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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BMBF Project ID: 02WGR1427A-G

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