German-Brazilian Research Cooperation in Water Science

Analysing, understanding and managing water resources in a changing world

Books of Abstracts

Edited by Eva Paton & Axel Bronstert
Preface

Research groups from Germany and Brazil have been cooperating in the last decade in the fields of hydrology, water resources and climate science under several bilateral arrangements. The aim of this German-Brazilian workshop on ‘Analysing, understanding and managing water resources in a changing world’ is to bring these initiatives together that they can share their outcomes, and learned lessons of ongoing and recent research projects, to discuss emerging research questions and to initiate new collaborations and project ideas.

Particular attention will be given to the water crisis that has been unfolding in Brazil in the last two decades. During this period, economic, social and technical progress took millions of Brazilians out of poverty. Similarly, water use increased steadily and anthropogenic environmental changes that are closely linked to the water cycle, such as deforestation, dam building, mining or urbanization, put more and more strain on the hydrological system. The otherwise water-rich country is currently facing a water crisis across large regions, in particular the Southeast and the Northeast. A key link between these two climatically distinct regions is the extended São Francisco river basin. A water transfer scheme is now being finalized which diverts water from the main flow of the São Francisco to the drylands in the Northeast.

We would like to address issues arising from extreme changes in the water regime at multiple scales in this technical workshop by giving both detailed information of running research projects in this context and by developing future research ideas, research needs, research questions and evaluation of possible funding sources.

The German-Brazilian Workshop is part of 7th Water Research Horizon Conference in Dessau (28.-29.6.2016).

Eva Nora Paton
Axel Bronstert
Workshop Organisers

Berlin & Potsdam, June 2016
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Interplay among multiple uses of water reservoirs via innovative coupling of substance cycles in aquatic and terrestrial ecosystems (INNOVATE)

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Which management options promote sustainable ecosystem services and economic viability under climate change conditions? (São Francisco Watershed, Itaparica Reservoir, Brazil)

A fair allocation of water resources is ever more at stake in the large and heterogeneous watershed of the São Francisco River. Even according to the climate change scenarios which are predicting an overall wetter climate, the occurrence of prolonged dry spells is increasing anyhow. Planning for these drought periods is required. Along with an increasing population and a strong insertion into the world market, the supply of water for productive uses and drinking water falls ever more behind demand. However, major players seem to plan separately so far. For instance, the regional development agency is promoting the expansion of irrigation agriculture in public schemes although simulations of future water availability indicate water shortages for the above mentioned prolonged dry periods. The water supply for the largest water infrastructure project of the last decades to be finished this year—the so-called “transposição”—is intended to deliver drinking water to dry areas within and outside of the river basin. In times of high water availability also irrigation water is to be supplied by the water diversion project. While in the wet climate scenarios the water supply is high in general, it falls much below expectations in the drier climate scenarios.

Supply and demand in times of scarcity are currently clearly falling apart. In order to negotiate a fair allocation of scarce resources, the river basin committee has started adopting a multi-criteria decision-making approach. The process is in its infancy and shall lead to an adapted reservoir management. Recommendations for an adapted reservoir management tested by project members in simulation runs include mimicking a ‘semi-natural’ discharge which allows for seasonal water level changes but would limit abrupt daily fluctuations, which are current practice to attend hydropower generation connected to the national grid. Aligning electricity generation with seasonal patterns, and extending wind (and solar) power to complement electricity generation in the dry season and to supplement daily peak demands is one step further towards an integrated management. Steps towards securing water quality include improving waste water treatment—urban sanitation being currently the major polluter at basin scale. Reducing diffuse phosphorous pollution by fertilizer incorporation is another key measure which points to the close relationships of the agricultural and water sectors.

At reservoir scale, managing the trophic level is the foremost concern to water quality. Besides some episodic exceptions, water quality in the Itaparica reservoir is currently acceptable and methane emissions are of less concern than initially anticipated. The trophic upsurge after dam completion in 1988 has already taken place. Moreover, biomass of the semiarid area is much less than the one of humid tropics reservoirs explaining the differences in observed GHG emissions. It is important to limit reservoir-based aquaculture in order to keep the trophic level as such. Promoting land-based aquaculture, along with the purification of its effluents, is an alternative. A water purification system has been prototyped within the project; its dissemination and approvability remain to be handled. Reducing reservoir water level dynamics (see above) to limit nutrient release from desiccated areas, in particular macrophytes, is an important measure for maintaining the trophic level. Studies of hydrodynamics of the artificial lake indicate that some of the formed bays need a special treatment—it is recommended to modify pumping practices in isolated bays to avoid critical water uptake affected from ephemeral tributaries flushing pollution into the reservoir. At both scales, the overall watershed and the local municipalities, good governance practices are needed to promote management and allocation practices which are fair, transparent and adaptive over time.

Project funding and time:
D: BMBF, Sustainable Land Management—Module A, 2012-2016
BRA: MCTI, CNPq, CAPES, UFPE

Key publications:


Sediment Export from Semi-Arid Regions: Monitoring and Modelling (SESAM)

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The SESAM project (Sediment Export from Semi-Arid Regions: Measurement and Modelling), running between January 2005 and December 2008 dealt with severe soil-erosion problems and resulting sedimentation of reservoirs that commonly occur in dryland regions of Spain and NE Brazil. In dryland environments, water availability for human, agricultural and industrial use often relies on the retention of surface waters in artificial reservoirs. Erosion of the land surface and deposition of the eroded material in such reservoirs threatens the reliability of reservoirs as a source of water supply and often has adverse effects on the local population.

The major achievements were a) the set-up of an extensive monitoring campaign on sediment budgets in dryland settings on NE Spain (Central and Pre-Pyrenees) and NE Brazil (Ceará) and b) the development of a model, the WASA-SED model, to assess sediment production in catchments, sediment transport in the river system, and sediment retention in reservoirs for meso-scale catchments in semi-arid regions. The basis for the modelling part of the project was the multi-scale hydrological model for semi-arid areas. The necessary data for the modelling development, model application and testing was planned for experimental catchments, dryland rivers and reservoirs of the co-operation partners in Spain and North-East Brazil, which have previously been instrumented during research activities of the cooperation partners. Hydrological and meteorological data were collected in the past by the cooperation partners, but still needed to be supplemented through field measurement and long-term monitoring campaigns, particularly to obtain data on for sediment yield from the catchment area, sediment transfer in the river system, and sediment retention and deposition in the reservoirs.

The 2nd DFG-project (Generation, Transport and Retention of Water and Suspended Sediments in Large Dryland Catchments: Monitoring and Integrated Modelling of Fluxes and Connectivity Phenomena) running between January 2011 and December 2015 observed, analysed and modelled the water and sediment fluxes in selected, typical dryland catchments focussing on the connectivity of different landscape compartments in meso-scale dryland catchments and the related water and sediment processes, including their typical space and time scale. With the phrase connectivity we understand transfer, storage and re-entrainment processes of water and sediments among different landscape components.

This third DFG project (Drought Forecast and Water Management System for the semi-arid region of the state of Ceará, Brazil), currently running, aims to make the knowledge and scientific results generated in the earlier projects effectively available in practical applications.

Those DFG-projects were complemented by a number of research projects from Brazilian Federal Sources (such as CNPq and CAPES) and by research money from State and environment agency sources. In addition, the involved universities in Germany, Brazil and Spain contributed to the success of this research.

Overall, this cooperation in research and education has resulted in an innovative system to measure and simulate comprehensively the water and sediment fluxes in such dry regions, including processes of retention and (re)mobilization in different, connected compartments of the landscape. Such “connectivity” issues of water and sediment pathways at the scale of river basins are crucial for effective management and intervention, i.e. in particular:
- the transition between the hillslopes, valley bottoms, and the river system,
- the temporal storage (of water and sediment) and transmission losses in the river network,
- the retention in reservoirs and the partial transfer from the reservoir entrance to its outlet.

This combined observation and modeling study deepened the understanding of hydro-sedimentological systems characterized by flashy runoff generation and by erosion and sediment transport pulses through the different landscape compartments. The connectivity between the different landscape compartments plays a very relevant role, regarding both the total mass of water and sediment transport and the transport time through the catchment.

Despite the model’s process-oriented concept, several parameters for the WASA-SED model remain immeasurable and have to be calibrated. Calibration also serves to compensate for the parameter inaccuracy that arose from the regionalization of sparse data and their incommensurability, caused by their scale- and model-structure dependent interpretation as compared to real measurements. Calibration is performed automatically where measured discharges
were available. The model yields simulated runoff [m³/s] and hydrological fluxes [m³/d], such as shown here for the gauge Villcarli (41km²) for 09/2006 until 05/2007.

**Figure 1:** Schematization of water and sediment transport through different landscape compartments and the associated connectivity phenomena.

Based on the simulated water fluxes, the total sediment fluxes and yields are modelled without calibration. As an example, the figure 3 shows the simulated and observed sediment fluxes of the Villcarli subcatchment during the period 01/2006 – 12/2006.

**Figure 2:** WASA-SED hydrological model results for Villcarli sub-catchment, 09/06–05/07: above: simulated runoff [m³/s]; below: hydrological fluxes [m³/d] (Francke 2009)
**Figure 3**: Sediment fluxes of the Villacarli subcatchment, 08/06 – 12/06 (sim: simulated with river module; sim_subbas: simulated without river module; CI: confidence interval of the observations)

**Project funding and time:**
- CAPES: PhD-scholarship (4 years: 04-2004 - 03/2008)
- CNPq: PhD-scholarship (4 years: 04-2008 - 03/2012)

**Key publications:**


The demand for concepts of integrated water resource management (IWRM) is increasing worldwide due to rising awareness for sustainable use of water resources and due to pressure from society for reliable and healthy water supply. For many regions in South America, where water scarcity and/or water quality are issues, this applies in particular. In addition to the specific natural conditions, i.e. strong seasonal contrasts and strong climatic variability, the rapid changes of land use/cover - mostly caused by the drastic expansion of agricultural land and urbanization processes - have severe effects on water resources. Effects of land use change on water resources seem to exceed the effects of climate change, but global climate models predict substantial changes in future climate and in consequence, severe effects on water resources are to be expected. As a result of the rapid changes of land use, rising demand for water supply and rising production of waste water can be expected – both in terms of amount and spatial expansion – due to higher population densities caused by natural population growth and migration as well as higher per capita consumption. The understanding of the complex interactions between water, climate, land use, society and water technologies is a crucial step to achieve sustainable water supply with high standards in regard of quality and reliability.

Central Brazil belongs to the type of region described above. As climate change and very dynamic processes of urbanization and expansion of agriculture are happening in this area, substantial impacts on water resources have been observed. Urbanization and high shares of urban population as well as substantial expansion of croplands are seen as major causes for ecological problems in Brazil, e.g. not sustainable use and pollution of water resources (Braga et al. 2008, Hespanhol 2008, Tucci 2001, 2008). The adaptation to changing frame conditions as well as the prevention and mitigation of negative impacts on water resources are the main challenges for the sustainable water supply of the region. Therefore, a consortium of Brazilian and German partners decided to start the IWRM project IWAS-ÂGUA DF focusing on the Distrito Federal including the national capital Brasília (IWAS-ÂGUA DF was funded through the program “International Water Research Alliance Saxony (IWAS) – Management of Water Resources in Hydrological Sensitive World Regions” by the BMBF).

During the period 2008-2013 the project IWAS-ÂGUA DF was carried out as joint activity by Brazilian and German partners, aiming at providing the scientific base for the sustainable use of water resources within the Distrito Federal (DF). The study area was chosen because of its model character due to outstanding data base on water relevant information and the existing high standards in terms of technology and capacity development in the water sector.

The general objective of the project was to contribute to the development of an IWRM approach for the Distrito Federal, identifying causes of problems and proposing solutions to maintain water supply for the region also with a focus on changing frame conditions. The project follows the DPSIR approach (EEA 1999 [Figure 1]), which identifies the driving forces and pressures on the compartments river basins, drinking water and waste water systems and analyses the state, impacts and response of these compartments.

The Distrito Federal covers an area of 5790 km² and is located in the high plains (planalto) of Western Central Brazil with altitudes between 1000 and 1450 m a.s.l. The topography might be characterized as rolling landscape where steep slopes are rather an exception. The geological underground consists of series of metasediments, i.e. argillic to sandy rocks of the Proterozoic period. Soils are mostly Oxisols, Cambisols and Gleisols developed in the regolith mantles of the rocks mentioned above.

The study region belongs to the outer tropics (Aw climate after Köppen) having mean annual precipitation of 1300-1700 mm and mean annual temperatures of 20-21° C (WMO 2010). The climatic conditions are characterized by strong seasonality. The dry season comprises 5-6 months, during south-winter, from late March to late September. The average amount of precipitation during rainy season is four times higher than during dry season. However, the temporal variability of mean annual temperature and precipitation as well as in terms of seasonality is high.
Figure 1. Driving forces-Pressures-State-Impacts-Responses (DPSIR) scheme of the project (modified after Lorz et al. 2012).

Effects of climate change are already observable for the last three decades (Borges et al. 2013). Since the end of the 1970s a trend to longer dry periods with less rain days at the begin and the end of the dry seasons as well as a general trend for lower mean annual precipitation have been observed for five stations in the Distrito Federal (Table 1). However, this trend is not significant for all stations and will not fully explain the dramatic decrease of base flow discharge during the dry period (Lorz et al. 2012). For the future, a further increase of seasonality, i.e. loner dry seasons, is predicted (Borges et al. 2013)

Table 1. Mean annual precipitation for five stations (see Figure 2 for location) in the Distrito Federal and trends (Kendall’s tau) for rain days and annual precipitation (Mann-Kendall test) (Lorz et al. 2012).

<table>
<thead>
<tr>
<th>monitoring station</th>
<th>period</th>
<th>MAP [mm]</th>
<th>rain days April/May</th>
<th>rain days October</th>
<th>annual precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 1547013</td>
<td>1978-2009</td>
<td>1332</td>
<td>-0.25° (May)</td>
<td>-0.26*</td>
<td>-0.24°</td>
</tr>
<tr>
<td>B 1547014</td>
<td>1979-2006</td>
<td>1480</td>
<td>-0.36** (April)</td>
<td>-0.18+</td>
<td>0.08+</td>
</tr>
<tr>
<td>C 1547015</td>
<td>1978-2004</td>
<td>1419</td>
<td>-0.17° (May)</td>
<td>-0.26*</td>
<td>-0.04*</td>
</tr>
<tr>
<td>D 1548007</td>
<td>1978-2008</td>
<td>1560</td>
<td>-0.25° (May)</td>
<td>-0.26*</td>
<td>-0.12*</td>
</tr>
<tr>
<td>E 1548008</td>
<td>1979-2006</td>
<td>1444</td>
<td>-0.31* (May)</td>
<td>-0.35**</td>
<td>-0.33*</td>
</tr>
</tbody>
</table>

- = two-sided p > 0.05 (not significant), * = two-sided p < 0.05 (significant), ** = two-sided p< 0.01 (very significant), rain days are days with any recorded rainfall

The region is part of the Cerrado biome, which covers nearly a quarter of the total surface area of Brazil, i.e. 2.5 million km². The dominating natural vegetation form is savannah (Figure 2). Grass dominated savannah (Campo) is interchanging with typical tree savannah (Cerrado) depending on topography and water availability (Oliveira and Marquis 2002, Silva et al. 2006).

Forested areas are divided in dry forests (Cerradão), gallery forests (Mata de Galeria) and pine or eucalyptus plantations. Protected areas include the National Park of Brasilia – around the reservoir Santa Maria (Figure 2) – and several smaller state reserves. Most of the region is covered by pastures and arable fields. Large mechanized agriculture cultivating soy bean, corn and beans account for more than 90 % of the total arable land (IGBE 2010). Large scale crop cultivation with no-tillage practice is prevailing in the eastern part of Distrito Federal, whereas in the western part small scale farming and horticulture are dominant. Large areas are urbanized with all development levels, i.e. irregular settlements with less developed infrastructure, highly developed urban areas and residential areas with high development standards. Industrial areas do not exist in the region.

The region has experienced a substantial change in land cover and land use since the foundation of the national capital Brasilia in 1960, as it has been also observed for other regions in Brazil (Simon et al. 2010). Land use/cover has changed mostly due to a substantial increase of agricultural land and urban sprawl occupying mostly natural areas, i.e. savannah or forest. The loss of areas with natural vegetation has been quantified with 58 % for the period 1954-1998 in DF (UNESCO 2002) which is in the same order as reported for the Cerrado biome (Klink and Machedo 2005). The share of (semi)natural vegetation was around 40 % in 2006 for the DF. From 2002 to 2007 the area of arable land (without orchards) increased by 47 %, from 84,240 ha in 2002 to 123,692 ha in 2007.

Urbanization is the second major process of land use change for the Distrito Federal and is associated with urban sprawl and the spatial expansion of sealed areas. The share of urban areas increased for the period 1954 to 2001 from 0.02 % to 10.62 % (CODEPLAN 2007, Fortes 2007). The nucleus of Brasilia – finished in 1960 - is the so-called Plano Piloto where the outlines have the shape of an airplane. Since then, the settlement structure developed polycentric with
fast growing suburbs, e.g. Itapoã. Recently, new upper standard residential areas have been developed, e.g. the quarter Noroeste.

![Location map of Distrito Federal](image)

**Figure 2.** Location and land cover of the Distrito Federal in 2006, 1 = Lago Paranoá, 2 = Lago Sta. Maria, 3 = Lago Descoberto, 4 = Pipiripau (after Fortes et al. 2007).

The Brasilia region is one of the large urban aggregations of Brazil where the capacities of the existing systems for water supply are already near their limits and demand will increase dramatically in the near future (ANA 2009; CAESB 2010). For the Distrito Federal the situation is even more pressing, since 94% of the population live in urban areas. The predicted growth of population for the region from currently 2.5 million to more than 3.2 million in 2025 will mostly take place in urban areas. Estimations of future water demand predict an exceeding of available water system capacities for the near future. During dry season the capacities for some drinking water treatment plants are already close to maximum. The average consumption per capita was in 2003 approximately 195 l d⁻¹, but minimum (110 l d⁻¹) and maximum average (597 l d⁻¹) per municipality are far apart (PGIRH 2006).

Currently, water supply for the region is provided by two major reservoirs (Figure 2), Lago Santa Maria and Lago Descoberto (Table 2). These reservoirs cover about 78% of the total water supply of the Distrito Federal. The remaining water comes from the extraction of stream water and of groundwater. For the future, the regional water supplier CAESB is planning to extract around 2.8 m³ s⁻¹ from the Lago Paranoá, an urban lake in the center of Brasilia. An additional plan in realization is to use the reservoir Corumba IV, a reservoir for hydropower generation around 80 km to the south, for the water supply of DF. However, both lakes might have water quality problems because the respective watersheds have less adequate land use and receive waste water from settlements.

**Table 2.** Contribution to the water supply of different types of water resources (CAESB 2003).

<table>
<thead>
<tr>
<th>Type of Water Resource</th>
<th>Discharge [m³ s⁻¹]</th>
<th>Percentage [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lago Santa Maria (area: 6 km², volume: 58 * 10⁶ m³)</td>
<td>1.9</td>
<td>21</td>
</tr>
<tr>
<td>Lago Descoberto (area: 14.8 km², volume: 102 * 10⁶ m³)</td>
<td>5.1</td>
<td>57</td>
</tr>
<tr>
<td>Stream water</td>
<td>1.6</td>
<td>18</td>
</tr>
<tr>
<td>Groundwater</td>
<td>0.3</td>
<td>4</td>
</tr>
<tr>
<td>Total water supply</td>
<td>8.9</td>
<td>100</td>
</tr>
<tr>
<td>Lago Paranoá (area: 38 km², volume: 498 * 10⁶ m³)</td>
<td>2.8</td>
<td>[29]</td>
</tr>
</tbody>
</table>

**Project funding and time:**
BMBF IWAS, 2008-2013

**References:**
Key publications:


Strategies and Technologies for Water Scarcity Mitigation in Northeast of Brazil: Water Reuse, Managed Aquifer Recharge and Integrated Water Resources Management (BRAMAR)

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A) Project outline

The research cooperation intends to close research gaps with regard to Water Reuse (WR) and Managed Aquifer Recharge (MAR) as part of Integrated Water Resources Management (IWRM) response strategies to combat water scarcity and guarantee sustainable development of semiarid Northeast of Brazil. For the research development, financial support is provided by Brazilian Ministry of Science, Technology and Innovation (MCTI) and the German Federal Ministry of Education and Research (BMBF).

The BRAMAR partner network is composed of 7 German and 18 Brazilian institutions, with RWTH Aachen and Universidade Federal de Campina Grande (UFCG) being responsible for the coordination of the German and Brazilian groups, respectively. It results from a long-term cooperation between Brazilian and German universities. The 7 German institutions are the universities RWTH Aachen (ISA and AVT), Universität Göttingen and TU Braunschweig, as also as the companies HUBER SE, ENVIROCHEMIE GmbH and AP Systems Engineering. The Brazilian institutions involved are the universities and research centers Universidade Federal de Campina Grande, Universidade Federal Rural do Semiárido, Universidade Federal de Ceará, Universidade de Fortaleza, Universidade de São Paulo, Universidade Federal Rural de Pernambuco, Universidade Federal do Paraíba, Universidade Federal de Pernambuco, Instituto Federal da Paraíba, Empresa Brasileira de Pesquisa Agropecuária, Instituto Nacional do Semiárido and Fundação Cearense de Meteorologia e Recursos Hídricos, the water agencies Agência Nacional das Águas, Agência Executiva de Gestão das Águas da Paraíba, Instituto de Gestão das Águas do Estado do Rio Grande do Norte and Agência Pernambucana de Águas e Clima, as also as the companies Companhia de Água e Esgotos da Paraíba and the INTRAFRUIT industry.

The semiarid area of Brazil, which covers 9 Federal States, is increasingly impacted by water scarcity. Spatial and temporal variability of rainfall and high evaporation rates along with regular droughts characterize the region, known as “Polígono das Secas”. The region has agricultural, industrial and technological potential, but integrated water management concepts as well as adapted technologies are still missing, and the combination of natural conditions with a growing demand of water will lead NE Brazil to face serious challenges in the near future.

Four representative case studies have been identified in the semiarid Northeast of Brazil. The case study areas (CSA) are Sumé, João Pessoa and Campina Grande, in Paraíba, as well Mossoró, in Rio Grande do Norte, and Recife, in Pernambuco. They feature typical situations according to the river basin area, climate, population, water users and conflicts, water resources and aquifer system, and related water problems. The project investigation goes further in the two first mentioned CSAs.

For the João Pessoa CSA, the water resources system consists of a costal sedimentary aquifer system, called Barreiras-Beberibe, and the hydrological basins in which it is located, specially the Gramame River Basin, with the Gramame-Mamauaba dam. Barreiras is the phreatic aquifer, while the Beberibe aquifer is confined. The Metropolitan Region of João Pessoa (MRJP), of about 800,000 inhabitants, is supplied by the surface and groundwater sources described above. The João Pessoa CSA is the “Technological” Site, since innovative waste water reclamation and reuse (WWR) schemes with adapted waste water treatment (WWT) technologies will be developed and applied there. The water resources system at the case study Recife is very similar to the system at Joao Pessoa, so they will be handled as “Twin” case study since the research at both sites complement each other towards the development of IWRM response strategies.

Campina Grande is one of the biggest cities in the inner NE region, with 400000 inhabitants. Its geology is basically formed by cristaline rocks, in which groundwater accumulation is not favorable. The city is supplied by a large reservoir, subject to recurrent droughts. Currently is passing through a very severe water crisis. Bramar is investigating alternative water sources, such as rainwater harvesting and wastewater reuse, improved reservoir management and local- and basin-levels water governance.

The water resources system Sumé, which is the “Rural and Semiarid Conjunctive Use Site”, consists of the ephemeral river Sucurú, a surface water reservoir dam (with a storage capacity of 45 hm³) and an alluvial groundwater system of very permeable sand and gravel layers (about 2 to 20 m deep, 20 to 500 m wide and a few kilometers long). Some inactive irrigation areas, the City of Sumé with 17,000 inhabitants and its low-tech waste water treatment facilities (WP4) are also part of the system.
In the Mossoró CSA, low-cost waste water reclamation schemes will be implemented and tested for water reuse in irrigated agriculture to control water pollution and contribute to conflict prevention. Project activities are grouped in 10 work packages (WP), which are presented in Figure 1, as also their interactions. According to the research approach, IWRM response strategies (WP8) based on Managed Aquifer Recharge - MAR (WP3), water reclamation and reuse (WP4, WP5) will be developed for representative areas in Northeast of Brazil (WP6). Additionally, under WP 3, 4, 5 and 8, the potential for regional implementation of technologies and management concepts will be studied.

![Figure 1: BRAMAR research approach](image)

Environmental impact of the developed set of site specific alternative IWRM strategies as well as their performance towards the achievement of the main water management goals (WP8) will be supported by means of hydro(geo)logical modelling (WP2) over an adequate planning horizon.

WP1 studies the socio-economic performance and is responsible to forecast regional socio-economic development as well as climate change scenarios, quantifying their impacts on future sector water demands and water availability, serving as boundary condition for hydrological modelling (WP2) and strategy analysis (WP8). An innovative decision support (DS) platform will be created under WP7 to support IWRM implementation. Different DS tools will be developed based on Multi-Criteria-Analysis to support evaluation and ranking of options with regards to MAR implementation (WP3), water reuse (WP4), reclamation technologies (WP5) and response strategies (WP8). The work will result in case studies specific IWRM response strategies with clear recommendations with regard to the planning of hydro-infrastructure and long-term WR management.

To support knowledge transfer and dissemination, an innovative web-based water resources information platform will be elaborated under WP9, which is the package responsible for knowledge transfer and dissemination of project results to other semi-arid regions in and outside Brazil.

B) Water budget analysis using hydro(geo)logical models with focus on implementation of managed aquifer recharge strategies, Brazil

Regular droughts and general water scarcity characterize the semi-arid region of Northeast Brazil. Climate change and unbroken growth of population and industries together with insufficient sanitation are predicted to exacerbate the serious water supply crisis. The German-Brazilian research cooperation and technology development project BRAMAR intends to close research gaps with regards to water reuse (WR) and managed aquifer recharge (MAR) as part of integrated water resources management (IWRM) response strategies to combat water scarcity and guarantee sustainable development of the region.

The base for developing IWRM is the combined application of hydrological and groundwater modeling tools to determine the surface and groundwater availability as well as the groundwater recharge for both present and future situations. The models will be used to simulate IWRM strategies on case study level and to support a ranking of alternative strategies based on environmental and socio-economic indicators. The simulation of climate change scenarios will additionally be conducted to strengthen these analyses.

The hydrological study of the surface water includes the basins of the rivers Paraíba (catchment about 20,070 km²) and Gramame (catchment about 590 km²). As available hydro(geo)logical studies merely focus on an integrated water
budget analysis the first step to be carried out was an extensive review and analysis of topographical, meteorological and hydrometric data compiled from several national and local institutions and universities. Based on an initial inspection of monitoring networks and an analysis of data availability from 1991 to 2015 the data situation has proven to be sufficient in terms of developing a first rough hydrological model although the quantity of gauges is extremely limited. The scope of the functional measurement network integrates approximately 103 precipitation stations (operator AESA and UFPB), 9 climate stations (operator AESA, INMET, UFCG, UFPB) and in total 8 gauges (operator ANA, CPRM) for which historical data could be provided. The water regime of the catchments is highly influenced by artificial impact which includes water retention in a high number of lakes and reservoirs (at least 40 reservoirs, operator AESA) as well as manual water extraction from reservoirs and river streams for water supply of surrounding cities and local industry. Information about reservoir operation (e.g. reservoir inflow or release) is highly uncertain and influences the accuracy of modeling results.

The groundwater modeling focuses on the coastal area including the city João Pessoa, its suburbs and the basin Gramame (joint catchment about 1,030 km²). The three-dimensional groundwater flow model integrates the formations Barreiras (unconfined aquifer, thickness about 45 m), Gramame (impervious slice, thickness about 55 m) and Beberibe (confined aquifer, thickness about 160 m). The analysis of monitoring network and data situation clearly emphasizes a high gap of geological data and groundwater water level information. Due to the limited data situation a first hydrogeological model and a steady regional groundwater flow model were built up which allows extension to a transient flow and transport model in the future. The calibration phase is still in progress. The quantification of water budgets and water deficits are supported by field and laboratory studies. This includes the implementation of meteorological stations, surface water gauges, and groundwater observation wells as well as the future conduction of pumping tests and exploratory drilling. Therefore the modeling results are still preliminary.

MAR studies at the case study area of João Pessoa focus on the conceptual planning of a Soil-Aquifer-Treatment (SAT) system utilizing treated waste water, as well as conventional MAR measures using surface water surpluses for recharge. First steps of MAR planning options development have been taken to develop mean monthly water budgets based on local available water sources (rivers, surface reservoir, wastewater) and demand sectors (agriculture, domestic, industry). The developed models will support this work by supplying more data for detailed water budgets analyses and by enabling the simulation of the impacts the recharge of certain quantities will have on the local system. Suitable locations are identified by constraint and suitability mapping based on a set of criteria (e.g. land use, infiltration rate, water table depth etc.) and can be validated by simulations with the groundwater flow model. Currently the site selection and determination of pre-treatment requirements for wastewater to be used for SAT is supported by conduction of soil-column-experiments at laboratory scale for the quantification of infiltration capacity and to assess the extent of alteration of soil and groundwater characteristics associated to a soil remediation process.

Figure 2: Water budget simulation for the basins Paraíba and Gramame (left) and application of groundwater modeling tools for the urban area of João Pessoa and the basin Gramame (right). The results of the calibrated models will be used for water budget analysis with focus on implementation of managed aquifer recharge (MAR) strategies as part of integrated water resources management (IWRM).

Project funding and time:  
BMBF (Client), FINEP, 2014 – 2017
Feedbacks between ecohydrological and hydrological systems (ECHO-Brazil)

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Analysis of water and land degradation in heavily modified Cerrado catchments in Mato Grosso, Brazil

The Brazilian Cerrado is recognized as one of the most threatened biomes of the world, as the region has faced a striking change from natural Cerrado vegetation to one of the top regions of the world’s cash crop production over the last 30 years. Impact studies on the effects of how current and future land use intensification affects land and water resources are pivotal to assess the Cerrado’s potential to ensure the continued provisioning of its ecosystem services. Available hydrological, ecological and soil studies merely focus on a singular aspect of the ecosystem, but no recent review was available that investigates the effects of land use change on soil properties and degradation and impact on water quality and catchment functioning. We therefore carried out an extensive review and meta-analysis of 95 available field studies of the Cerrado that investigated the impact of different land uses (crop, pasture and energy plantation) on soil-hydraulic and biogeochemical properties and changes to the quality of surface and groundwater for nutrients and pesticides and concluded that the combined effects of land use intensification and climate change are likely to seriously limit the Cerrado’s future productivity and ecosystem stability (Hunke et al., 2014).

In a second study we quantified the effects of land-use change for the most common croplands (soybean/cotton/maize rotation and sugarcane) and pastures in regard to changes in texture, soil aggregate stability, infiltrability, saturated hydraulic conductivity (Ksat), pH, and soil nutrients (NPK) and determined the impact of agricultural production on water quality by examining its seasonal patterns and the spatial distribution of water quality parameters across a meso-scale catchment. The soil analysis gave a clear picture of the current degradation status of the sampled fields. The most pronounced effects occurred on the soybean plot including a) a significantly decrease of infiltration rate, b) a significant decrease of soil aggregate stability and c) a significant increase of K at all sampled soil depths and very high topsoil P concentration, however no accumulation of P into deeper horizons. Under pastures, the effects on soil properties for pH, K and P concentrations were less pronounced but showed compared to the natural Cerrado site a significant loss of N in the entire soil profile. Figure 1 presents two exemplary results: infiltrability from natural Cerrado to croplands and pasture is reduced by an order of magnitude or more, and phosphorus increased significantly especially under soy production (Hunke et al., 2015).

Figure 1: Surface infiltrability and soil phosphorus content as a function of different land use types (CE-Cerrado, PA-Pasture, SOY-Soybean/cotton and SC-Sugarcane) on Ferralsols

The work in Mato Grosso was carried out in close co-operation with Prof. Peter Zeilhofer from the Federal Universidad Cuiaba, Mato Grosso, Brazil who provided excellent access to the university laboratories, existing field sites, logistical support, car and academic help. The project focus for the Cerrado was shifted from a merely remotely-sensing-based approach as was previously stated in the proposal (as at the time of proposal submission no definite local research contact was established) to a fieldwork-based approach, once the research contact with P. Zeilhofer was established at the beginning of the Emmy-Noether funding. Three fieldwork trips to Cuiaba (à 6 weeks each in 2010-2012) enabled the collection of water and soil data, the lab analysis at the Cuiaba university (nutrient analysis of water and soil samples, estimation of soil-hydraulic parameters etc.), the compilation of climate data, land-use data for different time periods, soil and terrain maps of a heavily modified catchment which allowed the parameterisation, testing and
scenarios runs for river discharge of past and future climate conditions of the meso-scale SWAT (Soil Water Assessment Tool) model (details in Hunke 2015).

**Project funding and time:**
DFG Emmy Noether Scheme, 2009-2015

**Key publications:**


Carbon-optimized land management strategies for Southern Amazonia (CarBioCial)

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Hydrological research in the Cerrado and Amazon biomes: recent results from a Brazilian-German research cooperation (CarBioCial)

On many levels, there is still a lack of understanding the impacts of deforestation on water resources on the Amazonian agricultural frontier. This frontier extends from the western to the southeastern Brazilian Amazon edge, comprising a widespread area along the Amazon-Cerrado ecotone. Both the large spatial extent of this region and the wide diversity of environmental conditions requires extensive field-based work to allow comprehensive process characterization and to improve the hydrological modelling parameterization. The Cerrado biome, where most of the deforestation has occurred, is often not integrated in the studies regarding the Amazon deforestation. In order to fill this gap, the CarBioCial project (Gerold et al., 2014) conducted several hydrological analyses in areas of rapid historic deforestation in Southern Amazonia. To that end, we selected two macro-catchments, one in the Amazon biome (Jamanxim catchment, 37,403 km²) and one in the Cerrado biome (das Mortes catchment, 17,556 km²), both located on the Amazon agricultural frontier. The main aim of this research was to assess: a) how deforestation and land-use types affect the water balance components (WBC); b) what are consequences of climate change and land-use scenarios on the water balance in a macro-scale, and c) how land-use types alter the hydrochemical dynamics in micro-catchments.

The das Mortes catchment is characterized by an extensive conversion from cerrado vegetation to agricultural land most intensively in the 70s, resulting today in over 65% of agricultural land in the total catchment area. Trend analysis in this catchment showed that the streamflow (Q) has increased particularly during the initial main deforestation phase, while the precipitation has shown no significant evidence of increase (Guzha et al., 2013). SWAT simulations using land-use scenarios show very small discharge changes for the last two decades. Compared to the das Mortes catchment, the deforestation in the Jamanxim catchment was relatively low, however increasing rapidly since the 1990s, and now reaching 15% of the total area. In order to evaluate the land-use change impacts on the WBCs in these contrasting macro-catchments we used SWAT (Soil Water Assessment Tool) with the application of gradual land use change (LUC) over the calibration and validation period. The model results show changes in WBC predominantly during the wet season, with strongest effects for the conversion of native vegetation (Cerrado and rainforest) to pasture. In the Jamanxim catchment, a deforestation of 26% leads to an increase of 8% in Q. The results also show that the inclusion of gradual LUC is necessary to ensure the best possible prediction quality in regions with intensive LUC during the application of a hydrological model (Lamparter, 2016).

In both the das Mortes and the Jamanxim catchments, we selected paired micro-catchments under different land-use, i.e. native vegetation (rainforest or cerrado) and pasture for extensive cattle ranching, to characterize the changes of pedohydrological properties and runoff due to these contrasting land-uses. Results at this scale show that the pasture catchments exhibited greater Q in the Amazon (35%) and Cerrado (55%) biomes. For the Amazonian catchments we attribute these results to the higher bulk density (36%) and lower saturated hydraulic conductivity (83%) found in the pasture catchment and the greater evapotranspiration (26%) in the forest catchment (Guzha et al., 2015). In the Cerrado biome, we found similar differences in pedohydrological properties between the catchments, with greater bulk density and smaller total porosity in the pasture catchment. Also we found that in the Cerrado biome evapotranspiration is much smaller in the pasture (639 ± 31% mm yr⁻¹) than in the cerrado catchment (1,004 ± 24% mm yr⁻¹), and that Q increase in the pasture catchment with runoff coefficients of 0.40 for the pasture and 0.27 for the cerrado catchment (Nobrega et al., 2016).

In the micro-catchments, we also quantified the hydrochemical differences under both regular streamflow and stormflow conditions. Our results show that in both biomes the pasture catchments have a greater concentration and nutrient output of inorganic carbon, nitrogen, and potassium in the stream water, especially during stormflow conditions, than in the catchments with native vegetation. In the cropland catchment, the well managed soy-crop rotation (e.g. no-tillage system) leads to lower nutrient concentration and output compared to the pasture land-use system. Measurements using overflow detectors in the cropland micro-catchment show a smaller nutrient concentration in the riparian zone (gallery forest) and streamflow compared to the agricultural area. These results indicate the importance of land management including the protection the existing native vegetation in the riparian zones to buffer effects of deforestation and land-use change on discharge generation and stream water quality.
Project funding and time:
BMBF (FONA), 2011–2016

Key publications:


Sharing experience to develop robust approaches to catchment monitoring and management in the Pantanal contribution area, Brazil

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There is increasing concern about water resources in the Central Western Brazil, where, principally since the last 40 years, savannas and forests have been replaced by intensive agricultural production systems, transformations, which had triggered as well an intensive economic development and city growth with ongoing, severe problems in sanitation infrastructure. In the contribution area of the Pantanal, the world’s largest floodplain and a UNESCO Natural Heritage and Biosphere Reserve, water resource monitoring and management is important not only on local scales, but also to support the conservation of the floodplain ecosystems because seasonal runoff and land use from the uplands drive their inundation regimes and influence their biogeochemical cycles. The GEOHIDRO research group, located at the Federal University of Mato Grosso (UFMT) and composed by members of several departments who lecture in five postgraduate courses, realizes since the 90ties interdisciplinary studies on water resource issues, this against the background of federal and state water legislation enacted in 1997, which governs water resources policy by a decentralized and participatory approach with watersheds as planning units. Research initiatives include multi-parameter and -scale hydrological and water quality monitoring efforts, development of remote sensing and GIS application for water resource management, studies on the impacts of land use change and hydropower plants on discharge and water quality and the application of statistical techniques for time series analysis. Recent activities are focussing on the implantation of a real-time climatic and water quality monitoring network called REMAPP, to understand short-term variations of water quality and influence of sampling frequency on the extractability of cyclical and trends from hydrological and water quality series. The improvement of laboratorial analytic capabilities objectives a better understanding of pesticide pollution risks and pathways in the region. Operationalization of a multirotor UAV remote sensing platform targets estimates of soil characteristics and plant physiological parameters studies at high resolution in small watersheds and its possible upscaling by satellite data. Remote sensing inundation monitoring in the Pantanal and planned comparisons between data-driven and process-oriented models should give insights on the interference of land use and hydropower plants on discharge and water quality on watershed scales in- and outside the Pantanal floodplain.
Remote sensing for water resources management in dryland areas (PROBRAL)

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The German-Brazilian cooperation aims at monitoring water resources and improving the understanding of its complex dynamics based on remote sensing technologies in dryland areas and specifically in the North East of Brazil, a region referred to as the drought polygon.

The North East of Brazil is characterized by a high spatial, seasonal and inter-annual variability of rainfall. The climate is semi-arid with pronounced wet and dry seasons. For the dry season, water supply is ensured by the construction of reservoirs of various sizes. The stored water is essential for the local population in terms of drinking and irrigation usage. However, the region regularly experiences drought spells when low rainfall rates during the wet season result in insufficient refill of reservoirs, inducing a need for effective and integrated water resource management. In recent years, an increasing growth of macrophytes has been observed indicating an increase in eutrophication of the reservoirs that in turn is related to changes in land use and land cover. Particularly direct access of cattle to the reservoirs and the degradation of the natural Caatinga vegetation are supposed to be major causes of increased nutrient inflow. Given the large number of reservoirs, the complex dynamics of water storage and quality and the size and remoteness of the area, multi-sensor satellite remote sensing is believed to be an ideal source to assist monitoring of water resources as a basis for a sustainable water resources management.

Specific objectives of the joint project are to (1) derive bathymetric information of the water surface reservoirs using satellite InSAR technology to estimate height-area-volume curves, (2) monitor the effective water storage dynamics from water surface delineation by radar and optical satellite image time-series and the previously derived storage curves, (3) monitor water quality by use of hyperspectral and multispectral imagery, (4) identify macrophyte types and monitor their spatial and temporal dynamics, (5) characterise reservoir sediments by spectroscopy, (6) detect land cover changes and relate it to the observed eutrophication dynamics and macrophyte growth and (7) use the information derived from satellite data for improving flood and drought forecasting in the region. The multi-sensor remote sensing approach is supported by an extensive ground-truthing programme to calibrate and validate image analysis as well as to identify processes on site.

Project funding and time:
DAAD/CAPES PROBRAL, 2014-2015

Key publications:
