Challenges and opportunities of German-Chinese cooperation in water science and technology

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Due to rapid economic development and population growth, China is facing severe water problems that include sea-level rise and increasing salinization, floods, water pollution, water shortage, soil erosion and ecosystem deterioration, as well as biodiversity loss. In recent decades, China is progressively more concerned with its water issues that are now at the center of social and political attention. Having to overcome similar challenges, Germany has taken a leading role in the field of water sciences and technology. In particular, China can benefit from the

lessons learnt in Germany concerning the rehabilitation of water resources in areas heavily affected by chemical industry and mining after the reunification in 1989. German-Chinese cooperation in water sciences started over 25 years ago and dealt with increasing challenges in the 21st century. Following the open space workshop during the Water Research Horizon Conference in Berlin 2014, this article provides a view of some of the challenges and potential opportunities of German-Chinese cooperation in water science and technology.

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Water crisis in China

China has experienced rapid urbanization and sustained high economic growth in the past several decades, especially after the implementation of the Reform and Open Policy in 1978 (WB 2014; WB and DRCSC 2014). With a population of about 1.4 billion, China recently became the second largest economy and is increasingly playing an influential role in the global economy (WPS 2014). Meanwhile, rapid economic ascendance has brought on many environmental issues. Among them, the environmental degradation induced water crisis, including water pollution, water shortage, floods, water salinization, groundwater depletion, catchment soil erosion, ecosystem deterioration and biodiversity loss, is one of the most serious environmental challenges. China's water issues are becoming such a pressing problem that these pose a threat to human health and may lead to severe consequences for future generations. In addition to air pollution, water pollution is extending from inland to coastal areas, from surface water to groundwater, from single agent pollution to compound pollution, and from conventional pollutants to non-conventional pollutants that are surely the largest threat to the Chinese society today. Furthermore, water shortages are occurring more and more often as nearly half of the 634 Chinese rivers, lakes and reservoirs tested in 2011 failed to meet drinking standards for all or part of the year (Tao and Xin 2014). Two-thirds of China's 669 cities have water shortages, more than 40 % of its rivers are severely polluted, and 80 % of its lakes suffer from eutrophication (Liu and Yang 2012). Since most of the drinking water comes from surface water, drinking water problems caused by harmful algal blooms and chemical spills are of a great concern (Tang et al. 2006; Tirado 2008; Wang et al. 2008; Chen and Liu 2014; Zhang 2014). In addition to toxins capable of causing illness or irritation, cyanobacteria (also known as blue-green algae) can pose wastewater treatment challenges for public water systems. Wells and aquifers are contaminated with fertilizers, pesticide residues and heavy metals from the mining (Li et al. 2013, 2014) and petrochemical industries as well as domestic and industrial wastes. China is short of 40 billion tons of water a year on average (Tao and Xin 2014). It is reported that about 300 million rural residents lack access to safe drinking water (Liu and Yang 2012; Dou et al. 2014). To tackle these problems, water resources management and wastewater treatments coupled with pollution control policies have been conducted and as a result, these have positively affected the water environment. However, great challenges remain in order to improve China's water situation in the area of cost-efficient and innovative technologies and sustainable development.

Water solutions in China

Advanced water science focusing on sustainable solutions in the field of water resources management, as well as the development of the technologies and infrastructure for the supply of clean water from natural and wastewater are the key to deal with the existing water problems in China. In recent years, China has initiated a series of programs to promote the research and development on water science and technology. A number of protection plans were launched as well. In 2006, for the first time, water had become a major topic within the Chinese 11th Five-Year Plan; the Major Science and Technology Program for Water Pollution Control and Treatment (Mega Water Projects 2006–2020) had been started in 2009. Investments in the order of 500 billion US Dollars are scheduled by the Chinese Government for improving wastewater treatment technology and drinking water supply as well as for rehabilitating rivers and lakes (Chinese Ministry of Environmental Protection <http://nwpcp.mep.gov.cn/>). In 2010, water still remained as a main issue within the 12th Five-Year Plan including e.g., significant efforts on improving the prevention, management and eco-friendly disposal of hazardous substances and wastes (MEP 2012). Additional improvements in water resource pollution prevention have been achieved in China by banning the production, circulation and usage of chemicals listed in the Stockholm Convention on Persistent Organic Pollutants (POPs) and by strengthening the identification and management of POPs contaminated sites (PRC 2007). In 2013, according to the new Chinese government program, China started to focus on slower economic growth but more improvement on environmental quality, and more innovation rather than investment. In addition, agricultural water saving, urban cyclic water utilization, and technologies for trans-basin water diversion, rainfall and flood-water utilization, and sea-water desalination were also listed as main areas and priority topics of the National Medium- and Long-Term Program for Science and Technology Development (2006–2020) released by the Chinese state council (Xinhua 2006). So far, China has mapped out water resource protection plans for all its seven major water basins in China: the Yangtze River, the Yellow River, the Huaihe River, the Zhujiang River, the Songhuajiang-Liaohe Rivers, the Haihe River, and the Taihu Lake. Currently, the Mega-Water-Program in China focuses on surface water, while soil and groundwater sectors need to be considered as well. China has formulated and implemented an in-depth Action Plan for the Prevention and Control of Air Pollution and is stepping up the preparation of the Clean Water Action Plan and Soil Action Plan, which highlight the determination to control pollution, improve environmental quality, and protect the people's health (Ministry of Environmental

Protection China (<http://www.mep.gov.cn/>). In addition, the South-to-North Water Division Project (SNWDP, <http://www.nsbd.gov.cn/>) is supposed to be a significant method to manage and prevent the continued shortage of ground-water resources in northern China (Zhang et al. 2014).

German-Chinese environmental collaboration activities

German-Chinese relations have been developing steadily since 1972 when the two countries established diplomatic relations. These ties have always been considered to be politically and economically one of the most stable relationships between China and major European powers (Ke 2014). Development of German-Chinese environmental cooperation began in the 1980s (FECO 2014) and could be separated in the official inter-governmental and non-governmental ones. Governmental cooperation started in 1982 with an agreement on technological cooperation signed between the two governments. In 1988, Germany and China had already started joint water research supported by the research ministers in both countries (BMBF 2012). In September 1994, the two countries signed the “Agreement on Environmental Cooperation.” The first Sino-German Conference for Environmental Cooperation was convened in Beijing in December 2000, which was proposed jointly by Chinese Premier Zhu Rongji and Chancellor Schroeder of Germany (MEP 2000). Bilateral cooperation reached an unprecedented point with a joint statement and agenda of action for environmental protection issued by both governments (MEP 2000). In December 2003, the first German-Chinese Environment Forum was hosted successfully by the Ministry of Environmental Protection of China and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety of Germany. In October 2014, the seventh German-Chinese Economic and Technological Cooperation Forum was held in Berlin, which Chinese Premier Li Keqiang and German Chancellor Angela Merkel attended. Also non-governmental exchanges and cooperation of water research and technology are very active between the research institutes and NGOs in both countries. The German-Chinese Promotion Centre for Environment and Energy (DCZUE) is a nonprofit organization in Berlin, which was founded by Chinese scientists in Germany in the field of environmental sciences and energy and closely works with the education section of the Embassy of China in Germany. Econet China is a non-profit initiative of German industries in China, coordinated by the German Industry and Commerce Greater China, for the promotion of German-Chinese cooperation for sustainability (Econet China 2014). Since 2011, German Water Partnership (GWP) has been organizing Sino-GWP Water Days that were held in several Chinese cities. Since 2010,

GWP has been involved in the China Urban Water Association (CUWA) conferences, holding lectures and taking part in meetings (GWP 2014).

In the past, Germany had to face similar challenges to those in China. Linking advanced management concepts and environmental technology, Germany was able to overcome most pollution problems and is now considered as leader in the field of environmental technology including water conservation and drinking water quality. Germany can be an attractive cooperation partner to support China in addressing its challenges. Forty years ago, Germany and China started their first cooperation in science and technology between the Max Planck Society and Chinese Academy of Sciences. The first German-Chinese cooperation in water sciences began in 1988 for the large-scale implementation in the field of wastewater and sludge treatment for the Olympic Park in Beijing. Innovations from Germany have been implemented in several cooperation projects up to now. Germany is also involved in the national Mega Water Projects as China’s exclusive foreign partner (German Ministry of Education and Science, BMBF). For instance, the joint German-Chinese Research and Innovation Programme “CLEAN WATER” launched in 2012 focusing on technology transfer and further development in the water sector. The German-Chinese Innovation Centre for Clean Water was established in Shanghai in April 2014. In October 2012, the kick-off meeting for BMBF’s joint project WAYS “Sustainable technologies and services for water and resource management at the upper Yangtze in Sichuan” (<http://www.client-ways.de/>) took place in Chengdu, China. The joint German-Chinese project “SEMIZENTRAL” successfully completed the world’s first semi centralized wastewater treatment and supply project in Qingdao in 2014 (<http://semizentral.de/>). Another important joint project about ‘Land Use and Water Resources Management under Changing Environmental Conditions’ was funded by the National Natural Science Foundation of China (NSFC) and German Research Foundation (DFG). Several projects funded on the German side by BMBF, and on the Chinese side by the Ministry of Science and Technology (MOST) or other agencies, currently focus on China’s water issues.

New opportunities and challenges of German-Chinese cooperation in water science and technology

The German-Chinese cooperation in water science and technology can benefit from international projects for water resources management in hydrologically and climate sensitive regions of the world such as the International Water Research Alliance Saxony (IWAS) (Kalbus et al. 2012) and

Water and Earth System Science (WESS) projects (Grathwohl et al. 2013), and other joint projects as well. With increasing challenges in the 21st century, there are new tasks and opportunities in water sciences for the Germany-China cooperation described by the following aspects.

Water information sciences

RCEIS, the joint Sino-German Research Centre for Environmental Information Sciences, was established in 2014 and funded by the Helmholtz Association in Germany and the China Academy of Sciences. This Centre will develop novel concepts using infrastructures for earth system observation and analysis in order to better understand the evolution and dynamics of environmental systems under global change. RCEIS shall become a Sino-German competence center and research platform for earth system monitoring and prediction by combining expertise in the fields of environmental and information sciences using modern information technology. According to the urgent environmental problems and political actions in China, we will focus on “Water and Soil” as the starting topic for the Helmholtz Network establishment. RCEIS activities will be related to the Mega Water Projects. Climate change has a particularly big potential impact on the water resources for the large river basins in China (Chen et al. 2014a; Paasche et al. 2014). Against this background, RCEIS will concentrate on the large rivers and lakes in China, i.e., the Songhuajiang-Liaohe, Yellow-, Yangtze-, and Pearl rivers, which are not only important transportation ways through the country but also most important sources for drinking water supply in many mega-cities, as well as relevant to energy supply (e.g., the Three Gorges). Furthermore, these all host unique ecosystems rich in biodiversity. RCEIS will also examine several smaller catchments (Poyang, Chaohu and Dongting lakes), exemplary for water and soil management problems. The river basins were selected also due to on-going projects and activities by both the Chinese and German partners that guarantees the availability of data and infrastructures as well as the involvement of stakeholders and authorities.

The investigation areas of RCEIS are depicted in Fig. 1. Work packages are organized related to the candidate river basins from north to south. Cross-cutting activities are organized according to the methodology and continuous work flow approach of the TERrestrial ENvironmental Observatories (TERENO) concept (Zacharias et al. 2011; Kolditz et al. 2012; Rink et al. 2012; Kunkel et al. 2013) to be implemented for each Chinese catchment. The South-to-North Water Diversion Project in China is also included for the future water supply of Beijing—as this project will impact the Yangtze and Yellow Rivers to a large extent.

RCEIS will utilize up-to-date data, information science approaches, and technology to generate insights and information products that can support stakeholder’s decision making in the respective river basins. Data utilized will stem from remote sensing earth observation—a field in which Germany (especially RCEIS partner DLR, the German Aerospace Center) plays a leading role. Access to national mission data such as TerraSAR-X, Tandem-X, as well as the upcoming European Sentinel satellite missions, together with the exploitation of international and freely accessible archives of e.g., Landsat, MODIS, or AVHRR will allow for the generation of high quality water related information products such as the maps of flood extent, flood frequency, inundation depth, water quality, sediment load, or land use/land use change products. Furthermore, geophysical parameters such as land surface temperature, water surface temperature or biomass can be retrieved, which can find their way into modelling approaches. Linked to the in situ sensor technologies from other partners (statistical data, as well as localized data gathered during field campaigns), such a multitude of data sources may enable RCEIS to generate a comprehensive information portfolio for the area of interest. Online or smart phone-based environmental information systems can help to transport research results to stakeholders and decision makers in an easy-to-access and readily comprehensible manner. This approach is currently also followed by the Sino-German DELIGHT project (www.delight.eoc.dlr.de), which is focusing on the set-up of River Delta Information System for Geoenvironment and Human Habitat Transition. The focus study area is the Yellow River Delta, an area in the midst of finding an equilibrium between oil industry driven economic development on the one hand, and the protection of natural resources and biodiversity on the other (Kuenzer et al. 2014; Ottinger et al. 2013). This project focusses on the topic of water quality and quantity combined with high resolution earth observation data analyses for the derivation of land surface dynamics. In the context of DELIGHT, the partners under the lead of DLR also touch the topic of land use changes in the Yellow River Basin and of general upstream–downstream challenges, which arrive in every river basin, such as the impacts of upstream hydropower dams, upstream water diversion and pollution, and related consequences on downstream locations such as the delta. Overall, the DELIGHT approach focused on stakeholder involvement from the very beginning to ensure that project results are of use for local politicians, scientists, and conservationists in the Dongying district of the Yellow River Delta, China. This river is also impacted by ongoing and future water diversion projects (Kuenzer 2007), which will link all four major Chinese rivers and mainly aim at ensuring water supply to large mega cities.

Fig. 1 Investigation areas of the Research Centre for Environmental Information Sciences (RCEIS) in 2014

Data collected from the Earth surface provides a lot of information about the earth environmental system, which serves as the fundamental for water information sciences. Earth surface systems are controlled by a combination of global factors and local factors, which cannot be understood without accounting for both the local and global components (Wilson and Gallant 2000). Ground observation can provide high accuracy data at observation points, but observations at fixed positions are confined within some limited dispersal points and not able to directly calculate relative parameters at regional scale. Satellite remote sensing can frequently supply surface information of geographical and ecological processes, however, remote sensing description is not able to directly observe process parameters. Maps derived from satellite observations are patchy and cannot be used reliably as an independent source of information for earth surface monitoring (Emili et al. 2011). A high accuracy and speed method (HASM) for surface modeling has been developed initially to efficiently combine remote sensing data with ground-based observation data by the China Academy of Sciences (Yue 2011). HASM takes approximate global information (e.g., remote sensing images) and locally accurate information (e.g., ground observation data) as optimum control constraints. It is essential to introduce HASM in the development of a data and modeling platform for dynamics of

environmental elements, especially for analyzing impacts of climate change on eco- and hydrosystems (Kolditz et al. 2012). One of the major tasks in the framework of RCEIS is to combine the HASM methods and the modeling platform for the mentioned large river studies in China.

Urban water management

The scale and pace of China's urbanization continues at an unprecedented rate. However, the rapid and undergoing urbanization has and will continue to cause severe environmental pollution. With regard to urban stormwater runoff, an increased fraction of impervious surface is the primary agent responsible for the changes in catchment hydrology associated with the urbanisation process (Shuster et al. 2005). The increase in impervious surface causes a decrease in the infiltration of stormwater and an increase in the production of surface runoff. The high flow rate and velocity of stormwater runoff has consequences for both runoff quantity and quality.

Pollution loads are boosted due to the washing off of road-deposited sediment (RDS) and its associated nutrients and pollutants such as pesticides, heavy metals, organic pollutants, oil, grease, polycyclic aromatic hydrocarbons and other toxics which are detrimental to aquatic life, wildlife, habitat, and human health (EPA 2007). Therefore,

the in-depth understanding of the catchment pollutants is significant to the context of stormwater pollution prevention and stormwater best management practices. In Germany (e.g., at Technical University Dresden), research was conducted on the toxic pollutants' temporal accumulation and spatial distribution on the urban catchment (Zhang et al. 2012), pollutants risk assessment (Zhang et al. 2014), source apportionment (Zhang et al. 2013), and also adsorption and desorption processes as a major aspect for stormwater pollution.

Pluvial flooding, where small-scale and short-term rain events of high intensity are responsible for local flooding (as opposed to fluvial flooding caused by large-scale and long-term events referring to the river basin scale), is intensified by the increase of imperviousness in urban areas and by climate change. At limiting cross sections, the drainage system is overcharged and causing surface runoff with potential damage. As drainage systems cannot be designed for zero risk, management strategies are developed based on coupled numerical modelling of drainage system and surface runoff. Besides the passive protection of buildings, real-time-control (RTC) in the drainage system may be used for provoking surcharge, where surface runoff pathways can be provided. With such an approach, the surface runoff can be better managed than with the classical system, where the prediction of surcharge points is not possible.

However, comparatively little or no attention has been paid to an integrated urban catchment management. Common research and development on these aspects bear the potential for Chinese-German co-operation, where the smaller German cities could serve as pilot cases. Transfer could be tested and approaches could be adapted. This seems important for China, where urbanization is still a primary and rapid process. The topics are part of a proposed Chinese-German project “Managing Water Resources for Urban Catchments”, that could become a starting point for common research on integrated urban catchment management. It can be expected that not only, China and Germany, but also other nations could benefit from such cooperation.

Aquatic ecosystem management

The integrated water management is also a topic of rapidly increasing importance in China. Anthropogenic activities have affected the hydrological, ecological, and geochemical processes on global, regional and local scales. Land use changes, influencing land cover, soil property, and geomorphology alter watershed hydrological processes and affect surface water quality. In recent years, very extensive land use changes have happened in China. As a result, excessive nutrients and heavy metals closely related

with non-point sources (NPS) have led to serious pollution and algae blooms and disturbed wetland hydrology in both inland and coastal waters. Specifically, nutrients from excessive fertilizer utilization and pesticide spraying were deposited into rivers, lakes and reservoirs, resulting in deterioration of water quality, eutrophication and reduction of biodiversity in the aquatic ecosystems (Wan et al. 2014). Findings indicate that river NPS water pollution continuously increased during the past 10 years in China. Chemical fertilizers, poultry and livestock breeding, aquaculture, and rural living are the major sources of elevated chemical oxygen demand, ammonia–nitrogen, total nitrogen, and total phosphorus loads discharged to receiving watercourses. In China, NPS pollution control will be one of the most important issues in water environmental protection in the next several decades (Hou et al. 2014). To control NPS pollution, it is important to increase the knowledge of governing pathways and transformation processes of nutrients from land to water and to improve our opportunities to quantify these processes to further develop abatement strategies. In Germany in-depth expertise has been gained on point and non-point source pollution loadings of surface waters within the last four decades because of continuously increased agricultural production and the related nutrient losses to surface waters. Furthermore quantification of these matter fluxes has greatly developed and numerous catchment models ranging from small-scale applications to large river basins have been developed. Although environmental and land use conditions vary greatly in both countries, there exists great potential for an intensive collaboration on water quality research including the development of water management issues. Main topics for collaboration comprise (1) new innovative measurement techniques encompassing new water quality sensors, e.g., UV spectrometry for nitrate and dissolved organic carbon (DOC) measurements, (2) development of new monitoring designs based on continued high resolution monitoring techniques, (3) improved process understanding for an increasing range of environmental conditions ranging from temperate to subtropical climate conditions and (4) further development of spatially distributed hydrological water quality modelling techniques that are able to represent a wide range of climate, land use and cropping conditions (Rode et al. 2010). These new collaboration directions can form the basis for an advanced and cost efficient water management to improve environmental conditions in China as well as in Germany.

Another important point of view about the water management is the integration with modeling tools. Importance of water management is today widely acknowledged, but there is still an ultimate and urgent need to improve the understanding of the interrelationships of the environment, biodiversity and ecosystem functioning, eventually

to estimate global change impacts and adapt management and conservation, respectively. Modeling, amongst experiments and monitoring, is an important tool to explore these relationships (Jeltsch et al. 2013). While much progress has been made e.g., to simulate the hydrology, water demand, water quality, biotic communities and ecological functions of river ecosystems or predictions of effects of climate change in running waters (Hejazi et al. 2014; Kuemmerlen et al. 2014; Schuwirth and Reichert 2013; Jähnig et al. 2012; Venohr et al. 2011; Döll et al. 2009; Schöl et al. 2006; Boyacioglu et al. 2012; Rode et al. 2007; Jiang et al. 2014), many modelling approaches are not very realistic in their assumptions, e.g., assuming linear behavior, ignoring regime shifts, uncertainty, or responses of humans to decisions taken, which are typical elements of complex ecosystems, as Schlüter et al. (2012) argue. For future water management special attention should be given to the hierarchical organization and longitudinal structure of rivers (Wagenschein and Rode 2008, Domisch et al. 2015), e.g., to analyse how the biodiversity of specific water bodies are influenced by the spatial arrangement of neighbouring water bodies or to consider scale-dependence in stream networks and their catchments. Thinking water management from such a complex ecosystem perspective would enable the application of the Ecosystem-based Management (EBM)—a concept so far rather applied in marine ecosystems (e.g., Curtin and Prellezo 2010; McLeod and Leslie 2009). Specifically for China it seems worthwhile to search and test for robust and cost-effective measures, apply integrated management practices, and address current or future changes in drivers and pressures occurring at unprecedented rate in China.

Drinking water quality and organic trace pollutants

With the continuous improvement of living standards, the demand for the quality of drinking water and the water environment is increasing, however, with the high speed economic development in China, the water resources shortage and drinking water pollution contradict this. According to a survey, in 430 cities in China, 90 % of the drinking water sources are subject to different degrees of pollution (Xiao et al. 2001). Amongst all different forms of pollutions, organic pollutants are mainly contaminants, which include the total organic matter (estimated as total organic carbon, TOC, or chemical oxygen demand, COD) and an increasing number of synthetic organic compounds in trace concentration range. The Chinese national standards for drinking water are also placing increasing emphasis on the detection of organic contaminants. From the 35 detection indicators of the drinking water quality standards that were introduced in 1985 (GB 5749–85,

http://hbj.zj.gov.cn/root14/xxgk/hjbz/shjbh/200911/t20091103_14527.html), only 6 organic indicators need to be detected. However, from the 106 detection indicators of the new drinking water standards implemented in 2007 (GB 5749–2006, <http://www.moh.gov.cn/zwgkzt/pgw/201212/33644.shtml>), the number of organic indices rose to 53.

Nowadays China is still facing serious challenges in drinking water and for example the drinking water quality standards are far higher than their counterparts in the European Union, the United States and Japan. Furthermore, while China is still paying most attention towards traditionally hydrophobic persistent organic pollutants (POPs), the awareness for emerging polar pollutants (e.g., pharmaceuticals and personal care products, PPCPs) is developing in some countries like Germany (Loos et al. 2008). Such contaminants may travel along a water cycle from wastewater to raw water used for drinking water, thus posing a significant problem to water quality, especially if they are resistant against chemical or biological degradation (Reemtsma and Jekel 2006). Meanwhile an increasing water demand calls for potable reuse of treated municipal wastewater, which would be difficult to realize in China due to lack of effective wastewater treatment technologies.

In Germany, a broad experience in analytical determination of trace pollutants and investigations of their fate in the aquatic environment and during water treatment has been gained. Currently, the existing list of priority substances within the European Water Framework Directive is under discussion to extend it with further polar trace pollutants, among them different pharmaceuticals, biocides, and endocrines (European Commission 2000). Using new specific solid phases for compound enrichment and chromatographic separation and application of improved analytical techniques, in particular ESI–MS, the multi-compound analysis of polar trace organic pollutants in trace and ultra-trace concentration is state of the art in Germany and has become well-established in routine as well in research laboratories.

It would be helpful and necessary to transfer experience on trace organic pollutants to other countries such as China. For example, the establishment of a comprehensive database, especially for some emerging contaminants, could be a possible topic for collaboration. Here, improved analytical methods and the evaluation of the pollution status in different areas should be included. Not only China and Germany, but also other countries would be expected to benefit from this work. Further topics and approaches for joints projects, research work, common workshops, or exchange of scientists and students are listed below:

- Identification of relevant trace organic pollutants (indicator or key compounds) relevant for surface and ground waters in specific regions of China, finding out

of similarities and differences to European/German relations.

- Determination of main input sources of polar organic pollutants into surface and ground waters, recommendations for reduction/prevention of pollutant entries.
- Based on analytical monitoring of polar trace pollutants, recommendations for effective and economical drinking treatment techniques (e.g., bank filtration), testing in laboratory and pilot plant scales.
- Investigation of the behaviour of relevant organic trace pollutants at specific boundary conditions (climate, matrices and hydraulic conditions).
- Prognosis of future tendencies of trace organic pollutants occurrence (consideration of climate change, economic development, introduction of new technologies, population growth and change of infrastructure).

Joint terrestrial and atmospheric regional water cycle analysis and investigation of land-surface atmosphere interactions

A lot of studies have shown the impact of climate change on the water cycle. The anthropogenic factors will be further amplified by expected climate change induced increases e.g., in extreme events. Detailed system understanding and process analysis methods are required when sustainable management options shall be delineated. Due to the interlinked atmospheric and terrestrial compartments of the regional water cycle, model systems are needed that allow the study of the joint atmospheric and terrestrial water balance and that also allow for the investigation of feedbacks between land use, land use change, and the atmosphere, particularly precipitation. Standard one-way coupled model systems, i.e., atmospheric models driving separate stand-alone hydrological models, are not able to account for long-term feedbacks between the subsurface and the atmosphere. Examples for these one-way coupling approaches are e.g., given in Kunstmann and Stadler (2005) and Smiatek et al. (2012). But in this traditional one-way coupling approach, particularly the role of lateral water fluxes at and beneath the surface cannot be accounted for. New fully coupled and compartment crossing hydrometeorological model systems aim at the description of the full and closed regional water cycle; i.e., within one source code they comprise process descriptions for the exchange and transformation of water and energy from the top of the troposphere, to the land surface until the unsaturated and saturated zone and finally to the river beds. Within a joint German-Chinese initiative, such a fully coupled hydrometeorological model system is currently being developed and exemplarily applied for the Poyang Lake region in China (Yuan et al. 2009; Wagner et al.

2013). It is based on the regional atmospheric model WRF-ARW (Skamarock et al. 2008) coupled to the distributed hydrological model HMS (Yu et al. 2006). These two models were selected because they share the same land surface model (LSM), the Noah-LSM (Chen and Dudhia, 2001), i.e., compatible water and energy flux formulations of state variables and interfaces for the boundary layer, the land surface and subsurface in both models. In addition, methods were implemented allowing for the interaction between the groundwater and soil moisture states of the LSM (Fersch et al. 2013). By capillary rise, the groundwater table can affect the moisture content of the upper unsaturated zone and therefore alter the lower boundary conditions for evapotranspiration or infiltration. This upward flux is often not taken into account in LSMs that are typically used with regional climate models. The computational demand allows long-term simulations of the coupled model system for climate-relevant scales of tens of years. We are now able to satisfactorily reproduce observed streamflow at the major gauges in the Poyang Lake region. Required next steps comprise the consideration of energy flux data for comparison, e.g., obtained from Eddy-Covariance stations and hydrometeorological testbeds (still to be established and operated) in this region. Only then can the energy partitioning at the land surface be understood in more detail and the long-term feedbacks between the interlinked terrestrial and atmospheric water cycle be addressed and accounted for.

Groundwater resources and regulation

A lot of attention has been paid to the surface water, but groundwater resources also play a significant role in ensuring the sustainable development of agriculture and industries in China, in particular in the arid northern and northwestern regions. Through cooperation between Chinese and German scientists, substantial achievements have been made in the study of water resources in (semi-)arid areas in the past decade. Through the monitoring of water isotopes of precipitation, Pang et al. (2011) found processes key to precipitation generation in an arid region, including adiabatic cooling, sub-cloud evaporation and moisture recycling, constrained by isotopes. Kong et al. (2013) quantified the effect of the recycling of moisture for the improved understanding of rain forming ability of internal moisture circulation. Flooding hazards in the summer season have been found to be caused by the increased mountain runoff as a result of enhanced snow and ice melting by global warming, which is about 10–40 %, depending on the location of the river catchments. This added flow by climate change can be better utilized through the use of groundwater reservoirs in the foreland basins,

combined with surface “leaky reservoir” (infiltration ponds) to enhance their recharge, connected to a modern Karez system. This has been found to be a feasible countermeasure towards water cycle changes as a consequence of climate change (Pang 2014). A full scale pilot test has been completed in the Tailan river basin in southern Xinjiang in China that showed groundwater has secured modern recharge. Another study has focused on the use of deuterium excess (d-exc) in water to understand water cycle processes and the evolution of water quality. In the arid Xinjiang Uygur Autonomous Region, d-exc has been found to be closely related to moisture recycling. It exhibits a negative correlation with altitude. It has also been found that d-exc can be used to distinguish water salinity formed by mineral dissolution from that by evaporation.

Other than geochemical and isotopic studies, collaboration on numerical modeling is further developing. In September 2014, a Sino-German workshop was held in China focussing on the identification of aquifer heterogeneity. Aquifer characterization is of great importance to the artificial groundwater management as demonstrated by the scientists in the workshop. Storing water in aquifers during times of excess, e.g., stormwater runoff, harvested rainwater, river water, desalinated sea water, or treated wastewater, can help address water scarcity challenges experienced especially in the northern parts of China. In principal, a large storage capacity is available in shallow aquifers, either due to thick unsaturated zones or due to already depleted water resources in overexploited aquifers. In addition, water quality can be improved due to chemical and biological reactions during transport of the infiltrated water through the unsaturated and saturated zones, and by infiltrating waters for hydraulic control, e.g., to prevent seawater intrusion. Therefore, Managed Aquifer Recharge (MAR), together with Soil-Aquifer-Treatment (SAT) systems and Aquifer Storage and Recovery (ASR) could be key *water resources management* tools for tackling water scarcity by linking water reclamation, water reuse and water resources management. In the future, a combined use of geochemical and modeling technologies is expected to shed light on the water cycle in China and to be used for artificial groundwater regulation.

Outlook

To conclude, the year 2015 will be the China-Germany year of innovation. Comprehensive scientific and technological cooperation between China and Germany has become an important part of a strategic partnership for the future. With opportunities to enhance that kind of mutually favorable collaboration, both trust and concrete actions are needed. A “German Chinese Water Conference”

was advocated by the Minister of Science and Technology of China, Prof. Wan Gang, and the President of the Helmholtz Association, Prof. Jürgen Mlynek, in October 2013. The first conference will provide an overview of the current water pollution status in China and related strategies for solving and mitigating water resources problems. It will serve to develop potential pathways for future water research in China, which considers and builds on research experiences gathered in Germany over the last decades.

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