in % of annual areal precipitation based on geomorphologic variables (height, slope, lithology, soils)

Assessment Tools for Water Resources - Groundwater Recharge -

Fuzzy-approach for characterising uncertain subsurface catchments → estimation of potential ranges of fresh water availability
Groundwater recharge estimation

**Approach 1: Straightforward**

60 – 73 MCM/a
Mean annual value
Gerner et al. 2011

**Approach 2: Inverse**

68 MCM/a
Steady state calibration of Groundwater model using optimization
Walther et al. 2012
Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -

"more crop per drop"

The UN World Water Development Report, 2003

sustainable IWRM requires reducing the amount of water used in Oman’s agriculture without reducing food production

Higher water productivity
Assessment & Planning Tools for Agriculture
- Simulation optimization of irrigation control and scheduling -

Real world irrigation system

Modeling the field in virtual reality and simulation of water, nutrient and salt transport

Implementation of optimal scheduling and control in the real world

Optimal and robust irrigation scheduling and control

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Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -

Basic TOOLS for Assessment, Management, Planning and Adaption:

- Irrigation experiments
- Validated SVAT Models → transfer of experiments in space and time
- Optimization tools → best layout, scheduling, cropping pattern
- Monte Carlo simulation → high reliability of irrigation management under climate and soil variability

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Assessment & Planning Tools for Agriculture - Increasing water use efficiency and food production -


Estimation of Crop Water Production Functions - CWPF
Assessment & Planning Tools for Agriculture
- Increasing water use efficiency and food production -

low cost Wifi Microcontroller system

Water scarcity versus agricultural production
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Optimal Management of coupled Hydrosystems - Challenges -

How can we manage an interacting groundwater - agriculture system sustainably regarding water quantity and quality under uncertain climatic and global impacts?

Challenges

• Long simulation times and the complexity of physically based models as well as global optimization procedures
• Consideration of the model interactions within the optimization process
How can we manage an interacting groundwater - agriculture system sustainably regarding water quantity and quality under uncertain climatic and global impacts?

**Methodology**

1. Development of appropriate surrogate models
2. Multicriterial simulation-based optimization
Optimal Management of coupled Hydrosystems
- Multicriteria simulation-based Optimization framework -

Water demands $Q_j$

Optimisation Module

Global Evolutionary Technique for Optimal Water Management

Cropping pattern $A_j$

Water demands $Q_j$

Cultivated Acreage $L_j$

Aquifer State $S(t_{i-1}), h(t_{i-1})$

OpenGeoSys-2D Groundwater Model packed in ANN

Aquifer State $[S(t_n), h(t_n)]$

Aquifer State $[S(t_0), h(t_0)]$

Sustainability Index

Groundwater Pumping Cost $C_{Pj}$

Maximize Profit and Sustainability

Objective Function

Yields $Y_j$ for $m$ crops

Revenues $P_j * Y_j$

Irrigation Water Salinity $S(t_i)$

Irrigation Schedule

Irrigation Costs $C_{Ij}$

2D-CWPF’s for $m$ crops

Optimal Management of coupled Hydrosystems

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Optimal Management of coupled Hydrosystems - Multicriterial simulation-based Optimization -

How can we manage an interacting groundwater - agriculture system sustainably regarding water quantity and quality under uncertain climatic and global impacts?

Management objective: 
Groundwater

- Long term availability of water resources
- Good water quality
- Abstraction < recharge

Contradicting objectives

Management objective: 
Farmer

- High profit
- Low costs
- High quality products
- Water with good quality

How to find the best compromise between the two objectives?
→ depends on the actual preferences of the decision makers

Multicriterial optimisation → Evaluation of *pareto-optimal solutions*
Optimal Management of coupled Hydrosystems - Exemplary Application - Results -

Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –
3 Optimal Management of coupled Hydrosystems - Results -

OUTPUT

- Crop pattern
- Abstraction rates
- Cultivated acreage
- Salinity of irrigation water
- Irrigation schedule
- Profit for farmers
- Salinity of the aquifer
- Water levels of the aquifer
- Cost benefit analysis for stakeholders

Long term profit

Multi-objective

- Crop fraction [%]
- Salinity [dS]
- Profit [$]

Sorghum
Maize

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3 Implementation

The integrated management process

Aim: sustainable IWRM and development of resources

Assessment
Resources, Impacts / Pressures, Players / Needs

Management options
Development, Investigation

Decision making
Evaluation of options

Implementation
Measures, Investments, Awareness

Monitoring
Follow up
Lessons learned

Appropriate methods and models are required

Recursion after 6-10 years
Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions –
4 Summary

• Some key issues of the new APPM-Tool for an integrated management of arid zone water resources were presented inclusive first steps of implementation.

• Modelling of density driven groundwater flow is mandatory.

• An increase of water productivity can be achieved by introducing novel irrigation methods.

• A prototype of a simulation based water management model for managing both water quality and quantity was presented.

• The methods of artificial intelligence (ANN) allow for a fast and robust application of the process models in an optimisation framework.

• Multicriterial optimization can provide a tool for decision makers to find sustainable solutions in an environmental, economical and social sense.

• A sustainable management of water and soils is a precondition for food security
Thank you for your attention!

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Journal papers


HONORABLE MENTION PAPER AWARD 2012


Technical realisation by Supply System

- Water of better quality delivered to consumers
- Extraction of groundwater at suitable sites

- Recultivation of salty farm land and of valuable soils for agriculture
- Incorporation of other sources of water
- Recycling of water for a sustainable economic and environmental development

Design of a water distribution network (Water-Backbone) to deliver water of good quality to the farms