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GRoW

WATER AS A GLOBAL RESOURCE

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Global analyses and local solutions for sustainable water resources management

Conference Proceedings

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Victoria Falls on the Zambezi River, at the border between Zambia and Zimbabwe; Foto: Vadim Petrakov / Shutterstock

The GRoW funding measure

The United Nations' 2030 Agenda for Sustainable Development emphasizes the global importance of water resources. Sustainable Development Goal 6 (SDG 6) specifically aims to "ensure availability and sustainable management of water and sanitation for all." By 2030, everyone should have access to clean drinking water and adequate sanitation systems, and water-related ecosystems should be protected or restored as natural resources. To help achieve SDG 6, the German Federal Ministry of Education and Research (BMBF) has launched the funding measure Water as a Global Resource (GRoW), which is part of a broader framework entitled Research for Sustainable Development (FONA). GRoW comprises twelve joint research projects with more than 90 partner institutions from research, business and practice. The projects aim to develop innovative ways of increasing governance capacities in the water sector while reflecting the close links between local and global action. This approach will bring together science, policy and practice to connect key water topics, consolidate knowledge on implementing the SDGs and thereby strengthen evidence-based decision-making. Each of the twelve projects addresses one of three overarching topics:

1. Global water resources

This topic focuses on innovative assessments and management tools for water resources and their related ecosystems. The researchers derive action-relevant information from large volumes of raw data (e.g. from satellite-based remote sensing) and explore how technology and innovative, solution-oriented models can be applied as compact solutions to improve information flows. These solutions can significantly reduce the time between collecting data, analysing the need for action, and subsequent management decisions taken by companies and authorities.

2. Global water demand

This topic focuses on analysing water demand and creating new incentive systems for using resources more efficiently. Future water demand must be viewed in light of the nexus between water, food and energy so that the growing need for food and renewable raw materials for energy can be taken into account. Water footprints and reliable, understandable forecasts of trends in water demand are therefore important tools for decision-makers in businesses and authorities.

3. Good governance in the water sector

Good water governance is at the heart of the funding measure. It includes information on water resources, water demand and innovative technologies. For this topic, researchers are developing methods and incentive mechanisms that consider societal and individual motivations for sustainable water management. An important part of this involves measuring and documenting progress on the SDGs. In particular, suitable indicators for the multidimensional concept of sustainability are being identified, and their applicability verified.

The GRoWnet networking and transfer project

The GRoW research activities are accompanied by GRoWnet, the networking and transfer project led by adelphi. GRoWnet aims to identify and effectively use synergies between the twelve joint research projects by strengthening cooperation and exchange between them. In addition, GRoWnet actively supports the projects in transferring and communicating their research findings and solutions to different target groups, such as the public, water experts, resource managers and policymakers. In doing so, GRoWnet aims to increase the overall impact of the funding measure.

The GRoW steering committee

The GRoW steering committee supports the work of the research projects. It consists of six external experts from development cooperation, policymaking and business, the coordinators of the twelve projects, representatives of the German Federal Ministry of Education and Research (BMBF), Project Management Agency Karlsruhe (PTKA) and the GRoWnet networking and transfer project. The objective of the steering committee is to increase public outreach and practical applicability of the research activities. Input from the steering committee will help the GRoW projects draft recommendations for making their research projects even more relevant in terms of achieving the SDGs.

Aim of this publication

The present conference proceedings show the interim research results of the twelve GRoW projects. We hope that this will provide the foundation for a fruitful discussion with water experts from academia, policy and practice. In particular, we want to explore the opportunities and challenges for transferring GRoW research results into practice.

Making GRoW more than the sum of its parts: The GRoW cross-cutting topics

Although the twelve GRoW research projects cover very diverse topics, a number of thematic and methodological overlaps exist. In order to harness synergies and ensure that knowledge is shared across the individual projects, participants are addressing a series of cross-cutting topics. These activities are designed to increase the impact of GRoW as a whole.

Under the direction of the steering committee, GRoW has so far defined and is working on three cross-cutting topics:

1. Incentive mechanisms in the context of governance
2. SDGs (Sustainable Development Goals): Hitting the targets
3. Water footprints

Work on these cross-cutting topics requires partners who are willing to invest time and energy, and are eager to engage with fellow researchers. Each topic therefore has a coordinator who directs the work and collaborates with GRoWnet to organise various meetings. Two rounds of workshops and several online meetings have taken place so far. For updates on the activities of the cross-cutting topics, see the GRoW website: www.bmbf-grow.de.

A visible example is the joint GRoW position paper prepared to inform the meeting of the High Level Political Forum on SDG6 in 2018 in New York. The paper is available for download at the GRoW website.

Incentive mechanisms in the context of governance

Coordinators:
Prof Karl-Ulrich Rudolph (IEEM GmbH)
Alexander Grieb (formerly KfW)

A number of the GRoW joint research projects are working on incentive mechanisms (e.g. economic, legal and reputational) to encourage better water resources management. However, much like the effectiveness of new technologies and processes, the impact of these tools depends heavily on the political and social frameworks in the target regions. At the first meeting of the cross-cutting topic, participants therefore decided to work on the link between the macro and micro level of water governance, which implies scaling down the focus to, for instance, the level of water utilities in order to achieve SDG 6. In addition, three sub-working groups were defined:

- Irrigated agriculture: This group focuses on legal frameworks and the potential of social innovations and digitalisation in the agricultural sector.
- Measuring governance: This group facilitates inter-project exchange on operationalising governance and defining governance indicators for measurement purposes.
- Turning governance research into practice: This group assesses the link between the macro and micro level and collects aspects of good governance from the projects, since general principles of governance do not always fit the water sector.

SDGs: Hitting the targets

Coordinators:
Prof Claudia Pahl-Wostl (University of Osnabrück)
Dr Ursula Eid

Helping achieve the SDGs in general, and SDG 6 in particular, is a key objective for all the GRoW research projects. They develop and test innovative approaches to achieving the goals and are also devising new concepts and key figures for evaluating progress on the goals. This cross-cutting topic addresses issues related to achieving SDG 6 and leverages synergies to create an effective network for strengthening and effectively demonstrating the ways in which the individual projects and the overall GRoW funding measure are helping to make the SDGs a reality.

One concrete result of the group's work so far is the aforementioned GRoW position paper highlighting what the GRoW projects see as the key challenges to achieving SDG 6 and how they envisage contributing to the SDG 6 process. This paper has since been channelled into the political process on SDG 6 monitoring and has received positive feedback from a number of institutions. The projects also identified a number of topics that are most relevant for their work, and are currently focusing on two topics:

- **Conflicting goals and synergies between different SDG targets:** This group decided, based on case studies from within GRoW, to develop a new assessment procedure for evaluating projects and/or different policy plans and their effects on SDG interactions.

- **Indicators, data and models:** This group aims to collect examples from GRoW on how the SDG 6 monitoring process can be improved and augmented to provide insights for more sustainable water resources management.

Both groups are currently working on specific outputs to summarize and disseminate their findings. These include policy briefs and an event at the Stockholm World Water Week.

Water footprints

Coordinators:
Dr Markus Berger (TU Berlin)
Dr Falk Schmidt (IASS Potsdam)

Trade in virtual water is increasingly creating global links between local and regional water resources. Several of the GRoW research projects therefore investigate how consumption is linked to and affects water resources in other parts of the world. They develop methods for measuring water footprints in order to identify areas where water is being used inefficiently, and implement practical measures for reducing water footprints. In the past two workshop meetings, the GRoW projects discussed three major topics:

- **Mitigation:** How can water footprints be reduced? How can the water footprint be used to guide mitigation? And how can it help to assess the effectiveness of mitigation measures?

- **Impact assessment:** How can water footprints be linked to economic and social impacts? How can trade influence water stress in certain regions and vice versa? What are the links to mitigation strategies?

- **Water quality:** How can aspects of water quality (including groundwater) be more effectively included in water footprint assessments?

To collect and disseminate their findings on these questions, participants in this cross-cutting topic are currently compiling a position paper. It will critically discuss the quantitative approach to water footprints, highlight which factors should be included and how this can be done, and analyse the potential and limitations of water footprints based on scientific discussions from the perspective of GRoW.

SaWaM: Seasonal water resource management for semiarid areas: Regionalized Global Data and transfer to practice

Using seasonal forecasts to support climate proofing and water management in semi-arid regions

Christof Lorenz, Harald Kunstmann, Tanja Portele, Anita Bayer, Patrick Laux, Anne Müller, Gerd Bürger, Axel Bronstert, Nazli Turini, Boris Thies, Anna Smetanova, Eva Paton, Pallav Kumar-Shrestha, Luis Samaniego, Saskia Förster, Robert Behling, Siegrid Roessner, Sajedeh Behnia, Nico Sneeuw, Berhon Dibrani, Thomas Kukuk
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Keywords: *Seasonal forecasts, semi-arid regions, sustainable water management, climate proofing*

ABSTRACT

In our project Seasonal Water Resources Management: Regionalized Global Data and Transfer to Practise (SaWaM), we analyse the potential of global hydrometeorological information for supporting the regional water management, particularly reservoir operation. Special focus is on seasonal forecasts, with which we aim to predict the availability of freshwater resources and the state of the ecosystem for up to 6 months in advance. This is achieved by a strongly interlinked model and data chain. After an in-depth evaluation during the period 1981 to 2010, global data sets are processed for regional water management purposes through dynamical and statistical downscaling approaches, hydrological and ecosystem modelling as well as the combination with remote-sensing-based information. To assess the transferability of our tools and products, we focus on eight different semi-arid basins in Iran, Sudan, Brazil, Ecuador, and West-Africa. The transfer into practice is ensured through the close cooperation with regional stakeholders, decision makers, research institutes, and water managers as well as the joint development of a tailor-made online decision support system for regional water management. The project also serves as a benchmark for the application of state-of-the-art seasonal forecast products. In-depth comparisons with reference datasets show a promising forecast skill, which allows e.g. for the prediction of the intensity of rainy seasons and droughts. The project is therefore strongly contributing to climate proofing and the accomplishment of SDG 6, that is to ensure the availability and sustainable management of water and sanitation for all, in particular in semi-arid regions.

INTRODUCTION

While weather forecasts are used for flood warnings and while climate projections are used for long-term climate adaptation measures, it is the knowledge of the climate of the coming months (Siegmund et al., 2015) that is crucial for the management and control of water reservoirs, e.g. for power generation or for irrigation in agriculture. This is particularly relevant in dry regions, i.e. arid and semi-arid areas. In semi-arid regions, unlike in arid regions, much can be achieved with sustainable and science-based water resource management. It is therefore of utmost importance to understand the local climate system including the dynamics and interactions of different water-related variables. However, due to the significant decrease in the number of hydrometeorological in situ stations (Lorenz and Kunstmann, 2012) and high uncertainties in estimates for the current and future water supply (Pilgrim et al., 1988), this is getting increasingly difficult. Scientists and decision makers may therefore rely their planning more and more on global hydrometeorological data sets, remote-sensing products, or global model systems. It is SaWaM's goal to investigate the performance of such global information and, in particular, global seasonal forecasts for which we develop methods and tools for the regionalization, the processing and, in the end, the transfer into practice for the regional water management in semi-arid regions. We focus on semi-arid regions in Brazil (Rio São Francisco basin), Iran (Karun and Lake Urmia basins), Sudan (Blue Nile and Atbara basins), Ecuador (Catamayo-Chira basin), and West-Africa (Niger and Volta basins). We further aim at the direct transfer to practice through a close cooperation with regional stakeholders, decision makers, and scientists. In the end, this cooperation shall demonstrate the potential of seasonal forecasts for climate proofing and for regional water management even beyond the project duration and our study regions.

METHODS

In SaWaM, we follow an interlinked chain of models and data in order to process global seasonal forecasts and other information for regional water management. While each sub-project requires specific data (e.g. runoff observations for hydrological modelling), all sub-projects use seasonal forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF), namely Version 5 of ECMWFs Seasonal Forecasting System (SEAS5).

Regionalization: Small scale precipitation variability cannot be resolved at the initial resolution of the global seasonal forecasts. For improving this resolution, we follow two regionalization approaches. High-resolution information is modelled with the Weather Research and Forecasting model (WRF). After finding a suitable parametrization for e.g. model physics of convection or radiation for each target region, this model allows us to provide information about precipitation and temperature down to a resolution of 3km, i.e. convection permitting scales. As this so-called dynamical downscaling requires huge computational resources, we also apply statistical approaches, where the interpolation of precipitation and other climatic variables to a higher resolution is based on statistical relationships between the coarse-scale global forecasts and either a gridded high-resolution reference dataset or in-situ observations. For the latter, we use the Expanded Downscaling (XDS, Bürger, 1996), which assumes that local climate covariance is linked bilinearly to the global circulation covariance. We also apply uni- and multivariate bias-correction and spatial disaggregation (BCSD, e.g. Lorenz et al., 2018) techniques, which are a compromise between the computationally expensive dynamical downscaling approaches and XDS, which provides information at selected stations only.

State of the hydrosystem: In order to get information about hydrological variables like streamflow and soil moisture but also the transport and entry of sediments, we use the downscaled seasonal forecasts as driving data for two hydrological models, namely the mesoscale Hydrological Model (mHM, Samaniego et al., 2010) and the Water Availability in Semi-Arid environments – SEDiments (WASA-SED, Mueller et al., 2010) model. The mHM-model with its different modules allows for a straightforward modelling of the catchments even if only limited local information is available. This is possible through mHMs multi-scale parameter regionalization technique, with which we assimilate and incorporate different satellite- and station-based observation datasets with different spatial resolutions. The WASA-SED-model, on the other hand, requires detailed information about the catchment. Then, by including the description of processes for erosion at the hillslope scale, for transport of suspended and bedload fluxes at the river scale and the retention and remobilisation of sediments in large reservoirs, it provides all relevant information for the regional water management especially in semi-arid regions.

State of the ecosystem: In order to predict the state and functionality of the ecosystem including indicators for ecosystem services for the next season, the global dynamic vegetation model LPJ-GUESS is modified for the application on the

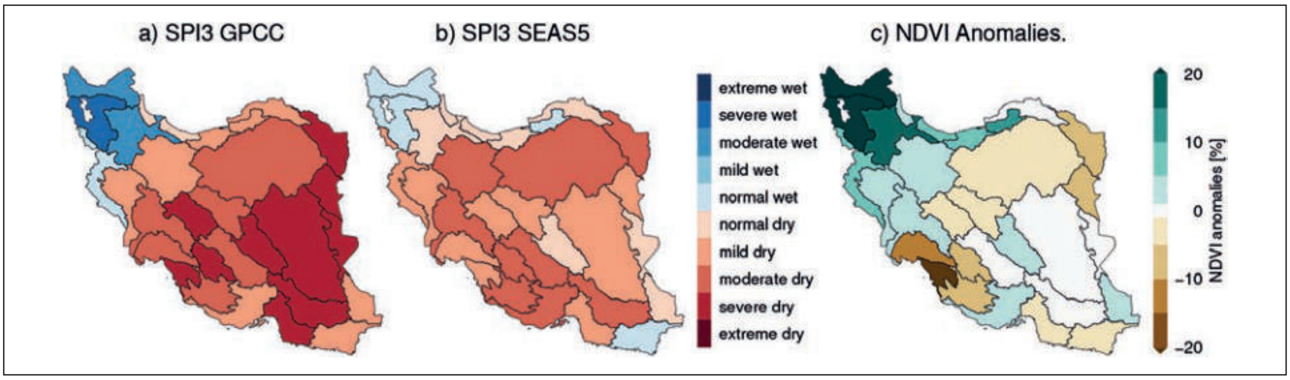

Figure 1: The drought in Iran from winter 2017/2018 picked up by different methods applied in the SaWaM project: (a) Drought index SPI3 from Monitoring (GPCC v6.0 for Dec 2017 to Feb 2018), (b) SPI3 from seasonal forecast system (ECMWF SEAS5, for Dec 2017 to Feb 2018) and (c) as detected by remote sensing (relative NDVI Anomaly from MODIS during the period Dec 2017 to Feb 2018 with respect to the long-term mean for 2001 to 2018). For the SEAS5-forecast, only the SPI-category with the most ensemble members is shown.

regional scale. Ensemble simulations will identify how uncertainties in the amount of precipitation and its temporal and spatial distribution are reflected in crucial ecosystem services, such as crop yields, carbon sequestration and ecosystem water balance. A semi-parametric approach is used to identify areas with degraded vegetation and soils, which contribute significantly to the infilling of reservoirs by sediments. In particular, sediment transport is approximated through a function of precipitation, connectivity, soil and vegetation properties. This allows us to prepare and test land management scenarios in degraded areas in order to prevent siltation.

Validation: We develop and apply several remote-sensing based approaches for validating the different derived products. In particular, we use data from the Global Precipitation Measurement (GPM) mission, which is combined with information from high-resolution optical sensors on board of geostationary satellite systems like the Meteosat Second Generation. A newly developed rainfall retrieval technique, based on a random forest machine learning approach, allows for a quasi-continuous observation of rainfall distribution in near–real time and in high spatial and temporal resolutions. Runoff is estimated from spaceborne altimetry sensors by computing a statistical relationship between altimetry-based water level time-series and observed runoff. Water levels can then be transformed into runoff even if the gauge-based observations are discontinued. Finally, time series of optical remote sensing data of varying spatial (Sentinel-2, Landsat, MODIS at 10m – 1000m pixel size) and temporal scales (decades to seasons) are used to derive long-term and seasonal vegetation dynamics patterns.

SELECTED INTERIM RESULTS AND DISCUSSION

Evaluation of the SEAS5 seasonal forecasts: For evaluating the performance and the forecast skill of SEAS5 seasonal predictions, we have compared the precipitation forecasts against gridded observation-based datasets from the Global Precipitation Climatology Centre (GPCC) in terms of accuracy, overall performance, sharpness, and reliability, which is expressed in the so-called Unified Skillscore. After a basic multiplicative bias correction, we can observe skilful predictions for the seasonal precipitation sums during the rainy season already two months (São Francisco, Karun, Urmia, Catamayo-Chira, Blue Nile) or one month ahead (Atbara, Niger, Volta).

The 2017/2018 drought in Iran: For testing the potential as regional decision support for water management, we evaluated the performance of our different tools and products during the 2017/2018 drought in Iran. Besides the evaluation of the performance of the precipitation forecasts, we are interested in the implications of such a drought on the ecosystem. While the prediction of ecosystem states is still work in progress, we can already use satellite-based information in order to assess the condition of the vegetation during this season. Figure 1 therefore shows the Standardized Precipitation Index (SPI), an index for meteorological droughts, and the differences between the vegetation climatology and the conditions during the rainy season 2017/2018. Comparing the GPCC-Monitoring product (Figure 1a) with the SEAS5-forecasts (Figure 1b) clearly shows that the low amount of precipitation was successfully predicted by the seasonal forecasts. The impact on the vegetation, however, shows a dry signal especially in the regions which are dominated by natural vegetation or low population (Figure 1c). In heavily irrigated areas like the Karun basin, vegetation is even slightly increasing, which indicates that despite the low freshwater resources, the available water has been used for irrigation in order to maintain food supply. This caused water shortages for other sectors like, e.g. drinking water, leading to protests and revolts especially in the Southern parts of Iran at that time.

Atmospheric, hydrological and ecosystem modelling: For all modelling approaches, we finalized the initial setups and first parametrization experiments. The hydrological modelling for the headwaters of the river basins using mHM shows already highly promising results and will be used in an operational setup after the implementation of a lake module. The LPJ-GUESS model has been used for modelling the ecosystem of the Rio São Francisco basin in particular during dry periods in order to assess the implications on the vegetation. First runs show a significant drought signal in both the vegetation parameters and also the excess water, which already indicates the potential of the LPJ-GUESS-model to assess changes in the vegetation that are driven by water availability.

Public relations: Due to the strong focus on the involvement of stakeholders, decision makers, and other potential users, we have organized workshops in our study regions in Brasília (Brazil), Ahvaz and Teheran (Iran), and Khartoum (Sudan). With up to 100 participants, these workshops have shown the great interest not only in our tools and methods, but in seasonal forecasts and climate proofing approaches in general. Besides site visits in the different basins, we also organized training courses e.g. for dynamical and statistical downscaling. Special highlights have been the presentation of SaWaM at side events both at the 8th World Water Forum in Brasília, Brazil, and the 24th Conference of the Parties (COP24) in Katowice, Poland.

CONCLUSIONS & OUTLOOK

In the SaWaM-project, we evaluate the performance of global hydrometeorological information and, in particular, seasonal forecasts, for the regional water management in semi-arid regions. Since the project start we have made significant progress especially in the understanding both the potential and the limitations of seasonal forecast products and their usage in different modelling approaches. While the regional adaptation especially for the hydrological and ecosystem models is still ongoing, the production of statistically corrected seasonal precipitation forecasts as well as the remote-sensing based monitoring of precipitation, runoff and vegetation parameters is almost in an operational status. Besides that, we follow the collection of regional data with a high effort, because, even if the project also includes the regional application of globally available data, the detailed evaluation of our products as well as the quantitative analysis of regional climate systems still require in-situ information which, however, is often hard to obtain and/or inconsistent.

During the kick-off workshops in our study regions and several side events, we have learned that regionalized seasonal forecasts and the derived products for the hydrological systems and ecosystems have a huge potential for predicting and therefore mitigating the impact of extreme events like droughts. The products, tools and methods that are developed in SaWaM are a benchmark for the application of seasonal forecasts for the regional water management and therefore contribute to climate proofing in particular in semi-arid regions.

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MuDak-WRM

MuDak-WRM: Multidisciplinary data acquisition as key for a globally applicable water resource management

Sustainable management of reservoirs – defining minimum data needs and model complexity

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Full information on author affiliations can be found p. 58

Keywords: *Minimum monitoring, reduced model complexity, catchment, reservoir, water quality*

ABSTRACT

The overall objective of the MuDak-WRM project is the development and application of a globally applicable management system for reservoirs and their basins. To succeed in this development, two major sub-goals have to be fulfilled. We will develop a methodology for a minimum monitoring to assess water quality. Additionally, the complexity of existing models needs to be reduced, to address globally restricted data and budget availability. The project includes monitoring of catchment and in-lake processes. Two case study sites were selected beforehand, the Große Dhünn reservoir in Germany and the Passauna reservoir in south-east Brazil. The monitoring results used for model parametrization lead to an improved system understanding, which again is the basis to define crucial monitoring parameters in space and time. With this information the efforts for an effective water quality observation will be reduced. A continuous assessment of the mass flux into the reservoir, water quality changes inside the reservoir as well as seasonal land cover changes have been successfully monitored in high resolution for an entire year. At the same time a water balance model has been set up in close relation to a catchment emission model.

INTRODUCTION

The core product of MuDak-WRM is a model for the prediction of medium to long term changes in water quality in reservoirs which is as simple as possible and uses globally available data. The key aspect is to reduce the complexity of the underlying scientific-mathematical approaches and the data required for the future model to enable the application of the model with reasonable effort and in a meaningful way in developing countries. The interdisciplinary research group on the German side is a consortium of four research and five industry partners. Each work package is handled by one or two German partners. On the Brazilian side, three research and four industry or public partners are involved in the project, so that the areas of competence are mirrored. In most cases the used models for water quality prediction and decision support for reservoir operators are too complex and data demanding for a world wide application. Limited understanding of processes in the catchment and the reservoir, so far hinders the development of simplified approaches. The project hypothesis is, that water quality of reservoirs changes on long-term scales due to changes in the catchment (input fluxes), and that these reactions can be modelled and verified by the assessment of monitoring data. The MuDak team aims at providing an applicable approach, which can be used by international reservoir operators and authorities to describe the actual status of one reservoir and to assess the potential future development of water quality under consideration of certain management options, like afforestation and waste water treatment plant development. This approach will deliver answers to achieve the sustainable development goals (SDGs).

METHODS

To solve the addressed challenges and to answer the scientific questions the project consortium is split into three methodological-technical parts. Three work packages produce primary data from field measurements, which is passed on for in-situ verification and the validation of models. Three work packages set up and adapt a water balance model (LARSIM) (Ludwig & Bremicker 2006), an emission model (MoRE) (Fuchs et al., 2017) and a hydrodynamic model combined with a water quality- and sediment transport model (Delft 3D) for the case study and derive approaches for a reduction of complexity (Figure 1). In order to reduce the complexity, the models are first developed to run with the best possible input data. From this stage on the input data will be reduced in terms of temporal and spatial resolution as well as measurement quality itself. Unnecessary model parts can be excluded from the calculations to reduce complexity. The aim is to find the minimum data demands for the models and to still reproduce the critical water quality status in a reservoir and the related long-term usage of the reservoir. The third part works on the integration of both, campaign-based and as real-time data, into a web framework that allows for standardized measurement data exchange among software components. This framework is called the Sensor Web (Botts et al. 2008).

The principal workflow is developed along two reservoir case studies (Figure 2). The first region, Große Dhünn reservoir (managed by Wupperverband), is used as a "best case" scenario in terms of data availability. The developed models are transferred to Passauna reservoir (managed by Sanepar), where a long time series of quality data and catchment information is missing. After further development and reduction a final simplified model version will be produced. This model will be applied by the reservoir operator in the Piraquara 2 catchment to predict water quality changes of the reservoir. By the transfer to a new catchment the functionality as well as the transferability of the product can be assessed.

Monitoring encompasses activities in the catchment like continuous water sampling at the river inflow to assess the particle and nutrient flux to the reservoir, sediment and soil sampling and the analysis of satellite imagery (Sentinel-1 with radar sensor and Sentinel-2 with optical sensor, revisiting time of ca. 6 days) to retrieve land use and land cover change and further model input parameters like Albedo- and LAI (Leaf Area Index).

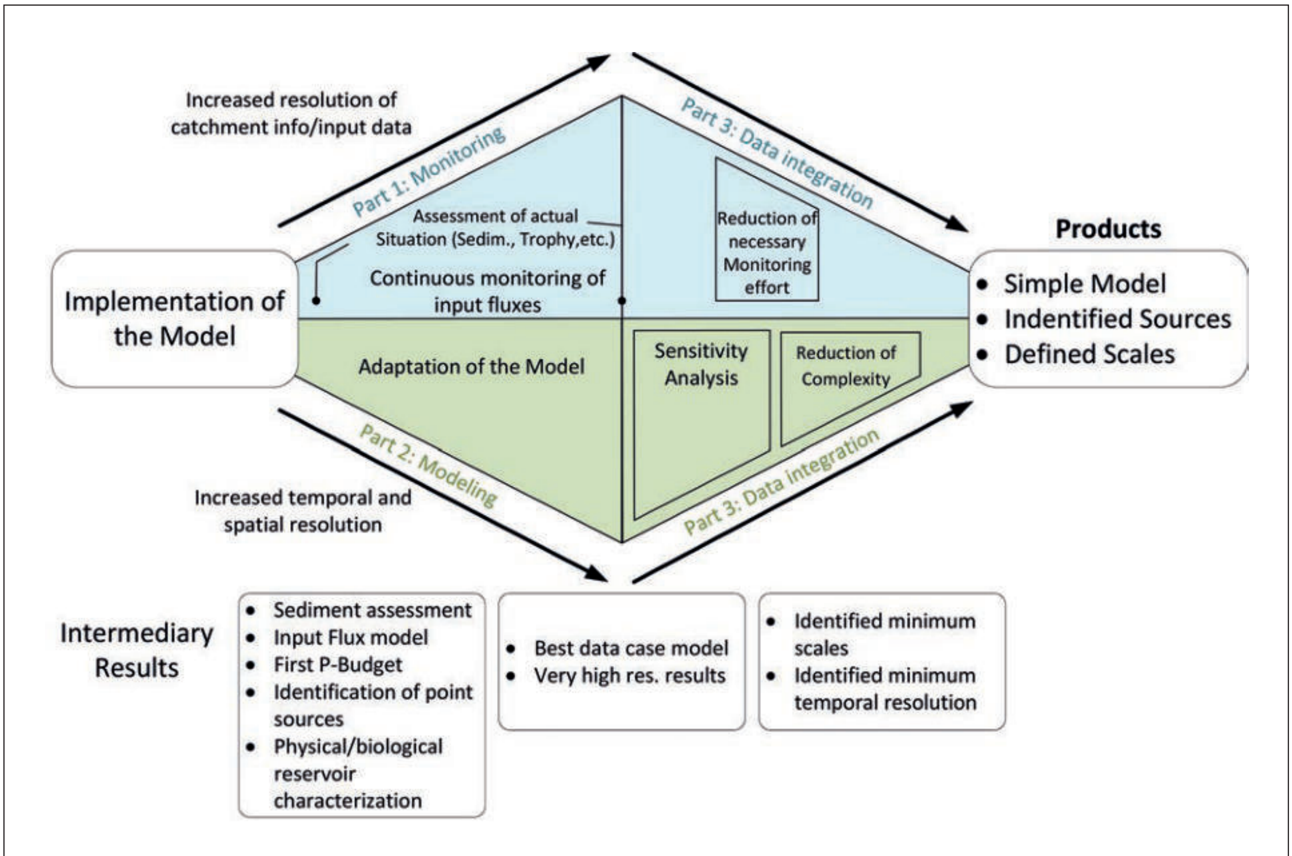

Figure 1: Methodological project approach.

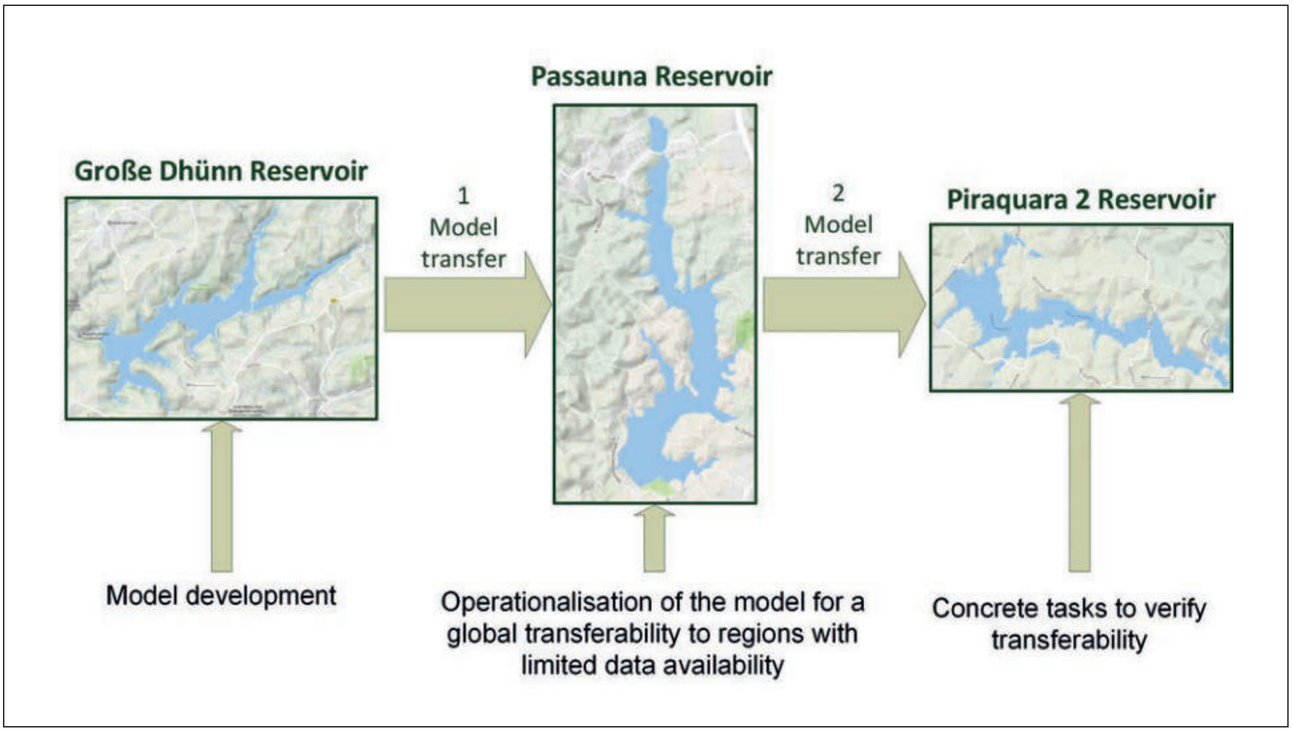

Figure 2: Model development and case study transfer work flow

Reservoir monitoring includes real-time water quality measurements on a platform (Figure 3) at the water intake in Passauna reservoir combined with monthly water sampling campaigns. Additionally an upward looking Acoustic Doppler Current Profiler gives insights in internal flow velocities and flow directions. The detailed investigation of in lake processes is complemented by campaign-based drone flights to better understand the spatial distribution of quality parameters (e.g. turbidity and chlorophyll conc.) and to bridge the information to the satellite imagery.

INTERIM RESULTS AND DISCUSSION

During four individual large measurement campaigns at Passauna and three measurement campaigns at the Große Dhünn Reservoir pre-dam the actual ecological and operational state of the reservoirs was evaluated. Water quality sensors were successfully tested at the Große Dhünn reservoir and were installed permanently later on in the Passauna reservoir. The Wupperverband has been operating a Sensor Web framework since more than ten years and serves a smaller set of real-time-data for the reservoir. During the project this homogeneous measurement data pool is extended by sampling data, taken during the project measurement campaigns. All data is available to researchers and the operators in a standardized manner.

Sedimentation assessment revealed that the siltation process in the pre-dam of the Große Dhünn reservoir is relatively slow due to limited erosion in the catchment. In contrast to this, the Passauna reservoir is affected by significant siltation and accumulation of nutrients, even though the actual status is mesotrophic. Continuous water sampling is ongoing and therefore final data and water quality model results are not available yet. However, for the big pre-dam of the Dhünn reservoir, the impact of various numerical and physical parameters was examined in sensitivity analyses adopting a 3D model. Collected input data for the hydrological model and the emission model was pre-processed and the first model runs were conducted. At the moment the modelled water balance is integrated into the emission model to calculate the sediment and nutrient flux into the reservoirs. The emission model results then will be validated by the measured fluxes in the rivers.

Partners from all work packages participated in an extended training and transfer session during five days. In parallel to the monitoring activities, the applied methods and tools were explained to employees from the operating company in theory as well as in the field. Additionally, bi- and trilateral meetings took place to exchange work package-specific demands from the company and authorities.

CONCLUSIONS & OUTLOOK

In order to investigate the formulated research hypothesis and to increase the process understanding as well as to reduce the model complexity and data demand, the following steps have been accomplished so far. In February 2019 the one year continuous measurement will be completed and obtained data will be processed to feed the models. The following steps were completed successfully:

- One year of continuous input flux monitoring at the Passauna River.
- Using satellite remote sensing to derive land use classes and several model parameter values
- Long-term high-resolution measurements of water quality in the reservoir and over 10 intensive sampling campaigns conducted.
- Testing of cutting-edge monitoring technology (hyperspectral sensors (drone- & boat-based), sediment penetration measurements, optical in-situ quality sensors)
- Real-time water quality data integration with the Sensor Web
- 3D numerical sensitivity analyses for one pre-dam of the Dhünn reservoir focusing on the effect of stratification processes on fine sediment transport.
- Watershed emission modelling and water balance modelling completed.

On a cooperation level, the MuDak-team is exited, that an intense and fruitful cooperation was established with Sanepar, a Brazilian reservoir operator as well as two Brazilian universities (Federal University of Paraná and University Positivo), several authorities and The Nature Conservancy (TNC). Sanepar contributed to the project with logistics, data access and even funding to purchase a joined research vessel. The universities contribute by providing 10 scholarships for PhD students working on different parts of the MuDak project.

After the finalization of the models (LARSIM, MoRE and Delft 3D) the sensitivity analysis will be performed. The models will be tested to produce relevant and correct results with reduced and simplified input data. Towards the end of 2019 central quality parameters together with temporal and spatial resolution demands will be defined. The Sensor Web framework, which already organizes data for the Große Dhünn reservoir will be extended with data from Sanepar to seamlessly access and visualize information on the Web. Not only will the product be introduced to potential users, but also will we distribute the scientific and technical outcomes to a broad range of target groups inside and outside the scientific community.

The MuDak-WRM team thanks all Brazilian partners and especially the colleges from Sanepar and the UFPR for huge efforts in the field, laboratory and for a great cooperation.

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iWaGSS: Integrated Water Governance Support System

Integrated solutions for water resources management and governance

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Keywords: *Water governance, realtime water management, sustainable resources management, river and reservoir modelling, water quality monitoring*

ABSTRACT

The objective of the research project iWaGSS is the development and practical pilot implementation of an innovative water governance system based on new technologies and tools for mitigating water stress and for sustainable management of the water resources in the South African pilot region as well as in other regions with overstressed water resources in Africa and worldwide. Based on four main components – real-time online monitoring, hydrological modelling, risk assessment and socio-economic analysis – the sustainable water governance system (Figure 1) will support decision makers and improve governance processes in the water sector. By increasing the efficiency of water utilisation and protecting natural resources and ecosystems, the iWaGSS project shall contribute to solve the urgent challenges of the global resource water and to achieve the sustainable development goals (SDGs). The iWaGSS consortium consists of eight German partners from research and practice: Institute of Environmental Engineering and Management at Witten/Herdecke University, Environmental Engineering and Ecology – Ruhr-University Bochum, Institute for Water and River Basin Management – Karlsruhe Institute of Technology, Center for Development Research – University of Bonn, Disy Informationssysteme, LAR Process Analysers AG, Global Water Franchise Agency and Die Gewässer-Experten! The German partners are working in close cooperation with South African partners and stakeholders from public administration, academia, development cooperation, industry and civil society. Up to now, several field campaigns have been conducted to collect data and to assess the situation in the pilot region. The installation of the monitoring stations is in a final stage. The current project status and the main components have been presented and discussed with local cooperation partners and stakeholders in several workshops and meetings. The iWaGSS project has been considered by South African National Parks as essential for the Kruger National Park. SANParks supports the project with own resources and logistical assistance.

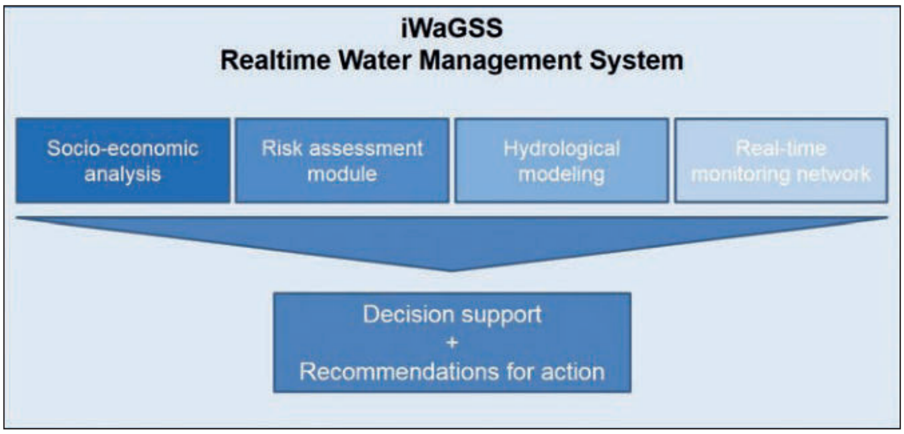

Figure 1: *iWaGSS Realtime Water Management System.*

INTRODUCTION

The Lower Olifants sub-catchment in South Africa has been chosen as the primary iWaGSS demonstration area including the Phalaborwa pilot zone (Figure 2). This pilot region has been selected in close cooperation with South African partners and stakeholders because the development of the region in terms of its ecological diversity and sustainability as well as economic progress and social stability is particularly vulnerable to water-related problems, including transboundary water issues. Thus, the chosen area can be seen as representative for other basins and should be appropriate to proof scalability and transfer of research and innovation results to other regions.

Figure 2: *iWaGSS pilot zone.*

Water uses and economic activity in the Olifants basin are diverse and range from mining, power generation, metallurgic industries, irrigation, subsistence agriculture and eco-tourism. The Lower Olifants sub-catchment is part of the UNESCO Kruger to Canyons Biosphere Reserve. This region – which includes the world renowned Kruger National Park (KNP), rural and peri-urban areas, copper and phosphate mining, subsistence and commercial farming – receives all the consequent pressures from upstream parts of the basin. The water quality of the lower Olifants River is influenced, inter alia, by return flows from mining and agriculture, for example in the Ga-Selati River. Deteriorating water quality at catchment scale (Ashton & Dabrowski, 2011) is not only threatening human health and KNP's animals and ecosystems but also the wide variety of ecosystem goods and services (EGS) that the catchment provides to society. To improve the status of the river and to strengthen the institutional governance framework in the region, a real-time water management system is to be developed. The practical demonstration area with the world-famous Kruger National Park serves as a flagship project for the global dissemination of the modular iWaGSS water management system.

METHODS

The project consists of 10 work packages:

1. Water Governance
   With a focus on economic aspects of governance and micro-level governance
2. Risk Assessment and Hydrological Modelling
   A combination of risk assessment tools and a 1-D hydrological model of the river system
3. Reservoir Modelling
   Numeric hydraulic modelling and morphodynamic simulation of the Phalaborwa Barrage
4. Realtime Water Quality Monitoring
   Installation and operation of a network of water quality monitoring stations
5. Data Management and Data Integration
   Development of a GIS-based realtime decision support and management system
6. Adapted Operation and Management Concepts
   Including wastewater management, water quality and emissions as well as water reuse
7. Transboundary Governance
   Focusing on impacts of transboundary water governance on people and nature protection
8. Remote Sensing
   Use of drones for river monitoring
9. Capacity Development
   Workshops and trainings
10. Dissemination and transfer of results
    Transfer of iWaGSS tolls and results to other river basins

INTERIM RESULTS AND DISCUSSION

Water Governance

Analysing water governance institutions and transboundary water governance in the Lower Olifants catchment, the project focuses on economic aspects of governance. With regard to the South African institutions, an implementation gap can be identified: South Africa has established a worldwide acknowledged body of water legislation (National Water Act 1998), but is struggling with its implementation. The implementation gap between the macro level (legislation, institutional framework) and the micro level (local institutions and water management practice) leads to water crisis, deterioration of resources, collapsing infrastructure and substandard services. Informal institutions and stakeholder groups are taking over some of the administrative and management functions (cf. Pollard et al 2011). iWaGSS is now focusing on utility governance on a micro-level scale taking (financial) incentives and economic aspects into account. With regard to transboundary water governance, the main issues are the impacts of current transboundary water governance on the provisioning and non-provisioning ecosystem services in the Kruger and Limpopo national parks as well as alternative transboundary water governance approaches and their transaction costs and economic benefits.

Water Quality Monitoring

Currently, iWaGSS water quality monitoring equipment has been installed permanently at three monitoring sites (Oxford, Sawong and Cleveland) at the Olifants River upstream the KNP border. Monitoring data of these stations will give a good overview of water quality from a) upstream parts of the Olifants catchment entering Phalaborwa barrage, b) Selati and Olifants water quality at the confluence and c) Olifants water quality before reaching the KNP border and flowing into the park. The water quality monitoring stations provide a real-time online toxicity analysis as well as monitoring of pH, conductivity, redox potential and weather/climate data. A large volume sampler has been installed at the Oxford station to determine the mass of transported sediments. Additional turbidity probes have been installed at Oxford and Sawong.

Field campaigns

Additional data (including aerial pictures, river-cross sections of the Olifants and Selati River as well as some minor tributaries upstream KNP, bathymetric and sediment remobilisation studies of the Phalaborwa barrage) has been collected during several field campaigns (Figure 3) using portable equipment like drones, acoustic doppler current profiler, echosounder and several samplers.

This data will be further processed and analysed to generate for example digital surface models of the river system and to calibrate hydrological models of the Lower Olifants catchment. Grab samples of water and sediment provide additional information on several locations in the project region.

Modelling

Combining aerial pictures of a drone with ADCP data seems to be a promising approach to generate river cross sections of high quality for the hydrological modelling. This approach will be further developed by eE+E, Die Gewässer-Experten! and the South African Council for Scientific and Industrial Research (CSIR). First models of both the river system and the Phalaborwa Barrage (Figure 4) have been created which will be evaluated and further refined.

Figure 3: *Field campaigns a) Sediment sampling (KIT), b) Bathymetric survey (KIT) and c) Analysing grab samples (LAR/SAEON)*

Figure 4: Phalaborwa Barrage – topography change over time (KIT)

CONCLUSIONS & OUTLOOK

The current status and first interim results have been presented and discussed with South African partners and stakeholders in October 2018. The project meets the needs of both water management institutions and water users in the region. Especially the modelling outcomes and the water quality data are expected to provide benefit for authorities and water management institutions as well as for water users and researchers. In addition, the assessment of the wastewater treatment plants and operational concepts for the water supply system including the management of the barrage are met with great interest. This is reflected by the strong support and various in-kind contributions of South African partners and stakeholders. Based on the interim modelling results of the sedimentation processes, alternative gate operations at the Phalaborwa barrage will be tested and analysed in 2019. A first transfer of the iWaGSS drone concept for river monitoring is now discussed with SANParks to generate a digital surface model of a remote river gorge at the Mozambican border. The unclear lines of responsibility and informal governance mechanisms in the water sector will be further investigated based on a case study of the provision of municipal water services including the financing mechanisms.

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go-CAM: Implementing strategic goals in Coastal Aquifer Management

Strengthening groundwater governance by means of system-relevant indicators

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Keywords: *Groundwater Indicators, Multiple-Criteria Decision Analysis, transparent Coastal Aquifer Management*

ABSTRACT

The main aim of the go-CAM-project is the development and application of an online-platform called CAM (Coastal Aquifer Management) which merges and analyses outputs of hydro(geo)logical models, water governance frameworks and socio-economic facts with multi-criteria decision analysis techniques (MCDA) to strengthen transparency and objectivity in decision-making processes among stakeholders in the water sector of coastal regions. CAM is thereby envisioned to facilitate the development of "best management practices" and enables the implementation of action plans through institutional capacity and stakeholder mobilization. In the framework of go-CAM several water-related case studies are carried out from physio-geographically varying coastal areas including North-Eastern Brazil, North-Western Germany, Turkey (Antalya) and South Africa (Eastern Cape). These serve as test-sites for the successful development of the CAM.

INTRODUCTION

Worldwide groundwater is the preferred source of drinking water due to its mostly outstanding natural quality. Therefore, groundwater reservoirs are of central importance to the 'resource-oriented' SDG target 6 of the UN Sustainable Agenda for 2030 to achieve security of water supply. At present, however, groundwater is not adequately expressed with respect to resource sustainability and quality protection. New physically based indicators are required which define groundwater status, risks and trends (Foster et al. 2017). To address these indicators and manage resources it is essential to fill gaps in scientific understanding of complex aquifer systems using numerical hydro(geo)logical models. This is even more challenging in coastal zones as respective groundwater abstractions are often restricted by the threat of a shift of the saltwater-freshwater interface towards inland which is particularly true at the shore-line of the Northern Sea in North-West Germany (Feseker 2007). Additional overuse of resources due to increasingly dense human occupation deteriorates the freshwater situation (Michael et. al., 2017). The degradation of the water resources is often increased by contamination from agricultural sources - and especially nitrate pollution – is still one of the most prominent concerns particularly in Germany (Salomon et al. 2016;). Further challenges are the still missing links between science, practice and policy that need to be overcome in order to address the continuing water quantity and quality problems in coastal zones (FAO 2016). Safeguarding a sustainable water supply depends not only on the available amount of groundwater, but also on the development of the future water demand. In this respect, important drivers are demographic change, climate change, technical progress and the future economic state of a region (Rohner 2018). However, water supply bottlenecks are not only the results of specific natural and hydrological conditions, but also significantly determined by the existing governance structures (Nölting & Mann 2018). Within this context the go-CAM project approaches the following targets:

- Improvement of scientific understanding of coastal aquifer systems using highly qualified numerical hydro (geo)logical modelling tools in combination with modern reconstruction techniques of the subsurface and complex monitoring systems.
- Derivation of new physically based groundwater indicators from modelling, socio-economic analysis and governance studies to evaluate and analyse the achievement of the SDG target 6.
- Development and application of an online dialogue platform called CAM (Coastal Aquifer Management) which merges information of numerical-model outputs, water governance frameworks and multi-criteria decision analysis techniques (MCDA) to fill the gaps between science, practice and policy.

METHODS

The project integrates the coastal study areas North-West Germany (Sandelermöns and Großenkneten, Lower Saxony), South Africa (Eastern Cape), North-Eastern Brazil and Turkey (Antalya). All case study areas are vulnerable to future changes (climate change, socio-economic change e.g. increasing tourism) and are located in agriculturally heavily used environments or are affected by saltwater intrusion. For all case study areas it is essential to evaluate and discuss the water management situation with focus on water stress and water scarcity and the development of future management practices. The international project partners include water agencies, water supply companies and local universities.

Several physically based modelling tools (hydrological modelling, hydrogeochemical modelling and groundwater modelling) and additional reconstruction and monitoring techniques are applied to asses current freshwater resources, understand flow conditions and solute transport and predict future conditions with regards to water supply, nitrate pollution and seawater intrusion. Different forecast scenarios as combinations of climate change scenarios and socio-economic scenarios are applied to consider the uncertainties of future development. Surface water balance components are calculated with the hydrologic modelling system PANTA RHEI for all case study areas. PANTA RHEI is a physically based hydrological model for both long term and single event simulations. All relevant water cycle components are calculated on a high temporal and spatial resolution. The simulated groundwater recharge forms the interface to the groundwater models. Future conditions are estimated using Euro-CORDEX data. For the density-driven modelling of groundwater flow and pollutant transport the code d^3f++ (distributed density-driven flow) is used, see Schneider (2016). This code has been developed with a view to the modelling of large, complex, strongly density-influenced aquifer systems over long time periods. It is based on finite volume methods and multigrid solvers and may be run on massively parallel computers. d^3f++ is used as model for the two target regions in Northern Germany and a further target region near Antalya/Turkey. In addition the MODFLOW based program SEAWAT is used to generate a density-driven hydrogeological groundwater model to predict possible changes of the saltwater-freshwater interface under different groundwater production plans. The model will be applied to the case study area Sandelermöns (Germany). For the reconstruction of the subsurface the powerful Geological Information System SubsurfaceViewer of INSIGHT is applied which is especially designed for the visualization and analysis of geological data of the near-surface range as well as for the creation of structure- and parameter models. Resistivity monitoring by a vertical electrode system is used to identify and to define the initial and boundary flow and transport conditions for density-driven groundwater movement and to develop an early warning system for seawater intrusion to support water management. In the framework of nitrate pollution hydrogeological and hydrogeochemical processes are further modelled using the program HST3D coupled with PHREEQC. These are fed with inputs from MODFLOW and PHAST. The modelling chain will be addressed to the case study area Großenkneten (Germany). An inventory of formal and informal water governance structures is set up particularly for the region Lower Saxony (Germany). Consequently the identified governance structures are checked for their appropriateness to deal with future challenges in the respective water sector. The main product of the project is the online communication or dialogue platform CAM (Coastal Aquifer Management) which should support decision-making. The spatially and temporally highly resolved modelling outputs should be manageable and visualisable via CAM and thus be transported user-oriented and practical for different stakeholders. Based on the model results, evidence-based indicators will be presented for assessing security of water supply through the CAM dialogue platform. Multi-criteria decision-making analyses e.g. Composite Programming are used in this context. Ultimately, long-term and sustainable options for action can be derived and evaluated interactively.

INTERIM RESULTS AND DISCUSSION

For all case study areas the hydrological models have been built up using the modelling system PANTA RHEI. The models are currently in the process of calibration and validation according to the data situation. Special challenges present the meteorological data situation in South-Africa as well as the hydrometric data situation in North-East Brazil. First climate change scenarios have been downloaded and analysed. The reconstruction of the subsurface focused on the regions Sandelermöns and Großenkneten (Germany) and North-East Brazil. Several steps have been carried out to develop the parameter models and address the specific challenges of the regions e.g. development of a Python parser for layer descriptions, test of different clustering-methods for the automated aggregation of lithological similar layers or test of machine learning methods for estimation of missing layer information. The density-driven model for the Sandelermöns region is a continuation of the works done in the former NAWAK-project. In the current project several challenges are addressed. Attention is focussed on the influence of different climatic and demographic scenarios to the position of the freshwater-saltwater-interface up to the year 2100. Further new measurements and additional data are successively integrated into the models to address the high sensitivity of the models to river drainage and improve the initial condition of the groundwater model using airborne electromagnetic data. Further works are carried out on the improvement of the numerical solvers to speed-up computations on finer grids. Computations are still ongoing. For the Großenkneten region a hydrogeological model was set-up in d^3f++. Works on nitrate transport are still in a conception stage. The challenge is to identify the significant chemical processes to be regarded in a regional scale model. The additional density-driven hydrogeological model of the saltwater-freshwater interface under different groundwater production scenarios for the Sandelermöns region using MODFLOW is in the development phase. For the study site in Großenkneten the underlying hydrogeological model is being calibrated and validated. A conceptual model for the numerical hydrogeochemical model that follows up on the hydrogeological model was developed. Further borehole drillings to derive hydrogeochemical parameters from subsurface samples are planned. For the development of an early warning system for seawater intrusion geoelectrical properties of the sediment layers are monitored. An important objective is to find a representative location for the monitoring system. The resistivity monitoring by the vertical electrode system SAMOS (Grinat et al 2018) covers a depth range of 20 m and is able to observe the transition zone towards the top freshwater aquifer. One system was installed recently, starting its monitoring in December 2018. It is planned to install a second system further east, where the depth of the saline water intrusion decreases. The exact horizontal position will be defined by a more detailed ERT (Electrical Resistivity Tomography) survey and the depth by geophysical borehole measurements. The concept and system architecture of the platform has been finalized and is currently in the implementation process. The architectural foundation of the platform is based on the open source GeoNode as a web-based application and platform for developing geospatial information systems (GIS) and for deploying spatial data infrastructures (SDI). GeoNode allows the easy and secure upload and storage of own data (modelling results, socio-economic studies, governance analyses) in the database server which will be published on the Local Geoserver of GeoNode as services (e.g. WMS, WFS). Regarding the modelling results a background process is implemented to store this data in the geodatabase. The main challenge is the integration of the interactive planning tools which uses MCDA techniques to evaluate data and scenarios. Interactive components should be the selection of indicators and weighting factors and the definition of objective functions. As indicators of particular interest have been defined: quality of raw water (chloride and nitrate concentration), location of the salt-freshwater boundary and distance to the pumping wells, trend of groundwater recharge, depth of groundwater table, volume of groundwater body, drought indices e.g. SPI, water budget, discharge through drainage and groundwater extraction. The development and transfer of the indicators and their objective function is in progress. Several international workshops have been conducted during the last year of the project to strengthen the cooperation and communication with project partners and discuss target regions, data availability and the modelling concepts.

CONCLUSIONS & OUTLOOK

Summarizing, the progress of the project shows first satisfactory results. The first challenging steps of data collection and concept development both for the modelling part and for the part of the online dialogue platform CAM are successfully finalized. For the Eastern Cape region, the availability of water from surface reservoirs is currently being modelled and possibilities for an additional source of supply from the regional aquifers are being examined. For the case study on the Antalya coast, model calculations are currently being prepared and the factors for the constantly increasing water stress are being identified. The go-CAM approach takes into account the UN SDG indicators, but adds additional factors such as available water quantity and demand. The temporal variability of the indicators and factors is considered. The weighting of individual indicators in the search for adaptation options is and remains a challenge. In this context, the concept of the project proposal, which involves a high degree of interaction and communication between different stakeholders (water agencies, water supply companies, agricultural chambers) already in the development phase of the CAM platform, proves essential in order to create a practice-orientated approach. We expect to be able to present a raw version of the CAM at the end of the year.

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MedWater: Sustainable management of politically and economically highly relevant water resources in hydraulically, climatically and ecologically highly dynamic carbonate groundwater aquifers of the Mediterranean

Quantification of large-scale and long-term groundwater recharge and water resources in karst aquifers under Mediterranean climate: deterministic versus stochastic approaches.

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Keywords: *Karst aquifer, Numerical Modelling, Water management, stochastic modelling*

ABSTRACT

Carbonate aquifers generally are highly vulnerable with respect to water availability and quality. Some of the key questions therefore are: what is the available quantity of groundwater, how can it be assessed and how will the water resource develop in the long-term? Therefore, one of the primary MedWater objectives is the optimal management of groundwater resources in carbonate aquifers in the Mediterranean climatic region. Frequently, the respective aquifers extend for hundreds of square kilometres and are characterised by low data density. Process-based deterministic and stochastic approaches are employed to quantify the hydrological processes at regional scale. Comparing these different techniques will allow us to assess i) the impact and relevance of specific model parameters and processes, ii) the need to replicate the hydrogeological history within the model, and iii) the validity and practicality of each approach with respect to scale and data availability. Model results shall be transferred to other carbonate aquifers in the Mediterranean employing an empirical hydro-pedotransfer function (HPTF) for different types of land cover, climate, degrees of karstification, and thicknesses of the vadose zone. The application of HPTFs to Mediterranean karst aquifers will enable us to determine daily recharge rates, just requiring easily accessible input data such as precipitation and potential evaporation which can be estimated from remote sensing data. Finally, the RCP 4.5 climate projection is used for scenario analyses that consider global, economic, and policy changes. Condensed modelling results are linked to a "data-based decision-support system" (DSS) to assist stakeholders with their water resource management strategies.

INTRODUCTION

Climate research shows that the Mediterranean region will be one of the „hotspots" of the predicted shifts in climate and will be affected by increasing water scarcity in the near future (IPCC, 2012). Projected climate change is expected to have a significant impact on the availability of food and water and ecosystem services. The interaction between external factors such as climate change, population growth, and land use requires adaptation strategies that consider specifics of a region, a high degree of system knowledge and regional development goals.

Carbonate aquifers constitute an important water resource because of their wide geographical distribution, large catchments, and their focussed discharge at individual springs. However, their usability is restricted by their low storage capacity and high transmissivity, explaining also their high system dynamics. Semi-arid regions are characterized by a high temporal and spatial variability of precipitation and thus groundwater recharge. Key issues of sustainable groundwater management of karst aquifers under Mediterranean climate are therefore the assessment of groundwater recharge at local and regional spatial-scales and the response of the subsurface to short-term, high intensity storm events and longer drought periods.

The groundwater system selected for the principal study is the Western Mountain Aquifer (WMA), a transboundary aquifer between Israel and the Palestinian Territories, with a size of more than 9,000 km^2. It was developed since 1950 and constitutes an important resource for both countries. The WMA is recharged by rainfall in the outcrop region covering an area of 2,000 km^2, mainly located in the West-Bank area. Natural discharge occurs via two major springs, the Yarkon/Ras Al Ain and Taninim/Timsah spring. The hydraulic behaviour of the WMA is strongly influenced by highly permeable conduits. Karst elements of the WMA extend to large depths, even to depths of 1,800 m below ground level. However, the distribution, the type of karst features and therefore the response to recharge events is highly uncertain. Therefore, one of the goals of MedWater is to identify the **optimal modelling concept for such a highly dynamic and complex system and to develop new management tools that are suitable to be applied by stakeholder within region.**

METHODS

In order to predict the dynamic response of the aquifer system, comprising two compartments, a highly conductive, low storage conduit system and a low permeability high storage fissured aquifer matrix, the FE-code HydroGeoSphere (HGS) is used to simulate the coupled hydrological-hydrogeological system with a deterministic multi-continuum approach. HGS simultaneously simulates the unsaturated zone and groundwater flow. The surface-subsurface flow regimes are coupled via a first-order exchange term to account for diffuse and rapid direct recharge. This concept is expected to accurately represent the characteristics of the rock-soil landscape, local recharge along karst features, transmission losses of ephemeral streams (wadis), and erratic precipitation pattern. Due to the large number of hydraulic parameters simulation results are subjected to considerable parameter uncertainty. Therefore, the regression-based polynomial chaos expansion according to Miller et al. (2018) is used to approximate parameters and to reduce required number of simulations considerably.

The above technique is employed to investigate the relevant processes and their interaction. However, to consider more optimal parameter uncertainty and to take into account data scarcity a stochastic single-continuum modelling concept using the FD-code MODFLOW is developed. Here, the unsaturated zone is not simulated and also the exchange between high permeable conduits and matrix is neglected, which is acceptable for large time steps (e.g. 1 month) and for management applications.

The single-continuum model is parameterised with a stochastic prediction of the karst networks distribution using a new pseudo-genetic algorithm (Stochastic Karst Simulator SKS, Borghi, 2012). Parameterization and location of the karst features are defined with probability density functions (PDF). Based on the PDF-information, a karst conduit network is generated that connects recharge areas with discharge points. Locations of assumed individual karst conduits and the geometry of the karstified horizons, assessed based on geophysical borehole data, are used for parametrization (Figure 1).

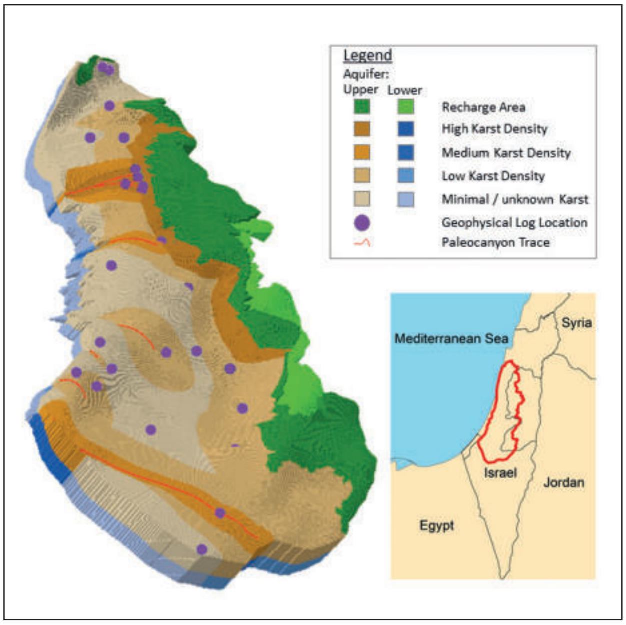

Figure 1: Numerical Groundwater model and key karst features implemented into the stochastic modelling concept

Both numerical flow models are calibrated using an inversion of time series of piezometric pressure heads and spring discharge measured between 1951 – 2006.

Both numerical approaches require a quantification of groundwater recharge. The management of the groundwater resource relies on an appropriate estimation of recharge that captures the influence of the unsaturated zone, semi-arid climatic conditions, extreme precipitation events, and periods with high draught intensity on the recharge total as well as its temporal distribution. In the HGS-model model groundwater the recharge distribution is directly simulated, while the stochastic model requires an external recharge calculation as source term.

Calculation of recharge is based on i) a spectral analysis (SA) and ii) on the development of a Hydro-Pedotransfer function

(HPTF). The SA consists of a cross-spectral analysis and compares input and output time series of the karst system, precipitation and spring discharge, respectively. Then the relation between input and output is examined and a transfer function (TF) is derived that represents the entire karst system behaviour and its hydrological characteristics using a set of lumped parameters. Our SA analyses spring discharge of a sub-catchment of the Eastern Mountain Aquifer (EMA) because high-resolution long-term data are only available for this region. The Hydro-Pedotransfer function (HPTF) calculates water fluxes in the unsaturated zone for synthetic scenarios considering variations in climate, land cover, soil type, degree of karstification, epikarst thickness, and depth of the groundwater table. Setting the percolation rate into correlation with the boundary conditions of the synthetic scenarios, the HPTF is derived with a non-linear multiple regression analysis. Data from remote sensing is employed to apply the HPTF for other Mediterranean karst aquifers.

Finally, using simulation of regional climate projections (scenario RCP 4.5) for Israel until 2071 (Hochman et al, 2018) scenarios are calculated considering predicted water demand based on population growth and changes in agriculture, industry, and land use.

FIRST RESULTS AND DISCUSSION

For the design of the karst network it is necessary to reconstruct the karst-genetic development. Carbonate rocks of the WMA were folded during the Oligocene into several NNE-SSW-trending anticlines (Bar et al., 2008). Subsequent erosion of these anticlines resulted in today's recharge areas in the Judean Mountains. Major changes in sea-level, especially during the Messinian Salinity Crisis, drove the formation of deep, multi-layer karst conduit systems (Laskow et al. 2011). Vertical distribution of conduits was controlled by i) the sea-level changes and consequently ii) the depths of new canyons draining the entire catchment. Especially within the coastal plain highly permeable karst was developed, explaining the low South-North trending hydraulic gradient. Karst conduits also cross the aquitard connecting Upper and Lower Aquifer. Our numerical model consists of 3 layers, representing the Upper and Lower sub-aquifers of the WMA, which are confined close to the coastal plain. The Hydrological Service of Israel (HSI) provided GIS-data of the geology of aquifer horizons and the outcrop area. Further data of the aquifer geometry are taken from Abusaada & Sauter (2012). Currently, the HSI manages groundwater abstraction based on 3 regional aquifer management "cells". For these cells average groundwater levels and therefore available resources are calculated that form the basis of future pumping rate. Further geophysical and geological borehole data are provi-ded by the Geophysical Research Institute of Israel and MEKOROT. Climatic data, such as temperature, precipitation, wind speed, humidity, and evaporation are provided by the Meteorological Service of Israel. In the future additional data of soil moisture and spring discharge will be collected. Spring discharge is available for some Eastern Aquifer catchments (Auja, Ein Sultan) since the 1960s and since 2008 at high temporal resolution, the basis for the SA analysis.

The deterministic model is parameterized into discrete parameter zones. Hydraulic conductivity, specific storage coefficients of the fissured matrix and conduit, respectively, are defined according to literature values with increasing hydraulic conductivities towards the springs. For the stochastic model a karst genesis model generates a 3-D karst probability field. The different degrees of karstification are converted into hydraulic parameter fields. This process will result in a catalogue of groundwater models representing different types of karst aquifers. The ensemble of different models generates a range of equally probable results. Detailed information on the geology and the karst aquifer genesis will assist in the selection of the most likely groundwater model. The stochastic concept is suitable to parameterize large-scale systems with only a limited number of data available and depends less on the avail-

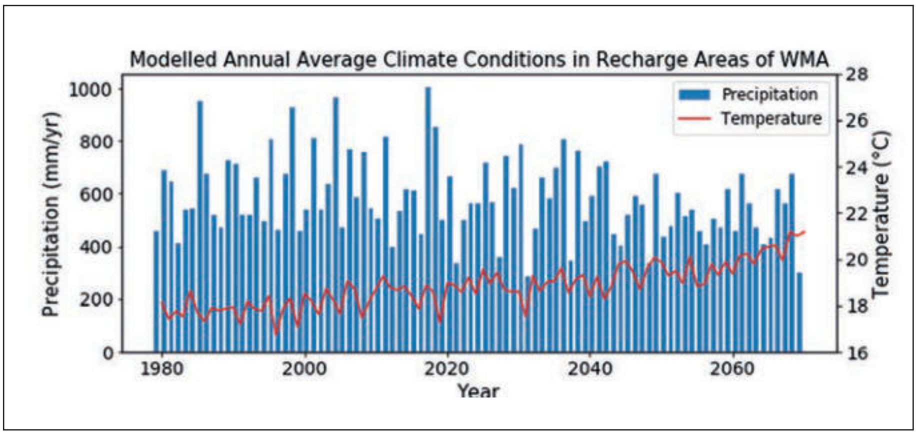

Figure 2: Predicted shifts in climate for the recharge area based on daily simulated precipitation and temperature of a regional climate model over Israel.

ability of high-quality observation time series. However, our deterministic model has the advantage of simulating the event-driven temporal pattern neglected by the single-continuum model which is matched less appropriate with the stochastic approach.

The response of the aquifer to changes in climate and socio-economic conditions is analysed by forward modelling. Climate data from a high-resolution (~8 km grid) regional climate model (Hochman et al., 2018) for 2041-2070 show that during winter mean temperatures will rise in the recharge area by up to 2°C, and that total precipitation depth will decrease by up to 20% (Figure 2). Climate modelling indicates that a larger proportion of rainfall will precipitate during extreme events with an increase of 10% in the Northern recharge area. However, this trend is not reflected in other parts of the recharge area.

Three socio-economic scenarios are defined: the "Trend" scenario updates the current trends in land use and water management, a steadily increasing population and moderate increase in imports of food/virtual water. The "Nature Conservation" scenario considers a drive towards more sustainable land use, a lower rate of population growth, and a strong increase in imports of food/virtual water (requiring less water to be abstracted locally). The "Economy" scenario includes maximal land use, but also maximal and efficient development of water resources (seawater desalination, artificial groundwater recharge). For this final scenario, imports of food would be reduced, requiring more locally produced water to be used for agriculture. A more dramatic population increase is included. The model results of the scenario simulations constitute the basis for the DSS. The DSS consists of three interlinked components: (1) an import routine to convert model results and configuration files into the DSS data environment, (2) a control environment to change the configuration files, and (3) a graphical user interface (GUI) to visualize the modelling results. Specific input files and scenario results can be requested and visualized by a browser based DSS client. Additionally, the DSS allows the user to change pumping rates or to add wells independently. The visualization of the results provides grid cell based information heads and total water budget as well as sustainable yield for specific times and locations as a basis for decision making by the stakeholder.

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TRUST: Sustainable, fair and environmentally sound drinking water supply for prosperous regions with water shortage: Developing solutions and planning tools for achieving the Sustainable Development Goals using the river catchments of the region Lima/Peru as an example

Solutions and planning tools for water supply and wastewater management in prosperous regions tackling water scarcity

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Keywords: *Remote sensing, monitoring, water balance, risk management tool, water and wastewater concepts, conflict analysis*

ABSTRACT

Innovative solutions and planning tools for safe drinking water supply and sustainable wastewater management are the focus of the TRUST project. In many prosperous regions of the world population and economic growth in combination with competing water demand often lead to water scarcity, i.e. higher abstraction than natural regeneration. TRUST tackles this challenge by combining satellite-based remote sensing techniques, microbiological and chemical monitoring and water balance modelling with decision support tools, water supply and wastewater management concepts and inclusive procedures for the conflict analysis of interests and goals. The focus area of the project is the Lurín catchment in Lima/Peru. In strong cooperation with local partners (Peruvian water authority, water company of Lima and communities in the upper and lower catchment area) the developed tools and concepts are implemented and tested for their transferability to other regions. The main findings so far include the development of innovative and integrative water supply, wastewater disposal, treatment and reuse concepts for the upper and lower catchment area. These concepts will be evaluated using SDG indicators, national standards and criteria determined through participatory processes involving local stakeholders. This will create concepts for access to safe drinking water and wastewater disposal that are tailored to local hydrological, geographical, social, cultural and political conditions.

INTRODUCTION

Achieving the UN Sustainable Development Goals (SDGs) is a major challenge for planning, governance and water management – especially in prosperous regions with water scarcity. Climate change is exacerbating water shortages in regions that are already struggling with water scarcity. Particularly in regions with fast-growing urban centres, the demand for safe drinking water and sanitation, irrigation water for agriculture and process water for industry is growing, and often already outweighs the renewal rate of surface and groundwater.

Achieving the SDGs in the water sector in these regions requires stronger interdisciplinary approaches for solving specific challenges. These challenges include, in particular, incomplete monitoring of polluted and overexploited water resources, competitive pressure over limited water resources and resulting social conflicts and the rigidity of existing infrastructures and planning tools in the face of changing frameworks for water supply and wastewater management systems. The main research questions that are addressed in the TRUST project are threefold:

1. How can remote sensing techniques and hydrological modelling be applied for assessment of situation, prognosis of changes in qualitative and quantitative status of surface waters?

2. How can methods of conflict analysis combined with participatory processes be used to prevent conflicts and thus, for future-oriented strategic planning?

3. Which kind of integrated water supply and wastewater management concepts are applicable, considering evolving boundary conditions (e.g. demographic development, seasonally changing availability of water resources)?

These questions are closely interwoven, and thus require an inter- and transdisciplinary approach, which combines expertise from researchers and practitioners of natural sciences, engineering and social sciences.

METHODS

The focus area of the project is the Lurín catchment in Peru. The Lurín River is one of three rivers that supply the capital Lima. Although the Lurín River itself has hardly been used for water supply of Lima so far due to the strong seasonality of the runoff, ground water extraction is high. The study area combines typical characteristics of prosperous regions of the world, characterized by water scarcity and complex governance structures on the one hand, and data scarcity and partly extreme climatic conditions on the other hand. A fundamental part of the work in the Lurín catchment consists of characterizing the catchment and the water resources quantitatively. Towards this goal, terrestrial observations, remote sensing data, and hydrological modelling are combined. Data on discharge, precipitation or meteorology are available, but mostly from neighbouring catchments, and not always in the desired quality or resolution. The monitoring in Lurín is therefore complemented with rain gauges, water level gauges, and a meteo station. The newly collected data will be analysed together with historical data from Lurín and current data from the neighbouring catchments (Chillón and Rímac), which are already monitored more extensively. Setting up hydrological models like mHM (Samaniego et al., 2010) or WASA (Mueller et al., 2010), which will enable scenario-based analyses, additionally require comprehensive derivation of land use, soil and topographic data using remote sensing techniques.

Trust uses hyperspectral cameras (e.g. in the SWIR spectrum, 950nm - 2500nm) statically and on flexible small platforms like drones; furthermore, the local measurements are expanded on larger scales through the EnMAP satellite mission (400nm - 2500nm). These data are used to i) develop and implement a spatio-temporal context-based classifier, from which the general type and the temporal change of land use can be monitored, ii) develop and implement descriptors specifically designed for irrigated areas, iii) develop image analysis methods to derive the soil type in the project region, and iv) to derive parameters of spectral signatures for characterizing the water hygiene. The latter is also developed and tested at the Klingenberg reservoir in Germany, in cooperation with the Saxonian state dam authority (Landestalsperrenverwaltung Sachsen).

The sociological analysis in Trust is based on a thorough stakeholder analysis (supported by literature review and on-site interviews), characterizing actors from different sectors (e.g. state, economy, civil society), and different levels of action (global, national, regional, local) throughout the (upper, middle and lower) catchment area of the Lurín River. Actors are classified according to their objectives, resources as well as bargaining power. This allows identifying relevant actors, how to include them into the participatory activities of the project and to anticipate interests and positions towards different policies, as e.g. towards varying options for wastewater treatment and reuse. It is followed by an analysis of (latent) water conflicts: With the help of the cross-impact-balance analysis (CIB) (Weimer-Jehle, 2006), interrelations and effects of different policies are analysed to identify (latent) goal conflicts and to bundle integrated policy mixes that avoid contradiction, but could help to reach the different goals of the various water users at the same time. The feasibility (e.g. political will, acceptability etc.) of these policy mixes is then dealt within dialogues with the actors of the catchment area.

An analysis of the local water cycles on a catchment scale based on an extended Water Accounting approach (FAO, 2016) is the basis to develop integrated concepts for water supply, wastewater management and reuse in cooperation with local stakeholders. These concepts are developed for rural areas in the Andean Mountains at over 3000 m a.s.l., urban and semi urban areas in the lower catchment as well as formal and informal settlements. Using an adopted PINCH-technology approach, local potentials for a more efficient water use and reuse are identified. In a final step the potential contributions of these integrated solutions to the achievement of SDG 6, national policy objectives and local stakeholder needs will be evaluated. A pre-feasibility study will be conducted for selected concepts.

Finally, a decision support system (DSS) for ensuring and increasing the security of drinking water supply and to foster preventive and sustainable protection of water resources is developed (Gottwalt et al., 2018). The methodological approach supported by the DSS is based on the Water Safety Plan approach (WSP) suggested by the WHO as a globally applicable instrument for achieving strategic goals for clean drinking water at a local level (Bartram et al., 2009). The DSS helps to install and operate a systematic risk management for drinking water resources and establishes a basis for the development of monitoring systems and further measures to ensure drinking water quality. Building-up a database of all relevant data and information also prevents redundant data acquisition, input and storage. In general, the homogeneous documentation will reduce efforts for data administration and maintenance.

INTERIM RESULTS AND DISCUSSION

The discharge regime of the Lurín River is characterized by a pronounced seasonality due to the seasonal rainfall input, which is essentially restricted to the upper parts (> 2000 m a.s.l.). Other significant aspects are the infiltration into the groundwater and a multitude of local, small-scale water management structures like reservoirs and channels for irrigation and infiltration. Especially the data on rainfall input is highly uncertain, as the upper parts are not sufficiently covered by monitoring stations. A correlation of observed monthly rainfall sums with elevation was found to be the most reliable grounds for extra- and interpolating existing rainfall stations.

Land use and land cover changes for the Lurín region in Peru can now be estimated with deep neural networks and long short-term memory networks. The descriptors for irrigated areas are implemented with supervised and unsupervised machine learning approaches such as Self-Organizing Maps (Riese & Keller, 2018).

Based on literature review, online search and local interviews, actors of the upper, middle and lower catchment area have been mapped and categorized according to presumed attitudes towards or influence on innovative water supply and wastewater concepts (internal report available) and supports identification of relevant actors and their possible interrelations. Against the background of a city-country conflict, several types of latent conflicts have been identified in the Lurín catchment area: value conflicts and conflicts of visions, governance and power conflicts, as well as goal and policy conflicts. The project focusses on the latter two. Based on the analysis of interviews, literature, policy reports, expert input as well as a stakeholder workshop in Lurín, an overview has been established on the central aims of the different water users throughout the catchment including alternative policies that reach these different goals. In the next months, interrelations and effects of policies (also on SDG 6) will be evaluated with the help of interviews with experts in Germany and Peru.

Several integrated water supply and wastewater treatment and reuse concepts for urban and rural areas have been developed, which are discussed and will be consequently improved jointly with local stakeholders such as authorities, user groups, water companies. In the catchment area there is a high potential for reuse of treated wastewater, especially in the urban areas, where the annual wastewater flow is about the same magnitude as the mean flow of Lurín River. Results indicate so far that there is additional potential for groundwater recharge in the catchment area. Main challenges are planning and designing of appropriate wastewater treatment plants for safe wastewater reuse.

The locally adapted integrated water supply and wastewater treatment concepts have been evaluated and discussed on local level with stakeholders in the upper catchment as well as on regional or national level with decision making entities such as regulators or water suppliers (upscaling of possible local solutions). It became apparent that a deficient coordination between several actors and a lack of authority, i.e. scarce regional water governance, are main challenges. According to relevant actors, the implementation of water supply and wastewater treatment solutions depends strongly on local acceptance of the techniques as well as on maintenance and operation capacities of the responsible companies or community members (ownership). Empowerment of stakeholders at all levels has to be taken into account with regard to the proposal of feasible integrated concepts.

A prototype of the DSS is being implemented as an interactive, web-based software system for defining, describing and assessing all risks in the catchment area of a water-supply system. Further it allows the documentation of measures for risk management. In contrast to existing tools for WSP support, the Trust system is based on a geographic information system (GIS), which helps to analyse and manage risks in a spatial context, using GIS data on land-use, topography, soils, risk sources, and water-extraction points.

All implementation efforts are accompanied by capacity development activities.

CONCLUSIONS & OUTLOOK

The planning of water management measures and development of scenarios may benefit from data of various kinds and of different sources. A minimum network of monitoring stations is essential, but remote sensing offers increasing possibilities for detecting and monitoring spatial variables and parameters. The combination of both provides the opportunity for setting up more site-specific hydrological models for the Lurín River. Involving stakeholders and organizing local collaboration in the study area is time-consuming, but is absolutely necessary and fruitful at different levels. Stakeholder analysis serves as a base for the derivation of participation strategies and tools during evaluation workshops for water supply and wastewater treatment concepts and future stakeholder dialogues. Since in-depth stakeholder analysis is complex, it needs constant revision and refinement. The Trust research questions tackle urgent and salient problems in the area. The local and national stakeholders so far evaluated the developed water supply and wastewater treatment concepts as promising and applicable. Regulatory authorities indicate financial opportunities for implementing the rural water concepts with a local water fund. The local communities and the water and wastewater company of Lima are very cooperative and interested in jointly developing integrated solutions including planning and technical implementation of local pilots.

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InoCottonGROW: Innovative impulses reducing the water footprint of the global cotton-textile industry towards the UN Sustainable Development Goals

Reducing the water footprint of the global cotton-textile industry towards the UN Sustainable Development Goals

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Keywords: *Water footprint, cotton, textile, wastewater, UN-Sustainable Development Goals*

ABSTRACT

InoCottonGROW aims at contributing to sustainable water use along the entire cotton-textile value chain „from cotton field to hanger". In case studies in Pakistan, a major supplier of German textile demand, our goal is to advance the water footprint (WF) concept to become a meaningful regional steering instrument for national decision makers in managing scarce water resources and for German consumers in making informed choices when purchasing textiles.

In cooperation with Pakistani partners, an inventory analysis of current water consumption and levels of pollution are conducted using multiple methods (M1-M7) in cotton farming and textile industry. The WF approach is extended to a region-specific impact assessment to quantify the impact the cotton-textile industry has on water scarcity, human health, ecosystems, and freshwater resources. Five demonstration projects (D1-D5) assess technical options for WF reduction. Strategies towards a more flexible irrigation scheduling and controlled deficit irrigation allow to increase water productivity, efficient textile machinery and resource-efficient dyestuff reduce water use, and wastewater treatment options improve effluent water quality. While each option is urgently important, from a WF perspective, the installation of functioning wastewater treatment has a main impact on reducing cotton-textiles' WF.

Five scenarios of how the cotton-textile industry can contribute towards achieving the UN-Sustainable Development Goals (SDGs) are discussed. By producing documentary videos, an internet-based WF tool, and assessing integration of the WF concept into textile labels, the project aims at raising the awareness of internationally operating brands, retailers, and German consumers for sustainable consumption. A 12 min video documentary is available on **https://www.inocottongrow.net/**

Figure 1: Anaerobic textile wastewater treatment produces biogas for water heating (© FiW)

INTRODUCTION

Pakistan is the world's fourth-largest producer of cotton. German demand for water-intensive cotton textiles (jeans, T-shirts, towels, and many others) has a major impact on water scarcity and water pollution in the mostly Asian manufacturing countries, where population growth and climate change further exacerbate the water-related challenges. The irrigation of cotton plants as well as dyeing and finishing processes in textile production require large quantities of water. In addition, rivers, soil, and groundwater are polluted by salinization, application of pesticides and fertilizers, and the discharge of untreated textile wastewater. The Indus basin in Pakistan sustains one of the world´s largest irrigation systems. Water is diverted by a hierarchy of 56.000 km of irrigation canals from mains, branch, and distributaries to watercourses for field application. Cotton is grown in Kharif season from April/May to October, with Monsoon rain in July to September. Allocation of irrigation water among farmers is organized by certain formal and informal rules known as the Warabandi system, in which water is allocated proportional to each field size in a strict rotation. Leaking canals, low field application efficiency and water theft results in a head-tail problem leaving the farmer at the tail-end to depend on often saline groundwater that is 15 to 20 times more expensive than canal water due to drilling and pumping costs – mainly cotton farmers since cotton is a comparably drought- and salt-resistant crop. In textile manufacturing, textile finishing is by far the most water-intensive process. Most textile mills operate own groundwater wells for freshwater supply. Only few have functioning wastewater treatment plants installed, and even if installed, activated sludge treatment processes are hardly operated due to high energy costs. Mainly untreated wastewater is thus discharged via open, partly unlined central drains into the river Ravi and Chenab. Percolation of untreated wastewater contaminates downstream ecosystems, groundwater pumped for irrigation, and drinking water supplies.

METHODS

The Lower Chenab Canal (LCC) is the main study area (15,700 km^2, irrigation water entitlement approx. 8 billion m^3/year, 12 million inhabitants). A combination of methods is applied in WF inventory analysis and impact assessment, including (M1) satellite remote sensing, (M2) field experiments and crop-irrigation modelling, (M3) hydrologic and (M4) hydraulic modelling, (M5) survey on the institutional framework of water use in cotton farming, as well as (M6) textile company audits, and (M7) laboratory and full-scale dyeing trails in textile finishing. Five demonstration projects illustrate strategies for WF reduction: (D1) flexible irrigation strategies to increase irrigation water productivity, (D2) water-saving textile machineries, (D3) resource-efficient dyestuffs, (D4) textile wastewater treatment by anaerobic treatment of highly polluted wastewater of desizing, (D5) pollutant analysis and regulatory enforcement of wastewater effluent standards.

INTERIM RESULTS AND DISCUSSION

Water Footprint as a Regional Steering Indicator

Regional water consumption of cotton was calculated based on hydrological modelling results (M3 below). In the irrigation subdivision Tarkhani, for example, the green water amounts to 1,681 L and blue water to 2,415 L/kg raw cotton, which is approx. 50% (for green water) and 30% (for blue water) higher than previous literature data for Punjab (Mekonnen & Hoekstra 2011), which do not consider regional patterns in crop evapotranspiration.

A regional Water Scarcity Footprint (WSF) was calculated based on the WAVE+ model (Berger et al. 2018). In Tarkhani, the WSF amounts 2,261 L deprived/kg cotton. The Grey WF was calculated for cotton farming (based on nitrate leaching from fertilizer application) and textile production (based on COD and other wastewater parameters). For the cotton cultivation, Grey WF varies between 1,035 and 4,582 L/kg raw cotton depending on the calculation method (leaching factor, water quality threshold). For the textile production, Grey WF amounts to 1,108 L/kg textile with BOD5 being the most penalizing pollution. For regional impact assessment, four cause-effect chains are considered: (I1) impact of irrigation water use on water scarcity, loss of yield, costs for groundwater pumping, income loss and malnutrition, (I2) impact of irrigation water use on reduced water flow and damage to aquatic ecosystems, (I3) impact of water pollution on human health, and (I4) toxicity to aquatic ecosystems.

Inventory Analysis

(M1) In satellite remote sensing, both unsupervised and machine-learning classification approaches are utilized for land use land cover mapping using MODIS NDVI data at 250 m and Sentinel 1 & 2 data at 20 m spatial resolutions. All major crops of spring (Rabi) and monsoonal autumn (Kharif) cropping seasons including cotton, wheat, rice, and sugarcane are classified from 2005 to 2017. In this period, cotton was grown in Punjab province on 2.35 ± 0.21 million ha (47% of cultivated irrigated land). In LCC cotton is less dominant (15% of irrigated land), grown mainly in the tail end of the irrigation system. Accuracy assessment is performed by using multiple approaches including official crop inventory and own ground-truthing surveying 1,400 locations. Ongoing research estimates cotton yield, crop specific consumptive water use, and irrigation system efficiencies. Analysis and ground-truthing of a study site in Söke, Turkey is conducted for comparison.

(M2) The current practices and techniques in cotton irrigation are analyzed bottom-up from field to farm, watercourse, and distributary canal level in Mungi Disty. In the period mid-May till mid-November 2017, a gross irrigation amount of 370 mm was inflow to Mungi, in addition to 184 mm of effective rainfall. An irrigation scheduling model (FAO-AquaCrop) was used to estimate the crop water demand of cotton considering daily meteo data, soil, crop features, and an irrigation supply interval of 7 days (Warabandi fixed rotation) and an irrigation amount at field level of 358 mm (based on a technical irrigation efficiency of 50% and a groundwater reuse by pumping 90% of the irrigation losses. These simulations lead to a raw cotton yield in the range of 2.2 t/ha which matches yield level in Mungi. Changing the irrigation interval from 7 to a 14-day rotation leads to 40 mm less evaporation losses.

(M3) A hydrological model (SWAT) was set up for the LCC area. Focus was put on modelling the changes of evapotranspiration rates as a proxy for changes in future water demand caused by changing land use patterns, alternative crop management strategies, and climate change scenarios. Remote sensing and ground station evapotranspiration measurements were used to calibrate and validate the model. Results show that optimized irrigation techniques examined in M2 can help to reduce irrigation water demand in LCC area by up to 20%. Reducing water demand by crop shifting according to local climatic patterns and climate change scenarios are currently assessed.

(M4) Groundwater hydraulic head hydrographs of 588 wells suggest that groundwater levels are constant or even rising in the study area for the last decade. Trends of falling groundwater were observed in 33% of the wells, located partly in the tail end of the irrigation system. A groundwater flow model (FEFLOW), considering all major irrigation channels, was set up for the Rechna Doab including LCC. The model utilizes groundwater recharge data of M3, classified land use data of M1, and abstraction rates given by farmer interviews in M5. Budget analysis suggests that leakage from irrigation channels is the largest single contributor to the groundwater balance. A validation of the groundwater model using GRACE satellite data is ongoing.

(M5) A detailed analysis of water laws, rules in use, and everyday practices in the province of Punjab provides a conceptual framework for proposals to improve the water efficiency in irrigation. A survey conducted in 2018 with 150 farmers in three districts in Punjab confirms a deficit in the representation of farmers as well as in communication between different levels of organization. Furthermore, monitoring and sanctioning mechanisms are only marginally applied. Thus, harmonizing formal and informal rules and coordinating responsibilities between different hydraulic levels in Pakistan are most crucial for a sustainable irrigation management.

(M6) Company surveys identified some 85 textile finishing plants in the Greater Faisalabad area, discharging approx. 100 million m^3/year of mainly untreated wastewater via central drains into the rivers Ravi and Chenab. To our information less than ten of these 80 finishing plants maintain activated sludge effluent treatment plants in steady operation.

(M7) The dyestuff chemicals employed, machine types and ages, but also operators´ experience determine the water use and wastewater production in textile finishing. Online log recordings of exhaust dyeing machinery operated in Pakistani companies revealed that dyeing light color shades currently uses 29 to 36 L/kg, dark color 35 to 50 L/kg and extra dark up to 69 L/kg. Laboratory and full-scale black dyeing trials of jersey fabric using advanced dyestuff and optimized processes in Germany show that up to 50% of water use reduction appears possible under certain conditions. Testing methods to assess color hue, strength, and color fastness to washing, rubbing, light and perspiration assured that in most cases product quality was not impaired.

Demonstration Projects

(D1) Improved scheduling strategies and advanced handling of irrigation techniques enabling a higher efficiency, effectiveness, and productivity of irrigation water and salt management are derived and tested at the University of Agriculture Faisalabad (UAF) WMRC test site and considered under real conditions in Mungi Disty. Field experiments consider different irrigation methods (furrow, raised-bed, drip) as well as full and deficit strategies. Experiments show that full irrigation by a drip system enables a yield of 3.25 t/ha raw cotton with an application efficiency of 83% and water productivity of 0.68 kg raw cotton per m^3 gross water input. Furrow irrigation was applied without deficit, and 10% and 20% deficit (related to evapotranspiration). Yields of 2.95, 2.64, and 2.35 t/ha raw cotton and efficiencies at full level of 64%, 71%, and 80% showed that in deficit irrigation lower gross water input (higher efficiency) compensated lower yields. Therefore, water productivity was rather constant at approx. 0.48 kg raw cotton per m^3 gross water input.

(D2/D3) At a textile finishing plant in Lahore, installation of a Thies DyeControl in existing iMaster exhaust dyeing machinery for online opacity measurements of the liquor to optimize rinsing time and number of rinsing baths resulted in a decrease of water use for black shade dyeing from 69 to 52-62 L/kg textile. Overall, a reduction of 10 to 15% of water use for textile finishing seems feasible by installing water efficient textile machinery. Introducing efficient dyestuff have not yet been conducted at any of the Pakistani cooperation partners, suggesting that companies are not yet fully convinced to pay higher prices for dyestuff despite the undisputed water and energy savings demonstrated within laboratory and full-scale demonstrations in Germany.

(D4) A pilot-scale anaerobic treatment of desizing wastewater has been planned, build, shipped, commissioned, tested, and optimized at Kohinoor Mills Ltd. textile factory south of Lahore to demonstrate the effectiveness of anaerobic pretreatment of heavily organically polluted wastewater of the desizing process. During pilot-plant operation a COD reduction of approx. 55.7% was achieved, while biogas at a specific methane yield of 0.25 m^3/kg COD was produced. A highlight was burning the produced biogas to boil a pot of tea in front of the factory employees to proof that wastewater can produce energy (Figure 2). A cost-benefit analysis that was conducted suggests that a projected full-scale anaerobic plant is financially viable given Pakistani energy prices, although payback period of ≥ 16 years is long.

(D5) Multi-parameter groundwater sensors installed at UAF test site monitor percolation under agricultural fields. The process of providing analytical instruments to Punjab authorities indicate that authorities are currently not in a position to routinely measure and thus control existing textile effluent standards. International brands and retailers are the key drivers increasingly mandating improvements of those textile manufacturers which produce for western markets.

CONCLUSIONS & OUTLOOK

InoCottonGROW identified several technically feasible measures to increase the efficiency and productivity of water consumption and to reduce water pollution along the cotton-textile value chain. Combining individual measures to different policy scenarios, including (S1) making the most of the current system, (S2) many pennies make a dollar, (S3) think big, (S4) regional shifting of water or crops, (S5) quality instead of quantity, are compared to a baseline scenario to investigate how implementation of these measures could contribute to achieving selected UN-Sustainable Development Goal targets in Pakistan. The baseline scenario is currently under development considering population growth, climate change, and land use change projections.

Workshops with Pakistani farmers' organisations, textile companies, water boards, and authorities are conducted to discuss policy options for implementation. In May 2018, Pakistani decision makers were invited to Lippeverband in cooperation with the Gesellschaft für Internationale Zusammenarbeit (GIZ) for a knowledge exchange on Integrated Water Resource Management, which is still fragmented in Punjab. A Mid-Term Conference with 100 participants, scientific presentations, training sessions, and policy seminar took place at University of Agriculture Faisalabad in January 2019.

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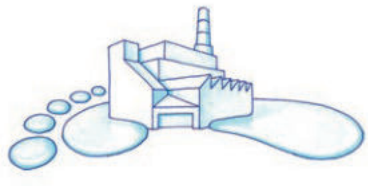

WELLE: Water footprints in companies: Organizational Water Footprint – Local measures in global value chains

WELLE: Organizational water footprint – local measures in global value chains

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Keywords: *Organizational water footprint, water stewardship, water risk, sustainable supply chains, case studies*

ABSTRACT

The WELLE research project aims to develop methodological and practical solutions for determining the overall water scarcity footprint of companies. Besides considering direct water consumption at production sites, WELLE's approach also takes account of the local effects of indirect water use in upstream energy and material chains. The method development is performed by i) reviewing and evaluating existing methods for assessing water-related environmental impacts of organizations and ii) combining the existing product-related water footprint approach and the organizational life cycle assessment method. To make the method applicable in practice, guidelines for companies are developed. The applicability is ensured through a water inventory database, developed to satisfy the industry partners' needs for regionalized water consumption data depicting their supply chain. An online tool for calculating a company's water footprint according to the organizational water footprint method developed in the project will be made available. These products are tested in four case studies. Deutsches Kupferinstitut assesses the water footprint of the European copper cathode production; Evonik compares two amino acids production lines for methionine and lysine located in facilities in Belgium and the U.S.; Neoperl analyses the organizational water footprint of the entire company (Neoperl GmbH, Germany); Volkswagen assesses the production facility in Uitenhage, South Africa. Based on assessments of water risks, WELLE will identify local hotspots in global supply chains in which water stewardship measures will be initiated.

INTRODUCTION

In current industry practice, water is managed at the production sites only, e.g. within the framework of environmental management systems. However, production activities are supported by complex upstream supply chains, which deliver energy and raw materials, and followed by possibly water intensive use phases. Recent research has shown that, in different sectors, the main impacts on water scarcity have their roots in such upstream activities, often located in different regions than the main production site. For example, the first published water footprint study of a complex industrial product carried out for three Volkswagen car models (Berger et al. 2012), identifies the largest share of water consumption in the upstream value chain, mainly in precious metals and natural rubber production, while only 5% takes place at production sites. Though delivering relevant information on water consumption and water-related impacts throughout specific life cycles, the mentioned studies are limited to single products and do not depict the impacts of an entire company or facility. To allow companies addressing their water-related impacts in an effective and targeted manner, a holistic approach taking into account all company-related activities is required.

Before this backdrop, WELLE aims at providing companies with applicable solutions to:

1. Recognize the possible sources of water consumption at production sites and throughout a company's supply chain in a systematic manner;

2. Identify the location of water consuming activity throughout supply chains;

3. Carry out a comprehensive water footprint study via an online tool.

By means of a company's water footprint, hotspots along the company's supply chain can be identified which are target areas for local mitigation measures. In addition to the physical water risk calculated by the WELLE tool, also regulatory and reputational risk factors are taken into account. The information gained will be used to:

4. Identify the most relevant geographical hotspots along the supply chains;

5. Initiate water stewardship dialogues with local stakeholders.

The entire WELLE approach targets at companies' and other organizations' willingness to explore their supply-chain impacts on water scarcity and initiate multi-stakeholder dialogues to put into place mitigation measures.

METHODS

Organizational water footprint method

The method was developed in a two-step approach. In a first publication, available tools to track the water-related environmental performance of companies were analysed via a multi-criteria approach evaluating e.g. their scientific soundness, environmental relevance, organizational system boundaries, and broadness of application (Forin et al. 2018a). As a result, the product related water footprint method was chosen as a starting point to develop the organizational water footprint approach, in combination with organizational Life Cycle Assessment (LCA). A submitted publication (Forin et al. 2018b) discussed how both methods, based on ISO standards, can be hybridized. Moreover, application guidelines e.g. to prioritize data collection, are delivered.

Regionalized water inventory database

While most companies can monitor their internal activities comparatively easy, they rely on external data about the water consumption of their indirect upstream activities (material and energy supply chain). Thinkstep's life cycle inventory database GaBi 8 is used as foundation for the case studies carried out in this project. As a first step, relevant datasets are identified by the participating companies. These datasets are investigated comprehensively and modified to better meet the demand for detailedness expressed in the case studies. Important modifications include the allocation of generic processes to their typical location, and the disaggregation of datasets, allowing the selection of country specific energy and material mixes or market mixes based on several countries.

WELLE tool

To facilitate the use of the provided inventory data, a web-based tool is created. The tool guides the user through the different compartments of the organizational water footprint. Starting with direct water use, the user can enter water use data of production sites in high geographical resolution. In terms of indirect upstream and downstream activities, users can enter purchased goods and materials as well as water consumption during product's use phase. In combination with the water inventory database described above, the tool allows to assess the water consumption of an entire organization and weights the results by water scarcity in its respective locations, using recent impact assessment methods (Pfister et al. 2009; Boulay et al. 2017).

INTERIM RESULTS AND DISCUSSION

Organizational water footprint method

Based on the two scientific publications mentioned above (Forin et al. 2018a, 2018b), practical guidelines for conducting the organizational water footprint have been developed and are currently tested by the industry partners.

WELLE database and tools

According to the methodology described above, water use data is provided for a set of 100 relevant material and energy datasets in a country-specific resolution, which allows for identifying local hotspots in a company's supply chain. This database is fed into the water footprint tool, which enables users to determine the water footprint of organizations. A prototype of the tool in an existing LCA software application (GaBi Envision), is currently transferred into a WebTool and tested by industry partners.

Case studies

Four industry partners tested the organizational water footprint method, the regionalized water scarcity database and the WELLE tool. The scope and preliminary results of the case studies are described in the following.

The **Evonik Nutrition & Care GmbH** participates in the WELLE project with two case studies which are conducted by the Life Cycle Management team which is part of the Evonik Technology and Infrastructure GmbH. Water scarcity footprints are assessed for two amino acids at different production sites: lysine in Blair (USA) and methionine in Antwerp (Belgium). Further, the use phases of those two amino acids will be modelled since these products significantly help to reduce water consumption of farmed animals.

The case study of the lysine production has shown that in this case the major share of the water consumption accrues upstream. Water required to irrigate the raw material corn is the most decisive factor regarding the water scarcity footprint whereas the water required for the fermentation process itself only plays a minor role. As Blair is situated in an area of medium to high water scarcity and the corn cultivation takes place roughly in a 150 km radius around the production site, the impact of the water withdraw in this region is stressed.

Motivated by the above mentioned insights, first steps were taken to improve the exchange with relevant suppliers in order to gain a deeper understanding of the upstream supply chain. This resulted in a more precise estimation of the water scarcity factor for the procured corn based on the actual region of cultivation. Further action will be taken within the context of the planned water stewardship measures.

Also in the case of methionine, raw materials are highly relevant when it comes to hotspots in a water scarcity footprint. A detailed review of the supply chain of selected raw materials illustrated that it is crucial to be precise when it comes to locating the origin of raw materials as deviations up to a factor of 100 were detected for local water scarcity. Whenever possible, an in depth analysis of the supply chain is important in order to draw a clearer picture in terms of water scarcity.

Neoperl GmbH is a medium-sized company that offers innovative solutions regarding drinking water for the plumbing industry. Within the WELLE project, Neoperl carries out the organizational water footprint of its main facility located in Müllheim, Germany, and aims at gaining insights in the facility's impact on water scarcity worldwide. The analysis includes, besides the water scarcity impacts of water consumed in the facility itself, also the upstream supply chain (purchased goods, materials and fuels), and the company's main supporting activities. Within an intensive data collection process, Neoperl tracked the country of origin of most of their purchased materials, which allows identifying regional water scarcity hotspots based on available country-specific characterization factors. In addition, Neoperl's supporting activities were analyzed with regard to water consumption and impacts on water scarcity. This implied a detailed data collection on on-site energy generation, company-owned vehicles, buildings and machinery (including component materials), work place equipment and the facility's canteen. Preliminary water footprint results show that purchased goods and materials contribute to a significant share of Neoperl's water consumption and water scarcity impacts. The prevalent product category is represented by purchased metals, especially stainless steel and brass. The region-specific data collection allows identifying in which countries the most water intense materials are produced. On this basis, the supply chain of selected materials will be analyzed more in depth based on suppliers' information and the WELLE database. This knowledge will inform management purchase decisions and increase awareness on Neoperl's impacts on freshwater scarcity.

Copper is a material needed to secure our modern life. With regard to the demand for e-mobility and green energy the demand for copper is assumed to be growing. As a result, resource demand, e.g. for water, might increase as well. Before this backdrop, **Deutsches Kupferinstitut Berufsverband e.V.** contributes to the WELLE project by assessing the water footprint of the European copper cathode production and identifies local hotspots with a granularity going down to local water management, e.g. intake, consumption and/or sewage. Since more than half of the copper processed and used in Europe is imported from different places of the world, it is worth to know the bottleneck to ensure production and supply risk are best monitored. In previous studies on the European copper supply chain we found out that in water rich regions, e.g. northern Europe, water is extremely abundant and groundwater is rather transformed in surface water, while in dry regions, e.g. Arizona in North America, water can be a limiting factor to deal with. A preliminary assessment of the European cathode production shows that the copper extraction taking place outside of Europe is dominant for the blue water consumption. Further steps in the granularity will help to identify and localize the hotspot of this upstream and help to best address the water management, taking into account production and supply risk perspective.

Volkswagen analyzed the organizational water footprint of its production site in Uitenhage, South Africa, which is part of Volkswagen South Africa. With its ca. 4,000 employees, it is the largest automobile production site in Africa and manufactures the Polo as well as engines. Apart from the direct water consumption at the site (Scope 1), the water consumption caused by the energy supply (Scope 2) and by the material and upstream product manufacturing (Scope 3) was analyzed. In addition to the water volume consumed, hotspots within the supply chain were identified. An initial regionalization at the country level was conducted. A more in-depth regionalization on the water basin level is in preparation.

Initial findings of the water footprint analysis for the production site Uitenhage: The predominant portion of the water consumption lies in the product supply chain (particularly in the raw material extraction/fabrication) and in the use phase of the products (particularly in the fuel supply), respectively. On the other hand, Scope 1 (direct on-site water consumption) and Scope 2 (energy supply) contribute less than five per cent to the overall water consumption. In the supply chain, steels, platinum-group metals and elastomers were identified as hotspots. To what extent these water consumption hotspots contribute to the generation of water stress is currently part of an in-depth analysis.

CONCLUSIONS & OUTLOOK

Based on the case study results, the identified physical hotspots will be further analyzed and prioritized according to the local physical, regulative and reputative risk assessment. In a further step, meeting with suppliers and local stakeholders at hotspot locations will be organized in order to initiate water stewardship measures.

The WELLE approach will be made available to the general public through a methodological guidance and an online WELLE tool. These deliverables will allow other companies to scope their case study, model their organization and screen the water consumption and water scarcity hotspots along their supply chain.

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STEER: Increasing good governance for achieving the objectives of Integrated Water Resources Management

More effective water resources management through improved coordination and cooperation

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Keywords: *Integrated Water Resources Management, water governance, diagnostic approach, coordination, cooperation*

ABSTRACT

In many regions of the world, different water uses are not coordinated sufficiently. This may cause a decline in water quality and/or quantity, with consequent conflicts among various water users as well as detrimental impacts on the environment. The STEER project studies water issues related to a lack of coordination among different water uses, with a focus on various aspects of the water governance and management system. Applying a diagnostic approach, STEER aims to find out which sets of factors are associated with certain regional coordination deficits. Based on the analysis, the project intends to develop recommendations how the respective situation can be improved through innovative forms of coordination and cooperation. In this way, STEER will contribute to the implementation of Integrated Water Resources Management by providing advice for more effective cross-sectoral governance.

INTRODUCTION

Water is a resource used by a range of different actors for a variety of purposes. Prominent examples are agricultural production, the generation of energy, and water consumption of private households. Water also represents a major habitat and is an essential element for countless ecological processes and associated environmental services. There is no sector of society not depending – directly or indirectly – on the availability of water in adequate quantity and quality (Rockström et al., 2014).

However, the diverse uses of water resources are not always free of conflicts. In many regions of the world, activities of water users are not coordinated sufficiently, leading to unsustainable use and a decline in the quantity and/or quality of water resources. To tackle such issues and deal with water more wisely, the concept of Integrated Water Resources Management (IWRM) has become popular worldwide in the last three decades. It strives to reconcile the water-related needs of different actors and regions and aims to achieve a more sustainable and equitable management of water resources. However, the implementation of IWRM faces several challenges. Among others, many problems have turned out to be too complex to be solved from a water-centered perspective. In such cases, sufficient knowledge about the causes of water-related problems is often available, but their solution requires the involvement of actors from other sectors – often with competing interests – and the adjustment of related structures. Aligning the activities of diverse water users requires effective cross-sectoral governance and good coordination mechanisms. This may for example include the modification of sectoral legislations, an adequate involvement of stakeholders in the development of sectoral strategies and plans, and new forms of voluntary cooperation crossing different sectors (Pahl-Wostl, 2015).

The STEER project explores innovative approaches for evaluating cooperation and coordination in order to solve use conflicts around water resources. Based on comprehensive analyses of inter-sectoral coordination problems in selected case studies, STEER develops recommendations to improve the situation in the respective region. Furthermore, STEER aims to examine under what circumstances lessons can be transferred to other socio-ecological contexts. In this way, STEER intends to improve cross-sectoral water governance and to support the achievement of Sustainable Development Goal (SDG) 6.5: successful implementation of IWRM worldwide.

Target groups for results of the STEER project will be professionals who aim to align different water uses and resolve water use conflicts through improved coordination. These are for example regional actors from the water sector (e.g. river basin organizations), national water ministries and authorities, and international organizations supporting a more sustainable management of water and related land resources. Insights from the project will also be of interest to consultants and scientists dealing with water governance and management.

METHODS

To study conflicts around competing water uses and develop recommendations for better cooperation and coordination, the STEER project has developed a diagnostic approach. It facilitates an assessment of typical characteristics of specific problem constellations and a subsequent identification of targeted solution strategies: systemic analyses allow identifying sets of factors that jointly represent the cause of a water use conflict, which can then be tackled with specific instruments. A diagnostic approach considers the respective local context, but it is not restricted to a specific context (Dombrowsky et al., 2014; Ostrom, 2007; Pahl-Wostl et al., 2012). Instead, it facilitates the development, adaptation, and transfer of strategies for better cooperation and coordination to similar problem constellations. In this way, the diagnostic approach supports inter-sectoral water governance. STEER tests its diagnostic approach in two empirical studies. **The first empirical study** covers five in-depth case studies: Emscher basin (Germany), Weser-Ems region (Germany), Guadalquivir basin (Spain, see Figure 1), uMngeni basin (South Africa, see Figure 2), and Kharaa-Yeroo basin (Mongolia). Each of these areas is characterized by one or more problems related to water quantity or quality, caused by insufficient coordination among water users from different sectors. For example, livestock farming and the cultivation of energy plants contribute to economic prosperity in the Weser-Ems region, but have also led to increased nitrate concentrations in the groundwater at several locations. This poses a challenge to the regional water supplier. In the Kharaa-Yeroo basin, insufficiently or untreated wastewaters from mining activities find their way into the river network, representing a risk to other water users and the environment. In the Emscher basin, main challenges arise from impacts caused by former mining, industrialization and urbanization in the region as well as from regulations that can impede or delay the current restoration process. Through comprehensive analyses, STEER investigates major problem constellations in all five case studies and develops recommendations for better inter-sectoral governance based on improved cooperation and coordination. Data is collected through document analyses as well as interviews with experts and stakeholders and is assessed systematically. A cross-case comparative analysis will serve to gain insights that may be applicable to other regions. The second empirical study will serve to validate these findings by means of fuzzy set Qualitative Comparative Analysis (fsQCA). In addition to the five case studies mentioned above, it will include

Figure 1: Reservoir of Castril in the Guadalquivir basin (photo: © Andreas Plischke).

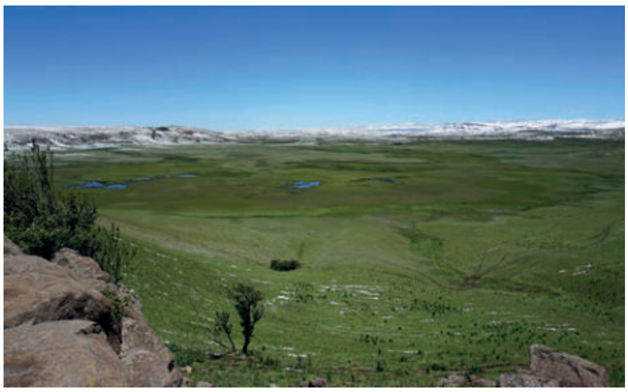

Figure 2: The uMngeni Vlei, the source of the uMngeni river, is a protected RAMSAR site and suffers from cattle grazing. (photo: © Evelyn Lukat)

about 15 further cases from different world regions. In this study, the diagnostic approach will be simplified to find out what combinations of factors result in positive or negative outcomes. This simplified approach will also be more amenable for further application in water management practice.

INTERIM RESULTS AND DISCUSSION

The STEER project developed a conceptual framework, which serves to operationalize the diagnostic approach. It guides both empirical studies sketched above, facilitating systemic analyses of water-related problem constellations and leverage points for cooperation and collaboration. Figure 3 shows the basic components of the conceptual framework.

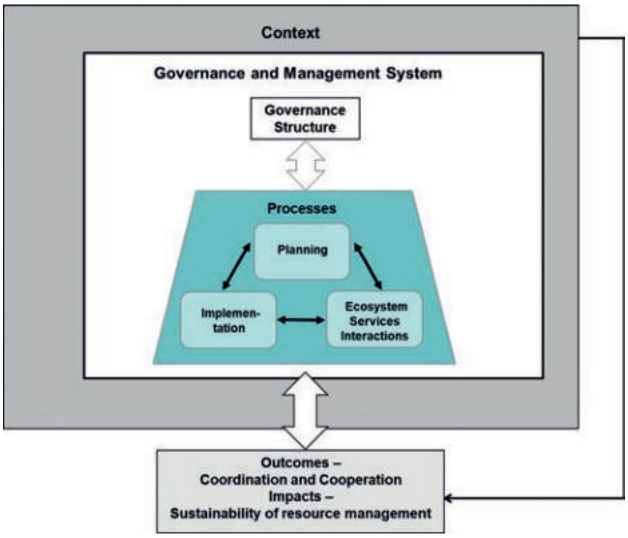

Figure 3: Basic components of STEER's conceptual framework.

The governance and management system comprises structures and processes designed to manage water resources and associated uses for various purposes. This system has a certain **performance** in achieving water-related goals, which can be assessed through the system's short- and medium-term **outcomes** (in terms of realized coordination and cooperation) and its long-term **impacts** (regarding the sustainability of dealing with water resources). The governance and management system is embedded in a broader environmental and societal **context**, which has an influence on how the system functions. Depending on the context conditions, a certain system may function well in one context but badly in another, which is reflected in processes within the system. The same applies to the impact of context conditions on the performance of the system: certain outputs of a governance and management system may translate into positive outcomes and impacts under some context conditions but lead to limited performance under others.

For each of the framework's basic components, various variables have been defined. These variables allow a comprehensive description of the situation in each case study. Hypotheses help to structure the empirical analyses. They reflect the current state of research regarding supposed links between governance aspects and associated performance in light of different environmental or social contexts. Supposed links, as formulated in the hypotheses, can be assessed with empirical data collected for the different variables. Some hypotheses will be examined in all in-depth case studies, whereas others play a role only in selected cases, reflecting regional circumstances and specific research interests of the involved scientists. This procedure allows both a common basis for comparative analyses and case-specific investigations.

Contacts have been established to the global process of monitoring SDG 6.5 on the implementation of IWRM. A first comparison of resulting country datasheets on national IWRM implementation (http://iwrmdataportal.unepdhi.org/iwrmmonitoring.html) and results of STEER case studies in respective countries suggest some differences. The results of the more detailed analyses conducted under the umbrella of STEER do not always agree with the scores obtained in the national monitoring processes. Furthermore, the diagnostic approach developed in STEER can support moving from monitoring at the national level to setting priorities and improving coordination structures and processes at the national and regional level.

CONCLUSIONS & OUTLOOK

Analyses of cross-sectoral coordination and coordination instruments have often focused on the national level. The regional level, where the consequences of insufficient coordination manifest themselves in tangible water management deficits, has received comparatively little attention. Furthermore, few studies have analyzed the effectiveness of coordination instruments and in particular combinations thereof with respect to reaching improved coordination outcomes. STEER will close this research gap and make innovative contributions to the science and practice of water governance and management.

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WANDEL Wasserressourcen als bedeutsame Faktoren der Energiewende auf lokaler und globaler Ebene

WANDEL: Water resources as important factor in the energy transition at local and global scale

Requirements for a water footprint approach to compare different energy generation systems

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Keywords: *Water footprint, water scarcity, water-energy nexus, energy transition, remote impacts*

ABSTRACT

Water and energy are crucial for sustainable development globally. As water needs energy and energy needs water, the on-going energy transition in industrialized countries but also the evolving transition in emerging and developing economies has to be scrutinized in terms of water usage. At the heart of WANDEL is the question of whether restrictions in water availability limit the use of conventional energy systems, thus accelerating or even slowing down the energy transition. Herewith WANDEL considers both, the on-site impacts of electricity generation on water resources locally and regionally by analysing four case studies in Germany, Brazil and Morocco, and the remote impacts worldwide by taking into account the entire supply chain in an integrated and interdisciplinary way. Central to this approach is an enhanced water footprint methodology that is able to assess the impacts on water resources from human activities, including water scarcity and water quality, in a comparable way and hence allows to answer the target question. WANDEL combines data- and model-based analysis of different water and energy scenarios, case-study-specific regulatory and technical solutions for the reduction of negative effects and qualified consulting services to present results in an innovative manner. So far, the conceptual framework of the water footprint approach has been outlined and data from the case studies are currently acquired to assess the water footprint of four energy generation systems.

INTRODUCTION

Both, water and energy, are part of the Sustainable Development Goals (SDGs) of the United Nations (UN, 2015) calling for "clean water and sanitation" and "affordable and clean energy". Recent research has provided insights into the interactions between the SDGs showing that the 17 goals are strongly intertwined and cannot be achieved without considering the interlinkages among them. These linkages give rise to possible synergies, but also trade-offs. In terms of energy supply, it becomes clear, that a transition towards renewable and low carbon technologies has to take place in order to mitigate climate change and reach the goals of the Paris Agreement. Renewable energy technologies can help achieving SDG 7 and SDG 13, but could counteract the targets of SDG 6 if they negatively affect water resources on-site or remotely along the supply chain. Vice versa, reduced water availability may limit the use of water demanding energy technologies. However, while also renewable energy technologies, like solar thermal energy, require water, it has been shown that especially the enormous cooling water demand of conventional thermal power plants based on fossil resources will result in cooling water gaps in several regions of the world in 2050 (Flörke et al., 2013). WANDEL focuses on this water-energy nexus and aims to answer the question whether restricting water availability limits the use of conventional energy systems, thus accelerating or even slowing down the energy transition. To answer this question WANDEL develops an enhanced water footprint methodology taking existing water footprint concepts into account.

METHODS

Water footprint assessment framework for electricity generation

In recent years, the initial water footprint concept developed by Hoekstra & Hung (2002) where green, blue and grey water footprints are calculated, has been intensively discussed, further developed and modified for many purposes. An assessment of water footprints with respect to regional water scarcity (e. g. Alcamo, Flörke, & Märker, 2007) has been adopted, and most recently, the water footprint has been introduced to Life Cycle Assessment (LCA, Kounina et al., 2013). However, there is no general approach and discussions are ongoing. Either way, simple green, blue and grey water calculations (see e.g. Water Footprint Network) fail to relate water usage to regional water scarcity, whereas highly aggregated LCA impact assessment indicators are complex and contain many uncertainties. To address WANDEL's objectives, concepts have to be enhanced: It is crucial to combine spatially explicit information on grid cell level, as provided by the applied hydrological modelling framework WaterGAP3, with a LCA systems perspective that covers the entire supply chain. Every process and related components along this chain contributing to the water footprint of the final product (i.e., generated electricity) have to be identified and quantified to determine the total water footprint. In terms of blue water (i.e., freshwater stored in surface and groundwater bodies, snow and glaciers) a clear differentiation must be made between impacts on surface and groundwater bodies which have to be assessed separately. Facilities to store blue water, like reservoirs and sewers, may have a direct impact on water availability for downstream users, but so far, water footprint approaches have only focused on the evaporation losses (Mekonnen & Hoekstra, 2012). Indicators quantifying the volume of retention and the associated evaporation losses with respect to river discharge volume (Grill et al., 2015) should be added to the water footprint in order to improve the concept for hydropower. Presenting green water (i.e., soil moisture from precipitation, used by plants via transpiration) as own water footprint category still has to be discussed with respect to the different case studies. Either way, it is calculated by the modelling framework WaterGAP3 that simulates also sectoral human water use, water availability and regional water scarcity. Impacts on water quality have to be included, as poor water quality can result in water scarcity if it is below agreed water quality standards and cannot be used without any treatment, by means of the virtual dilution volume (grey water footprint). The spatially explicit water footprint developed in WANDEL should be able to answer the question whether water use in a specific watershed is within the 'safe operating space', given by the SDGs (UN, 2015), or not. A sustainability assessment with respect to regional water availability is required respectively. Finally, a transparent reporting of each single indicator is required while the aggregation of the single indicators into one common water footprint can be helpful to disseminate results easily to specific audiences. A web-based data and information portal, called WANDEL-Share, that is developed based on using Free and Open Source Software (FOSS) and international standards of the Open Geospatial Consortium (OGC) and thus adaptable, will be used to do so. It enables the storage, management and processing of Earth Observation data and geo-data in order to give a geo-related comprehension not only on the water footprint.

Case studies

To develop and test the water footprint methodology, meeting the demands as described above, four case studies were selected as practical examples. For the water footprint approach different sets of data are required to address direct and remote impacts on water resources in terms of quantity and quality. In collaboration with local praxis partners, the required datasets are gathered and evaluated.

Weser: Coal-fired power plants in Germany in times of progressing energy transition fulfil the role of stabilizing the power grid, but no new investments are arranged. Hence, the conventional coal-fired power plant, a classical in-stream cooling water user located at the Weser River, Germany, serves as a reference for the other case studies representing renewable energy systems as part of the energy transition. On-site impacts on water resources are mainly due to the use of cooling water from the river and heated return flows discharged back to the river, while remote impacts are related to the origin of construction materials and, probably most important, the origin of coal. Trading mix data of coal have to be traced back to the countries of origin, i. e. to single mines, to make the water footprint spatially explicit. Uniper as the local praxis partner supports the project with data on cooling water use and return flows, construction materials and origin of coal.

Danube: The case study at the Danube River, Germany, is a cascade of barrages that generate electricity in run-of-river hydropower stations. This kind of power stations does not cause significant retention effects in terms of water availability. Likewise, the evaporation losses due to backwater effects (e. g. increased water surface area) are rarely quantifiable. Rather of importance here is the water footprint of the construction materials of the barrage facilities. Also, in the course of the supply chain analysis of construction materials (for all case studies) retention volume and evaporation losses from damming in areas, where it matters, may play a role again. The local project partners are the Bayerische Elektrizitätswerke GmbH (BEW) and the Bayerisches Landesamt für Umwelt (LfU Bayern) providing essential information on hydropower generation, construction materials and impacts of cascades on ecosystems.

Brazil: In the Cerrados biome in Brazil sugar cane is cultivated to produce sugar and ethanol. Originally, mills burnt bagasse, the fibrous raw material, to remove waste and to generate electricity for self-supply. Currently, as the energy market opened the possibility for them to sell electricity surplus, mills invest in improving their facilities to increase the electricity generation. To calculate and assess the water footprint of the bagasse-based electricity, it is necessary to determine both the water footprint of the sugarcane production and that of the sugar mill separately: (i) sugarcane production demands blue and green water for irrigation. For the grey water footprint the application of fertilizer and pesticides have to be considered. (ii) To calculate the water footprint of the sugar mill, its water balance is analysed. To determine remote impacts, the water use at the places of origin for construction materials and fertilizer/pesticides is assessed and included in the footprint. In this case study, the attribution of the water use to the different output products (sugar, ethanol, electricity and yeast) is a challenge, since in the past, bagasse was considered as a waste with zero water footprint, while today the produced electricity is sold and has therefore an economic value. Thus, the footprint allocation has to be adjusted. The WANDEL consortium collaborates with EMBRAPA as local praxis partner with expertise in water use efficiency and water balance in sugarcane production as well as long-year of trust based relationship with the sugar mills in the study area.

Morocco: The Moroccan case study focuses on the utility-scale concentrated solar power (CSP) plant NOORO I in Ouarzazate, Morocco. CSP plants need high direct solar radiation, a condition usually found in arid and semi-arid areas where water resources are often scarce. This is also the case for the province Ouarzazate, which is characterized by a semi-arid to arid climate. Accordingly, the operational water demand is a critical aspect in the case study NOORO I. The main operational water demand of CSP plants include water for cooling processes and mirror cleaning. The water demand for cooling varies significantly depending on the cooling technology applied. NOORO I was designed as a wet-cooling plant, requiring high amounts of water. Next to this direct operational water use, this study will also analyse the indirect water demand for the construction materials along the entire value chain. The focus of the analysis lies on the water footprint of different mineral resources needed for the solar mirrors and energy storage facilities. The case study itself is conducted together with the local partner MENARES.

Scenarios and global modelling

In the second step, the methodology developed at case study level will be used to determine the water footprint under different energy scenarios up to 2030 and 2050 on a global level. In order to evaluate the key question on how water availability will influence the energy transition, land use and climate changes as well as socio-economic developments will be taken into consideration. The water footprint will be used to identify hot spots of water scarcity along the energy supply chains outlined by the selected energy scenarios and provide information about potential problem shifts due to remote impacts. This is an important step to support the achievement of SDG 6 and SDG 7.

INTERIM RESULTS AND DISCUSSION

The water footprint concept was discussed with local and international praxis partners in regional stakeholder meetings (March-June 2018) and at the first International Workshop in November 2018. Currently the team incorporates the stakeholder's feedback into concepts, methodologies and data needs to address practitioner's needs. Figure 1 shows how the water footprint approach will bring together spatially explicit on-site and remote impacts on water resources in order to assess sustainable usage (as indicated by different colours in the figure) at different scales (local case studies, global energy supply chains) for the analysed case studies.

Figure 1: *On-site and remote water footprints that contribute to one energy production system along its supply chain. Coloured dots indicate the assessment of sustainable water use (green = no impact, yellow = medium, red = severe).*

SUMMARY & OUTLOOK

- WANDEL developed the first water footprint approach for comprehensive and spatially explicit assessment of different energy systems.
- Uses a data- and model-driven methodology that combines local knowledge and information with global pathways in a systems approach.
- Collaborates with local partners as a key element of successful evaluation and implementation.
- Implements four case studies on different energy systems in different regions to allow for a differentiated and comprehensive assessment of the water footprint.
- Will integrate the local level case studies and the global energy scenarios to draw a holistic picture that allows the key research question to be answered in a science-based way.
- Will carry out a global analysis to allow linking results to freshwater biodiversity effects, to analyse SDG achievement related to conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems, and their services (Target 15.1).

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GlobeDrought: A global-scale tool for characterising droughts and quantifying their impact on water resources

GlobeDrought – towards improved drought risk analysis and projection at global and regional scales

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Keywords: *Integrated risk assessment, vulnerability, agricultural systems, water supply, drought*

ABSTRACT

In times of drought, water resources are insufficient. These water shortages often have negative effects on agricultural productivity and on associated socioeconomic factors, causing reduced income, food shortages and even famines. The overall objective of GlobeDrought is to develop an integrated drought risk information system which will adequately describe causal links in the formation and development of droughts, connections between the various types of drought hazards (meteorological, hydrological and soil moisture), and associated vulnerabilities. With its planned monitoring and experimental early warning system, the project aims to reduce the time between satellite-based data collection, identification of a drought risk and the implementation of potential countermeasures by political decision-makers and those involved in international humanitarian aid. The global-scale analyses focusing on drought impacts on agricultural systems will be supplemented by detailed analyses for regions heavily affected by droughts such as Southern Africa (South Africa and Zimbabwe), Eastern Brazil, Western India, and the Missouri River Basin of the United States. The results of literature reviews and expert consultations show that it is very important how drought risk analyses are conceptualized and that there is no consolidated, commonly shared framework and methodology for drought risk assessments at the moment. GlobeDrought is therefore also going to contribute to methodological improvements and more precise terminology in drought risk and impact assessments. First outcomes of the global and regional studies show that the modeling tools and sensor data used in GlobeDrought provide a consistent picture of drought development across the domains meteorology, hydrology, agronomy and economy.

INTRODUCTION

Drought is considered a major determinant of variability in crop yields and crop production worldwide. In particular regions that are less integrated into the world market face challenges to ensure sufficient food supply when exposed to drought. Historically, one adaptation to aridity or frequent drought events was the development of irrigation infrastructure to protect crops and farms against missing rainfall. The global area equipped for irrigation increased from about 63 million hectares in year 1900 to more than 306 million hectares in year 2005. It is estimated that about 90% of the global consumptive freshwater use is for irrigation (Döll et al., 2012). In particular during droughts irrigation water requirement is high so that meteorological droughts caused by missing rainfall can translate faster into hydrological droughts characterized by declining water storage in surface water bodies and aquifers. Shortage in water supply for irrigation schemes can then transfer a hydrological drought into a soil moisture drought, characterized by low soil moisture and low crop yields. It is therefore essential to monitor the drought situation and to propose useful countermeasures when critical thresholds are surpassed. Operational early warning systems for droughts try to address the problem. However, they are mostly only capable of characterizing the status quo, or offer limited forecasts for droughts in the near future – e.g. the next three to six months. These early warning systems generally do not sufficiently integrate variables and drought indicators. In particular, they do not adequately describe causal links in the formation and development of droughts, connections between the various types of droughts (meteorological, hydrological and soil moisture), and socioeconomic and ecological factors as key drivers of exposure and vulnerability. The project intends to fill this gap by developing an integrated drought risk information system, including a monitoring and experimental early warning system. The overall objective is to gain a better understanding of the development of droughts and the links between different drought types, including the role of the socio-economic setup affecting the vulnerability and exposure to drought. Existing drought risk analyses and impact frameworks will be evaluated and an improved drought risk analysis framework will be implemented into the new drought risk information system. The drought information system will provide general information at global scale and more detailed region specific information for project regions with a distinct socio-economic setup and distinct environmental and climatic conditions. Consequently, target groups differ and comprise organizations with the mandate to inform policy makers such as the Global Drought Observatory (GDO) of the European Union, organizations involved in international humanitarian aid, regional and national water management organizations or farmers in the project regions.

METHODS

To analyze drought risks and drought impacts, an improved drought risk analysis framework is being developed and used, comprising of indicators for drought hazard, exposure and vulnerability which together determine drought risk and related impacts (Figure 1). Indicators for drought hazard, exposure and vulnerability are specific to the impacts to be analyzed.
The drought risk information system will comprise of both, a global component and regional components, providing more specific analyses for the regions Southern Africa (South Africa and Zimbabwe), Western India (Maharashtra), Eastern Brazil (Ceará) and the Missouri River Basin in the United States. The information system will be developed and tested using historical data for climate, satellite based water storage anomalies, land use, crop yields, water use, trade and socio-economic indicators complemented with vegetation health analyses, using remote sensing. The experimental early warning system will provide data, maps and tools for near real time drought monitoring. In addition, a projection of the development of droughts within the next year will be provided, based on ensembles of historical climate data as a replacement of climatic data for the future. Probabilities will be calculated to quantify how likely it is that a drought becomes more severe, remains similar, becomes less severe or disappears within the projected time period. The drought hazard analysis will be complemented by an indicator-based assessment of present-day vulnerabilities as a major determinant of sectoral drought impacts.

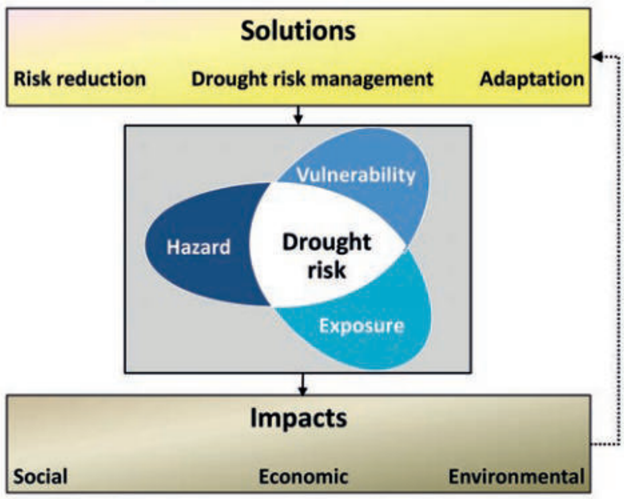

Figure 1: The conceptual framework used in the GlobeDrought project to analyze drought risk and drought impacts at global and regional scale.

The regional drought assessments will be adapted in a co-design process to the requirements of partners and stakeholders in the project regions. Therefore, the regional drought information systems will be more precise and of higher spatial resolution while the indicators used and the impacts studied will vary for the specific regions. In contrast, the global information system will facilitate comparisons of drought impacts, drought risks and drought conditions across the globe.
To quantify drought hazard and drought impacts, a set of hydrological and crop models will be combined with advanced methods to generate drought related information from remote sensing. Total water storage anomalies detected from the gravity satellite mission GRACE are used to improve trends in water storages simulated by the hydrological model WaterGAP. Further, we also compute hydrological indicators by using total water storage changes from GRACE directly. Spatial patterns and interannual variability in sowing and

harvest dates for major crops determined by MODIS satellite data are used to inform the crop model solution SIMPLACE <LINTUL5,SLIMWater,SLIMRoots> to improve the simulation of drought impacts on crop productivity and irrigation water requirement.

INTERIM RESULTS AND DISCUSSION

Indicators to be considered for drought hazard, exposure, and vulnerability analysis and hence for characterizing the risk of specific drought impacts, were selected based on a comprehensive literature review (Hagenlocher et al., submitted), internal discussions during an indicator workshop held at the University of Bonn on 16 Feb 2018, and expert consultations during the first stakeholder workshop (03/04 May 2018) at United Nations University in Bonn, Germany. The specific relevance of each indicator was evaluated using an online survey which was designed in collaboration with the Global Drought Observatory (GDO) of the European Commission, and sent to 124 international drought experts. A set of more than 50 indicators was defined and out of this indicator set specific indicators are selected, depending on the drought impact to be studied, the project region and the relevance identified by the experts. Based on the response of the regional and global experts it was decided that drought impacts on agricultural systems (irrigated agriculture, rainfed agriculture, agro-pastoral

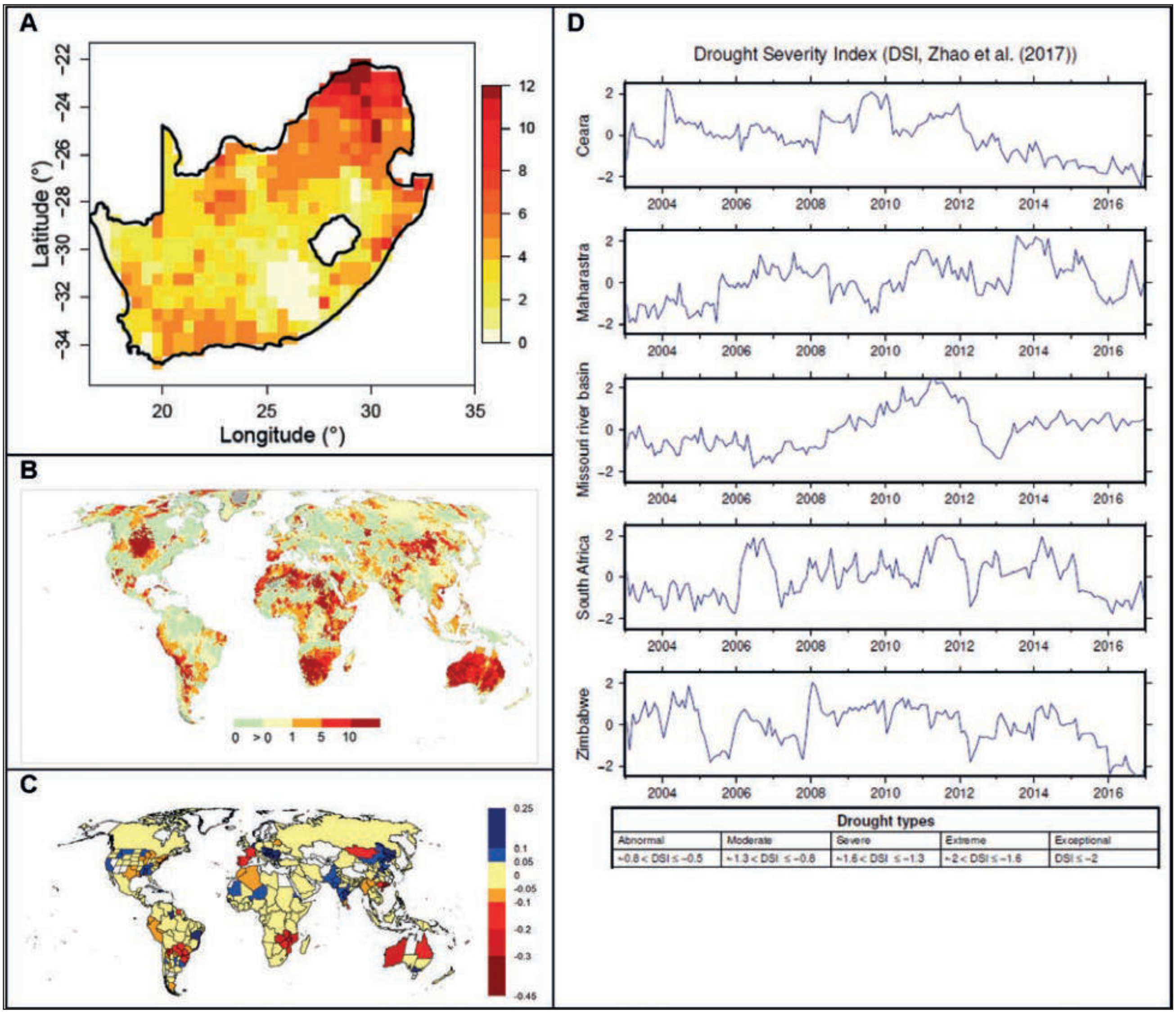

Figure 2: Accumulated drought months per year from 3−Month−SPEI in RSA (A), accumulated water storage deficit volume calculated with the model WaterGAP (B), deviation of AET/PET ratio from long-term mean for maize calculated with GCWM (C) for year 2005. Drought Severity Index (Zhao et al., 2017) for the project regions using total water storage changes from GRACE gravity measurements (D) for period 2003-2017.

systems) and drought impacts on water supply will be studied at the global scale. In addition, depending on the relevance and local user needs, more specific impacts will be studied at the regional level. A publication, describing the novel drought risk analysis framework and the indicators selected so far, is under preparation.

By analysing remote sensing based indicators and the output of the global hydrological and crop models, we found that the different, independent data sources provide consistent information on the development of different types of drought (Figure 2). There is also a good agreement to survey data for agricultural production. For example, crop production in Zimbabwe and South Africa was extremely low in year 2005, identified as severe drought for Southern Africa (Figure 2). The results of the crop model applied at global scale showed that the severity of drought impacts differs between the specific crops, for example between crop cultivated in the winter or summer season or those cultivated in the wet or dry season, so that crop specific information needs to be considered in drought impact assessments (Eyshi Rezaei & Siebert, 2018).

The GlobeDrought teams could also make considerable progress with the coupling of models and the assimilation of remote sensing data into hydrological and crop models. This is of major importance for the more detailed analyses to be performed at regional level. Results were presented so far at four international conferences and in four journal articles. Additional publications in journals are under preparation. The project received considerable attention in the media, for example it was featured in WaterSolutions (issue 03/18).

The indicator data obtained from analyses at global scale are currently being categorized and implemented into the web-based drought information system hosted by Remote Sensing Solutions. Metadata descriptions have already been collected, the data itself are now being structured according to the conceptual framework shown in Figure 1.

CONCLUSIONS & OUTLOOK

The results of the global drought risk analysis and first regional results are promising. The indicator data are now being transferred to the web-based information system to be presented and discussed at the second stakeholder workshop of the project which will take place in autumn 2019.

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ViWA: Virtual Water Values

Multiscale monitoring of global water resources and options for their efficient and sustainable use

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Keywords: *Virtual water, agricultural water-use-efficiency, yield, Sentinel-2, irrigation*

ABSTRACT

For sustainable development it is imperative to use natural resources, like water, globally with the highest possible sustainable efficiency. ViWA aims at monitoring global water use efficiency (WUE) in agriculture using the hydro-agro-model PROMET and simulating its economic and ecological implications. ViWA extends the general-computable-equilibrium (CGE) economic model DART of global agricultural trade to consider virtual water. Scenarios for regulations of and incentives for global trade are developed and simulated to identify trade-offs and a global hot-spot sustainability analysis. Global methodologies are applied in the Danube and Zambesi basins and in smaller hot-spots to analyse allocation conflicts and the effects of improved WUE and to identify trade-offs on the way to proposing solutions. First hourly, 30 arcsec global simulations of WUEs have been carried out for different seeding dates, cultivars, fertilizer uses and irrigation for 18 crops on the HPC-facility SuperMUC. Time series of Sentinel-satellite images were assimilated into PROMET. Spatial studies were carried out for the Danube to extend CGE DART by determining the irrigation water demand, elasticity of yield towards green and blue water and sustainability of water use. They will spatially connect simulation of irrigation with water abstraction from surface and groundwater. A sustainability assessment will reveal the degree of sustainability of the virtual water connected to the different crops in specific locations. WUE results for maize show hot-spots of water waste in rainfed and irrigated maize and high-potential regions to improve WUE. The next decade will see huge investments for irrigation in the Danube basin. ViWA for the first time develops a comprehensive spatial picture of the Danube irrigation water demands which point at serious future upstream-downstream and ecological conflicts.

INTRODUCTION

98% of global water use is estimated to be allocated to producing food and biomaterials through green (rainfall) and blue (irrigation) water. Water- and food-related SDGs can therefore only be met through increasing efficiency and ensuring sustainability of the water used in agriculture. Two key parameters describe agricultural water use: use efficiency (WUE, kg yield/m^3 evapotranspiration) and sustainable water availability (mm/growing season). WUE generally increases when closing yield gaps, which we define as the difference between actual and sustainably achievable agricultural yields (t/ha). Sustainable water availability strongly varies across the globe and depends on the localization of a site both within a basin and within a climatic zone (precipitation, temperature, etc.). Agricultural commodities from different locations meet in a global market, in which currently neither WUE nor sustainable water availability influence pricing of agricultural commodities. In order to investigate different options to consider these parameters in pricing and thereby use trade to foster sustainable and efficient water use by agriculture ViWA aims at 1) developing ways to globally monitor the local WUE of agriculture and determine sustainable water availability using COPERNICUS Sentinel-2 times series data, 2) develop scenarios of trade incentives and regulations and investigate their respective trade-offs in promoting more efficient and sustainable water use in agriculture, 3) determine the sustainability of water use in agriculture for the identified scenarios. ViWA therefore addresses the following research questions: 1) What is the global state of local water use efficiency? 2) To what extent is the water that is diverted by agriculture supplied regionally from sustainably available surface and groundwater sources and what conflicts exist among water users in regional pilot basins? 3) How can agricultural trade contribute to foster water use efficiency and sustainable water use in agriculture? 4) Where are hot-spots of actual and potential water use efficiency and sustainable/unsustainable water use in agriculture? The developed methods can be applied to monitor year by year and, on a global basis, local changes in water use efficiency in agriculture considering climate variability and changes in land use and to determine potentials for its improvement. The monitored data will allow to investigate coupled agro-ecological-hydrological-economic scenarios of water use and agricultural trade regarding their local and global potential to increase the sustainability of agricultural use both of green and blue (irrigation) water use. The project addresses national and international decision makers in politics, administration and economy and intends to provide them with orientation knowledge.

METHODS

ViWA investigates the potential of large environmental remote sensing data sets, high performance computing resources and integrated scenario simulations to verify the water-related Sustainable Development Goals. ViWA uses a transdisciplinary approach of coupling environmental data with a sophisticated set of coupled agro-hydrological, water-food and economic simulation models and assessment approaches to investigate its research topic. In order to create the WUE monitoring system it combines global high-resolution Sentinel-2 times series and global crop growth modelling that is driven by ERA-re-analysis as well as dynamically downscaled meteo-drivers using REMO. An ensemble of global simulations provides LAI, WUE and yield for a broad range of agricultural management options; thousands of Sentinel-2 images of randomly selected global tiles were processed to determine for each 10 m sample point which member is implemented in reality. Within the irrigation ensemble, the members blue water demand is determined and connected to water abstraction from the river network and ground water to evaluate its up- and downstream ecological and economic effects. The monitoring results are analysed for global hot- and cold-spots of WUE in agriculture. A CGE-global-trade model is extended to consider water availability in agricultural trade with systematic studies of yield dependence on green rainwater and blue surface and groundwater water supply. A set of scenarios are developed together with stakeholders to investigate trade-offs of agricultural trade alternatives to foster water use efficiency and sustainable water use in agriculture by systematically using the global agri-management ensemble members. The results are carefully analysed with respect to their sustainability. The integrated methodology is applied to the Danube and Zambesi basin to demonstrate its regional usefulness and applicability. The complete water cycle is simulated there and conflicts of green and blue water alloca-tion, specifically with regard to agricultural yield, irrigation, domestic and industrial water use and ecological water demands are analysed. A more detailed description of the ViWA approach can be found at **www.viwa.geographie-muenchen.de.**

INTERIM RESULTS AND DISCUSSION

First results were achieved in developing the ViWA WUE monitoring system. Large ensembles of evapotranspiration, yield, WUE and LAI time-series were simulated for the 18 most important global crops (in terms of revenue). ViWA for the first time successfully demonstrated that a complex agro-ecological crop growth model can be globally parameterized in a consistent way. High-spatial (30 arcsecs) / high-temporal (1h) global simulations can be carried out to cover all major water-related agricultural management decisions including cultivar selection, seeding date, fertilization and irrigation. The 283-member ensemble was driven by statistically downscaled reanalysis meteo data and was simulated for 2016/17 on the SuperMUC using approx. 1.5 Mio CPU hours. Figure 1 shows a result for maize in 2017. Figure 1 was composed by selecting the WUE of the highest-yielding cultivar for each pixel both under local water stress (left) and full irrigation (right) and no nutrient stress. Hot-spots of high WUE are identified in Central America (origin of maize), tropical Western Africa and Indonesia. Large increase of WUE can potentially be achieved through irrigation in the N-American cornbelt, NE-China, SE-Europe, Australia and Sub-Saharan Africa.

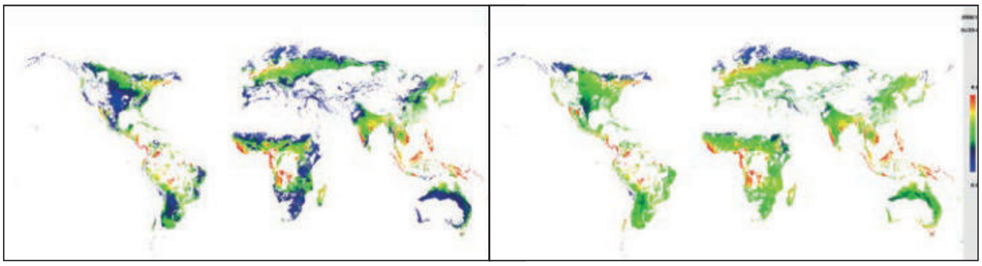

Figure 1: Global distribution of WUE of maize (kg yield/m³ ET) for 2016/17 simulated with PROM-ET. Left: rainfed WUE, right: max. irrigation WUE

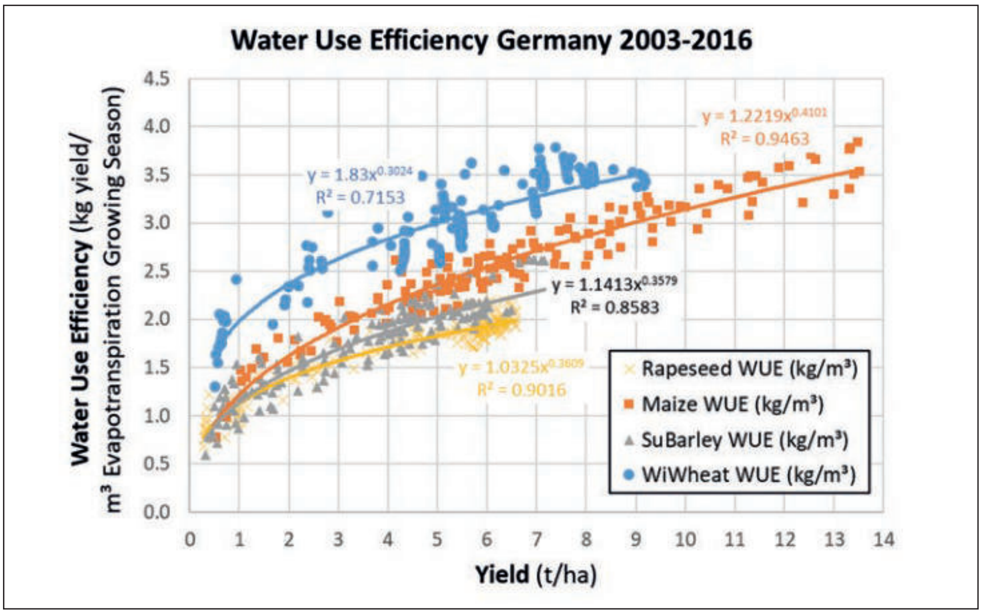

Figure 2: Water use efficiency of rapseed, maize, summer barley and winter wheat for Germany

Simulations were carried out with PROMET to determine the WUE-yield relation for a broad variety of environmental conditions around the globe. These relations are used to incorporate green and blue virtual water elasticities in the CGE DART and thereby enable to consider virtual water values in global trade. Figure2 shows the average relation for Germany for the years 2001-2015. They resemble the general shape of a saturation elasticity curve. The results of the full simulation ensemble is being systematically compared with the observations of LAI-times series results from selected Sentinel-2 tiles. Figure 3 shows the processed 100x100 km Sentinel-2 tile 33UUS in Saxonia (resolution: 10m) and identified maize pixels and two typical LAI-development curves for 2017 and 2018. The ensemble members most similar to the measured LAI-development determine which simulated yield and WUE (right) belongs to the observed pixel. Assimilated and observed average yields for 2017 differ by 0.2 t/ha. This kind of analysis will be carried out for 150 Sentinel-2 tiles, which were selected randomly to represent the global cropland. Figure 3 gives a first impression of the detail of the Sentinel observations, the interannual variations of a normal (2017) and drought (2018) year and of the variety of actual yield and WUE of maize in the Saxonia tile. The analysis addresses key questions of the Saxonian Ministry for Environment as ViWA stakeholder. Interest was also expressed by ViWA's stakeholders on irrigation and its WUE as well as on the sustainable availability of water resources for irrigation in river basins. This issue was taken up by the ViWA consortium and methodologies were developed as well as data analysed using the Danube basin as a pilot region. Agriculture was a key economic development perspective in the Lower Danube basin. National plans are drafted (independently) to expand irrigation which makes an overall strategy to maximize its benefit across the Danube basin desirable. ViWA develops a new approach to spatially simulate the water flows of the Danube basin for a variety of irrigation scenarios to analyse yield and WUE increases and water conflicts most likely arising from expanding irrigation. Figure 4 shows the simulated discharge with irrigation (% actual discharge) for the August 2017 season. The irrigation simulations results show a yield increase e.g. for maize of ~30 Mio. t p.a. across the basin with a WUE increase from 1.8 to 2.7 kg/m³. The red colour in Figure 4 shows that this yield increase would exceed the water availability of many downstream tributaries of the Danube and considerably decrease summer discharge of the Lower Danube. Figure 4 illustrates the upstream-downstream gradient in water demand for irrigation.

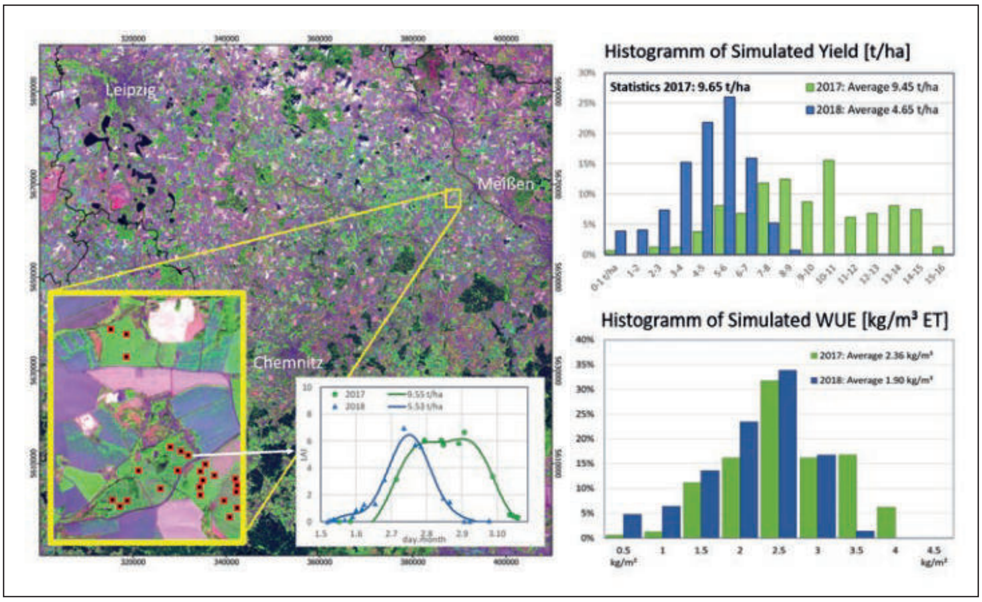

Figure 3: Sentinel-2 tile 33UUS in Saxonia on July 3 2018, inlays show identified maize pixels (left) and typical processed LAI time series for 2017 and 2018 (right). Histograms to the right show the tile's yield distributions estimated through assimilation of LAI in PROMET and resulting PROM-ET-WUE distributions of 2017 and 2018.

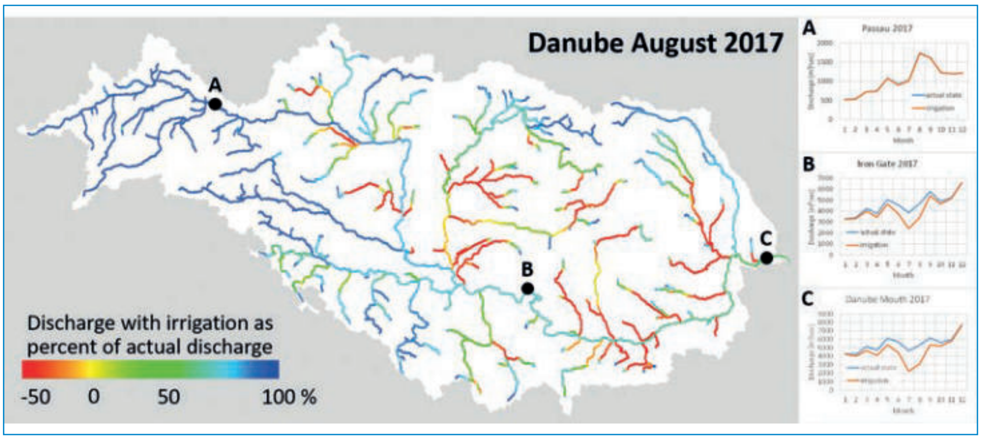

Figure 4: Simulated % change in runoff in the Danube river network in August 2017 due to irrigation (left) and actual and irrigated discharge for selected locations A, B and C (right).

CONCLUSIONS & OUTLOOK

ViWA has successfully established the basic tools to monitor WUE and to use Sentinel-2 time series. This big-data approach is new and challenging and will produce, once fully developed, deeper insights into the global water-food nexus as well as valuable practical applications in the context of achieving the water-related SDGs. It will be further used within ViWA to simulate scenarios, to analyse their sustainability and to identify agricultural WUE hot spots. Most efficient and sustainable basin wide irrigation was taken up by ViWA as result of stakeholder interactions. It completes the emerging global picture of the strongly varying WUE of green and blue water in agriculture as well as its value both in terms of economy and ecology.

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