Implementing Integrated Water Resources Management: Experiences from a Central Asian Model Region

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Abstract
The Kharaa catchment in Northern Mongolia was chosen as a model region for Central Asia in order to develop, implement and assess the concept for an Integrated Water Resources Management (IWRM). In the region, a highly continental climate results in a natural scarcity of water resources, a problem which may in the near future be intensified by the effects of climate, land use and demographic changes. Of particular importance is a growing water demand due to irrigation and mining activities, which are also an important source of water pollution. At the same time, institutional structures have in the past not permitted to respond effectively to such complex challenges. An integrated strategy, consisting of an investigation of the scientific basis, implementation of technical solutions, institutional analysis and a multilevel capacity development approach, is the key feature of the joint German-Mongolian research project presented here.

Keywords
Integrated Water Resources Management (IWRM); Central Asia; Mongolia; continental climate; land use change; environmental monitoring; institutional analysis; water governance; waterborne diseases; sanitation; wastewater treatment

INTRODUCTION

The sufficient availability of water is not only an essential resource for human survival, but also an important prerequisite for economic and social development. However, these developments themselves have an increasing impact on the state of water resources and the natural water cycle: overexploitation of water resources has led to the desiccation of surface and subsurface water bodies in many regions of the world, while nutrient input and contamination with hazardous substances and pathogens not only disturb aquatic ecosystems but may also adversely affect human health and socio-economic development in general. A necessity of a sustainable water management is therefore widely accepted but in practice often complicated by two factors: Firstly, specialists in water supply, sanitation, hydropower, irrigation etc. often have narrow, sectoral perspectives. Secondly, many important decisions affecting water resources are made outside the water sector. Such external drivers (e.g. demographic development, global change, economic growth, technical innovations, societal norms) tend to be dynamic and their combined effect hard to predict (UNESCO 2009). This complexity means that integrated approaches are necessary to assess and improve water management practices.

In this paper, the authors outline findings of an ongoing project working towards an integrated water resources management in the Kharaa river basin in Mongolia, which was selected as a model region for Central Asia. In a first step, the scientific basis for an IWRM in the region is described, including both hydrological evidence and insights into the underlying causes. Secondly, selected measures are discussed with regard to their (potential) contribution towards a sustainable water management. Finally, preliminary conclusions based on the scientific assessment of the situation and experiences from the measures implemented so far are drawn.

The IWRM Concept

Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Global Water Partnership 2000). Thus, IWRM promotes the consideration of water in a holistic fashion and within natural ecosystem limits. Therefore, river catchments are considered the optimal management units (Swatuk & Motsholapheko 2008). IWRM aims at the integrative management of water resources and takes into account anthropogenic water usage (drinking water supply, irrigation, hydropower generation, industrial water needs), ecological functions of water bodies as well as cultural and emotional values. Water resources are dealt with from a perspective that is not only hydrological but transdisciplinary, including management issues (Ibisch et al. 2011). Key elements of the IWRM concept are shown in figure 1.

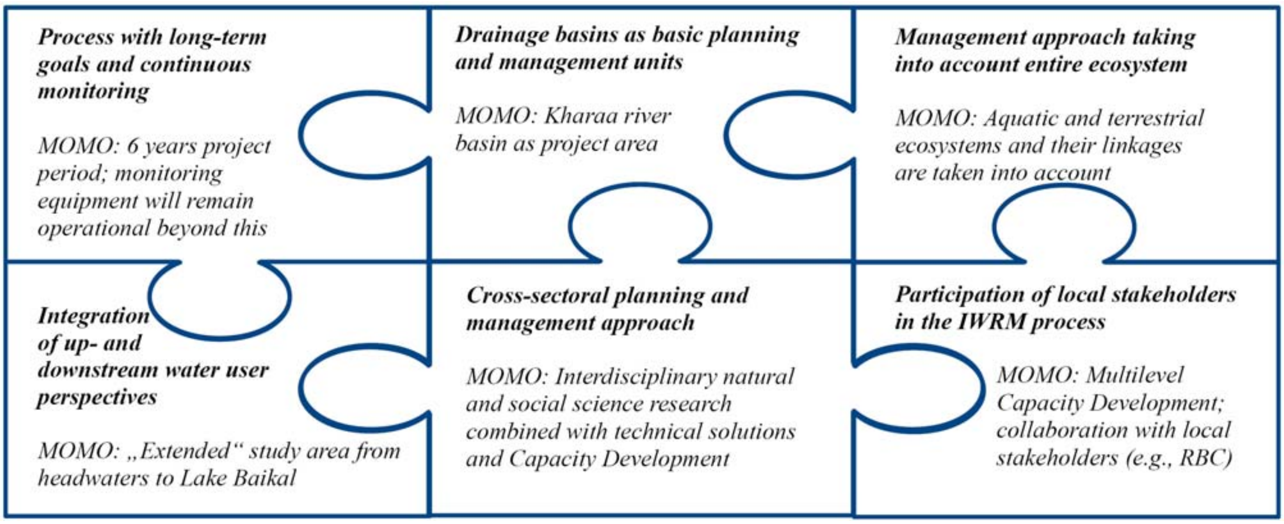

Figure 1: The IWRM Concept – Theory and Practice in the MoMo project. Based on Ibisch et al. (2011)

The Kharaa catchment – A Central Asian Model Region

The catchment of the Kharaa River was chosen as a Central Asian model region in the framework of IWRM MoMo ("Model Region Mongolia") project (see figure 2). Its basin covers an area of 14534 km² that ranges between 654 m (at the confluence with the Orkhon) and 2668 m in the Khentii Mountains. At its outlet, the 362 km Kharaa River has a mean long-term annual discharge of 12.1 m³/s (MoMo Consortium 2009). Like most of its tributaries, the Kharaa has its source in the Khentii Mountains. The river then flows north towards Darkhan, Mongolia's third largest city, shortly after which it becomes a tributary to the Orkhon River. Ultimately, via the Selenge River, it discharges into Lake Baikal in Russia.

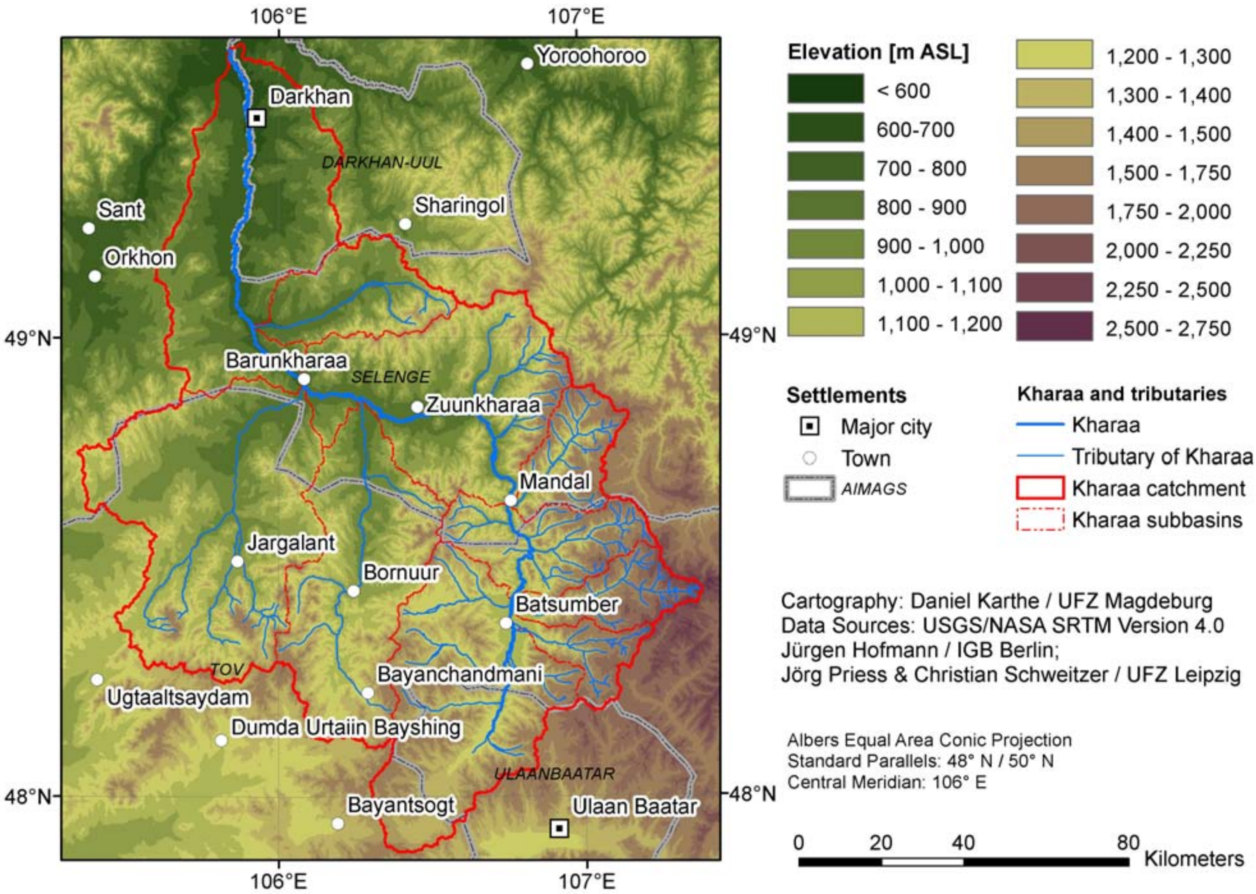

Figure 2: Map of the Kharaa catchment

The Kharaa catchment is diverse regarding both the physical environment and land use. The upper reaches of the Kharaa are characterized by the mountain ranges of the Khentii with steep valley slopes and relatively high specific runoff rates (Menzel et. al 2011). In the middle reaches, the relief is dominated by broad valleys with significant terrace levels. In this section, the Kharaa flows through a wide floodplain and has a meandering channel. The lower reaches, where the character of a natural meandering river system continues, are largely dominated by open steppe (Hofmann et al. 2011).

The highly continental climate (see figure 3) is characterized by very cold winters with temperatures regularly reaching -40°C and below, warm summers and an average precipitation ranging between 250 mm and 350 mm. For orographic reasons, a considerable variation is likely. Largely because of the climate conditions, the vegetation ranges from grass steppes covering most of the lowland regions (and 59% of the total catchment) to forest steppes and boreal forests (26% of the total catchment; Schweitzer & Priess 2009).

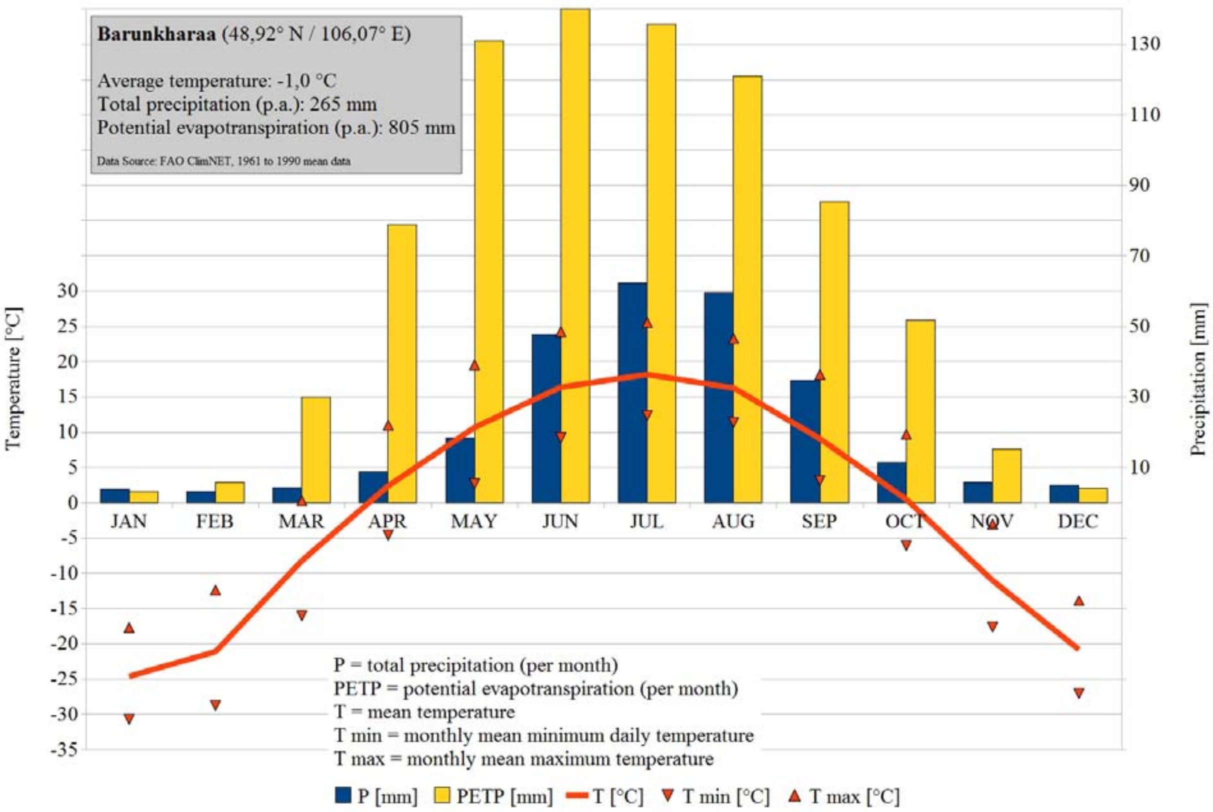

Figure 3: Climate graph for Barunkharaa

Despite its proximity to the national capital, the upstream region of the Kharaa is sparsely settled and has a mountainous character. The Kharaa valley then becomes increasingly broader, with agriculture and animal grazing dominating its floodplains. Major settlements along the downstream of the Kharaa include Dzuunkharaa, Barunkharaa and Darkhan, which was founded as an industrial city in 1961. Nomadism and seminomadism are still an important feature of rural lifestyles, where animal husbandry (and, around rivers, fishing) are the key source of income. In the past 20 years or so, irrigated agriculture and mining –particularly for gold and copper– have been of growing economic importance and emerged as major water users.

WORKING TOWARDS AN IWRM FOR THE KHARAA CATCHMENT

Monitoring Trends in Climate, Land Use and Hydrology

Climate variability and change is one major driver of hydrological trends in drylands. In Mongolia, air temperature has increased by 2.1°C since the 1940s (see figure 4), and precipitation decreased in some parts of the country, including the Western slopes of the Khentii mountains. Seasonally, winter and spring precipitation has decreased slightly, while there has been little change in summer and autumn precipitation (Batimaa et al. 2008).

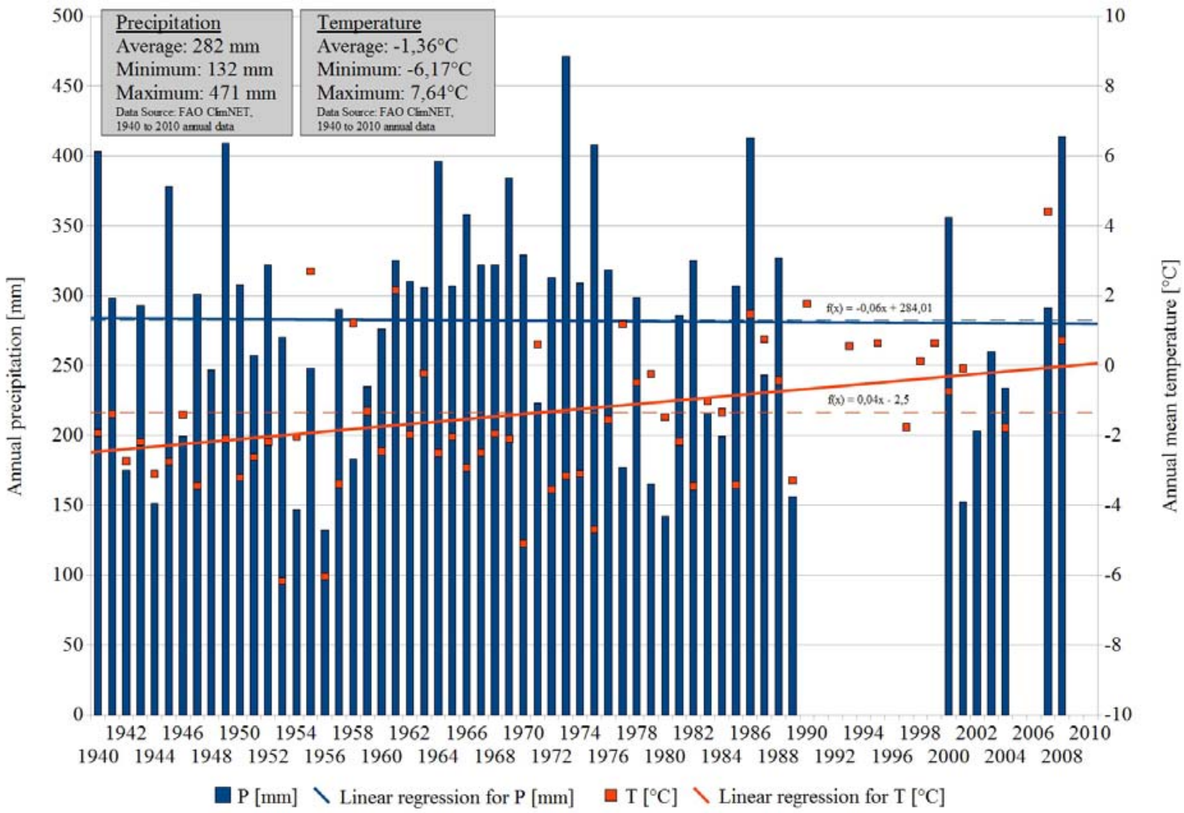

Figure 4: Observed climate trends for Barunkharaa

By the 2040s, climate models predict increasing temperatures (with a particularly marked winter warming), increasing evaporation during the summer and greater climatic variability. These effects will, in combination, result in a decrease in runoff and an increased likelihood of water scarcity (Batimaa et al. 2005; Batimaa et al. 2008). For the 2070s, Sato et al. (2007) predict a statistically significant decrease in precipitation in northern Mongolia. The main cause of this trend is expected to be a decrease in moderate to strong rainfall events (> 4 mm/d). Because of rising winter temperatures, sublimation which already equals about 80% of the total snowfall may increase even further (Wimmer et al. 2009). While snowfall only accounts for 5% to 6% of annual precipitation in lowland regions, the formation of continuous snow covers in the Khentii Mountains plays an important role for the water availability in the adjoining catchments during snowmelt (Menzel et al. 2011). An increase in sublimation may therefore have a negative impact on the water supply in spring.

However, there are high uncertainties regarding future precipitation, and projected precipitation changes between different climate models for the same scenario are often larger than between two scenarios (Menzel et al. 2008). Different datasets vary widely even with respect to the present situation: In a comparison of four climate datasets (CRU; ECMWF; GPCC; WFD) for the 1961 to 2001 period (ECMWF: 1992-2001), Malsy et al. (2011) observed large differences regarding their capacity to model precipitation. In terms of mean annual precipitation, the ‘dryest’ is GPCC (238 mm) and the ‘wettest’ is ECMWF (791 mm). Modelling surface water flow is complicated by these discrepancies and the lack of validation data (paucity of gauging stations, short periods of discharge data availability). Moreover, “non-climatic stresses are like to increase regional vulnerability to climate change and reduce adaptive capacity” (Lioubimtseva & Henebry 2009).

Mongolia’s agricultural sector is currently recovering from a period of land abandonment just after the communist period. Formerly state-managed farms were no longer profitable for private farmers and were partly given up. After two decades of decreasing agricultural activities, in 2008 the Mongolian government started the "Third Campaign of Reclaiming Virgin Lands", aiming at massive expansion and intensification of the agricultural sector (Priess et al. 2010; see figure 5). Both crop production and animal herding are two sectors that are land and water intensive. High animal densities are an important cause of land degradation, as are forestry and mining activities (Menzel et al. 2011).

For Mongolia, around 220 mm of annual precipitation has been described as a threshold below which high livestock numbers tend to create a non-equilibrium system that is prone to exceed the steppe's carrying capacity (von Wehrden et al. 2010; Retzer & Reudenbach 2005). For the study region, the average annual precipitation is higher, but due to large interannual variations (see figure 4), food and/or water for larger herds may become scarce during dry years.

Given the climatic conditions in the region, water is already the most important limiting factor for agricultural production. Irrigation is seen as one solution to this dilemma, even more so because climate change leads to an increase in agricultural water demand in large parts of Mongolia, including parts of the Kharaa Basin (Menzel et al. 2008).

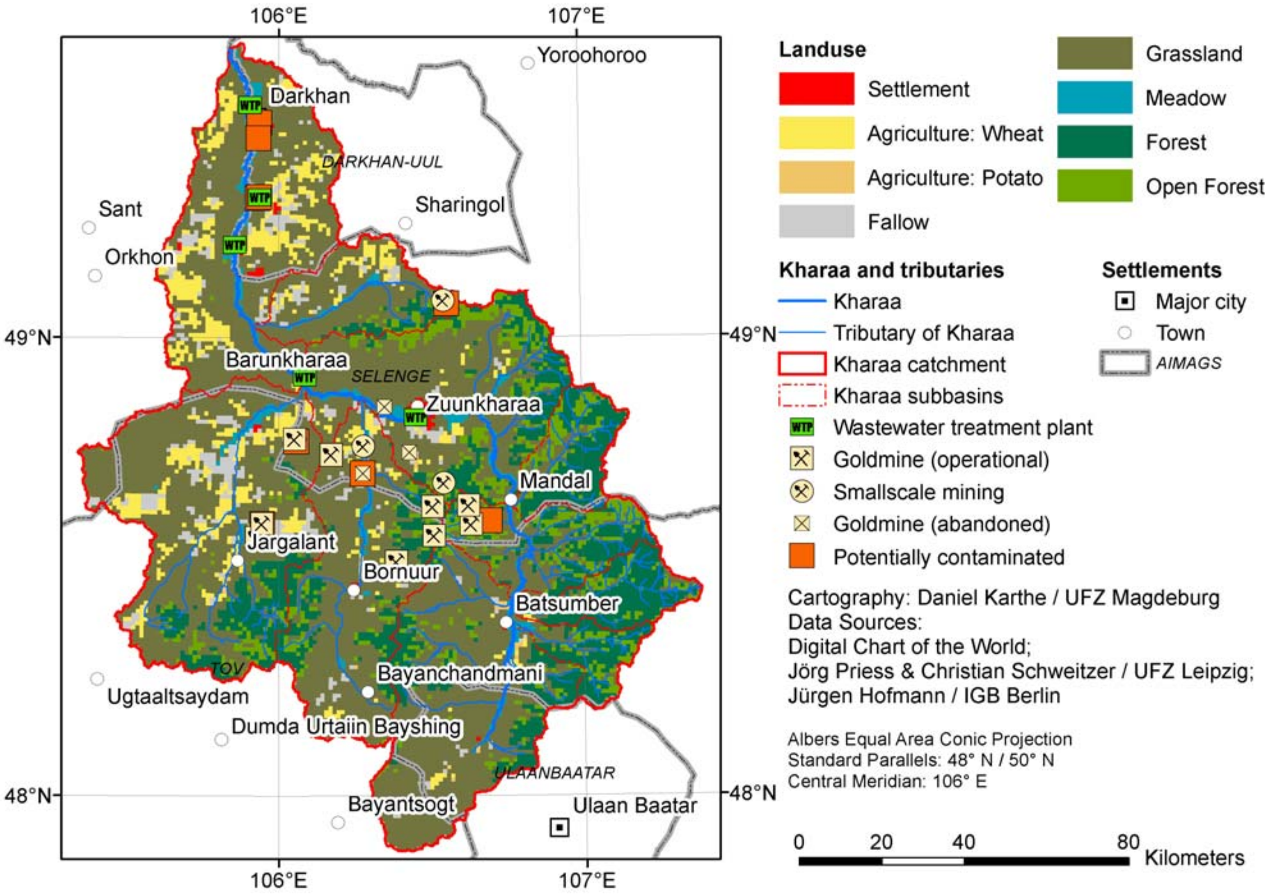

Figure 5: Land use, mining centers and location of waste water treatment plants

Concessions for a large number of underground and open pit (gold) mines have been issued in the Kharaa catchment within recent years (see figure 5). The area covered by these mines is around 130 km², but relatively little is known about their water consumption. Given the geological conditions and technology in use, a consumption of around 7 m³ of water per 1 m³ of ore seems to be realistic (MoMo Consortium 2009). Moreover, gold mining activities have in the past led to several hazardous situations, including the release of mercury and cyanide compounds (Hofmann et al. 2010).

Assessing Aquatic Ecology and Water Quality

For a comprehensive assessment of the ecological status of streams and rivers, the physico-chemical water quality, the state of the aquatic flora and fauna and the hydrological and hydromorphological characteristics of water bodies in the study region were investigated (see table 1).

Table 1: Assessment of Aquatic Ecology and Water Quality

	Physico-chemical water quality	**Aquatic ecology**	**Hydrology and Hydromorphology**
Important findings	- good water quality at most sampling sites - elevated nutrient levels in the Zagdelin river - for the catchment: total annual emissions of around 500 t N and 120 t P - elevated concentrations of heavy metals in the Boroo river and in the Kharaa downstream of Darkhan - high levels of As close to ash basins of Darkhan's thermal power plant	- fish communities indicate a moderate, good or very good ecological status - macroinvertrebrate communities indicate good ecological status for most of the Kharaa's catchment Deficits in benthic communities were detected in the mid- and downstream reaches of the Kharaa - fine-grained sediment influx was found to be a cause of habitat loss in the hyporheic zone	- Good or very good ecological status indicated by riverbed morphology - Deficient riparian vegetation (partially due to intensive grazing); erosion of river banks - some streams dried out completely (e.g. Bayangol), whereas a reduced flow was observed for others, including the Kharaa river
Sources: MoMo Consortium (2009); Hofmann et al. (2010); Menzel et al. (2011); Hartwig et al. (2011)			

The headwaters of the Kharaa represent natural background conditions with regard to nutrient loads (total nitrogen up to 0.58 mg/L; total phosphorus up to 0.018 mg/L). Despite relatively low population densitites (< 10 inhabitants/km² for the catchment), these levels rise massively towards the rivers lower sections (total nitrogen up to 1.52 mg/L and total phosphorus up to 0.26 mg/L). Potential nutrient sources include the disposal of poorly or untreated wastewater and, to a lesser extent, agricultural activities (Hofmann et al. 2011).

Recreational fishing in Mongolia recently emerged to become the primary threat to Mongolian fishes, contributing the most to the decline of nine out of fourteen threatened and near-threatened Red Listed species. Other important factors include habitat degradation and climate change (Ocock et al 2006). Current research aims to address several key fundamental questions about the status of the local recreational fishery and its existing impact on Kharaa River fish populations. This information will ultimately feed into vital scientifically supported recommendations for the Mongolian fisheries and water management authorities in an effort to secure protection and fisheries sustainability. The study will attempt to fill gaps in the biological and ecological knowledge of understudied, threatened species which include *Brachymystax lenok*, *Thymallus arcticus* and *Hucho taimen* (Krätz et al. 2006). These salmonids have been selected as they are regularly targeted by fishers and thus are expected to make up a significant proportion of the total recreational catch in the study basin (Kaus et al. 2011).

Planning and Implementing an Integrated Water Resources Management

Establishing a water resources monitoring system

Mongolia has a low density of hydrological and meteorological monitoring stations. For the Kharaa catchment, the monitoring network operated by the National Institute for Meteorology and Hydrology currently consists of two gauging stations (Baruunkharaa and Buren Tolgoi close to Darkhan) and 15 meteorological stations and posts (Menzel et al. 2011). One major problem are data gaps, particularly for the post-socialist period (see figure 4).

The purpose of a water body monitoring system is to obtain a conclusive and comparable overview of anthropogenic pressures, whose assessment is demanding by the fact that suitable assessment methods must be developed and applied for water bodies. Against this background the water resources monitoring system within the context of the MoMo project has to accomplish the following objectives: (1) to assess local/regional water resources and ecosystem status; (2) to translate scientific data into an “understandable” language for the public; (3) to make problems transparent in order to induce the implementation of measures (understandable for engineers and decision makers); (4) to identify those waters and ecosystem functions which need protection; (5) to verify the efficiency and anticipated effect of measures. In this respect the monitoring schemes are essential instruments for efficient integrated water resources management.

The monitoring elements comprise biological quality elements (fish, invertebrates, and aquatic flora), physicochemical and chemical characteristics, river-basin specific pollutants, and priority substances. A large number of methods for biological quality elements have been developed that allow for identification of various anthropogenic pressures based on biota composition (e. g. Hauer & Lamberti 1997). The research required in this regard is the adaptation and intercalibration with the conditions in Mongolia (Hofmann et al. 2011). Furthermore, special emphasis is placed on linkages of hydrological and matter flux modelling with ecological assessments (Hartwig et al. 2011).

Surface water monitoring can be classified as operational, surveillance and investigative monitoring. Surveillance monitoring aims at the assessment of the overall status of a specific river basin area or sub-basin. At surveillance monitoring sites, it is necessary to measure all relevant quality elements: biological elements; hydro-morphological and physicochemical elements; river basin specific pollutants and substances that are relevant for chemical water body status classification. Operational monitoring is used for status assessments of water bodies that are likely not to meet standards, and is thus also an instrument for verifying the success of the measures that have been taken. Whereas surveillance monitoring allows for the measurement of all characteristics and quality elements, operational monitoring normally focuses solely on those biological, chemical and physicochemical quality elements that indicate the presence of extensive anthropogenic pressures. Investigative monitoring is used in cases where the causes of a problem are unknown, or to determine the impact of adventitious water pollution such as that arising from accidental pollutant discharges or sudden accidents.

Currently, relatively little is known about the region's groundwater resources. At the same time, groundwater is an important source of water, including the water supply of major settlements. Investigations into the groundwater situation in and around Darkhan revealed a strong dependence on groundwater recharge in the Kharaa's upper catchment, from where the groundwater flow approximately follows the course of the river (Scharaw et al. 2009). In order to better understand the hydrogeological situation and investigate recent trends, groundwater level loggers were installed in Darkhan. A monitoring network for groundwater quantity will also be implemented. This network, which integrates monitoring sites in each groundwater body, monitors groundwater bodies at intervals in such a way that both short and long term fluctuations occasioned by aquifer recharge, water abstraction and discharges are monitored. This network also allows for monitoring of natural and long term changes in water volumes and quality.

One particular challenge in the study region is the difficult –or at least time-consuming– access to some of the study sites. Therefore, project-run monitoring stations are equipped with transmitters sending data to a web GIS server via satellite (Paulsen 2011).

Improving drinking water supply, sanitation and wastewater disposal

In 2000, the Mongolian government committed itself to achieving the Millenium Development Goals. With respect to water and sanitation, the plans are to achieve coverage rates of 80% for 'improved' drinking water sources and 70% for 'improved' sanitation facilities (UNDP 2010). Current data suggest, however, that these goals may not be met, particularly in rural and peri-urban ger areas (Sigel 2012).

In Mongolia, about half of the urban population lives in ger areas, which are peri-urban, largely informal and relatively low-income settlements (Gawel et al. 2011). This also holds true for Darkhan, where 43.7% of the population (43.7%) live in ger districts without access to this centralized supply system. Instead, local residents rely either on shallow wells or buy their water from water kiosks (see figure 6). In Darkhan, 9 out of 33 water kiosks are connected to the centralized supply system while the others are supplied by trucks (MoMo Consortium 2009). The water supply pattern in the ger districts result in two key problems: an underconsumption which may be explained by affordability problems and difficult transportation (Gawel et al. 2011), and serious health risks. The morbidity pattern in urban ger districts typically reveal high rates of (potentially) waterborne diseases (Basandorj & Altanzagas 2007; City of Ulaanbaatar 2006). It is believed that high incidence rates of hepatitis A, particularly among children, are linked to water. However, since technology for detecting the virus in water is not available in Mongolia, this hypothesis is yet to be proven (personal communication with Dr. Davaajav Abmed and Dr. B. Darmaa, Center of Infectious Diseases, Ulan Bator). Official data, including data for Darkhan, are scarce. However, at least the ger areas located in the floodplain close to the river are exposed to high risks as families often use private wells for the abstraction of shallow groundwater. The quality of this water is not monitored, but the likelihood of contamination from unsealed pit latrines and animal excreta is considerable (Sigel et al. 2012).

With regards to the situation in the ger settlements, the project pursues several strategies. In accordance with the National Water Programme (Parliament of Mongolia 2010), which states the need for advanced and environmental friendly (biological and dry) toilet systems, one project team developed an innovative type of toilet called iPIT which is currently being tested in one ger district of Darkhan. This dry separation toilet does not only allow for the collection of urine and feces without disturbing its users, but is in fact part of an integrated approach: While it is planned to use the urine as a fertilizer, the feces is collected and taken to the central wastewater treatment plant where it will be co-fermented with sludge in a biogas reactor. The development and implementation of this system involved a participatory approach, taking into accounts the perceived needs of the local population. As there are several indications of water-associated health problems (proximity of water sources and human/animal excreta; problems reported by hospitals, health authorities and leading medical scientists) but no reliable data which would allow for a scientific assessment of the situation, the project together with Mongolian partners plans to investigate both the quality of the water used and the prevalence of water-borne diseases. Several reports of a considerable rise in hepatitis A (and potentially hepatitis E) cases means that bacteriological tests will be supplemented by virological testing.

Darkhan's centralized drinking water supply system was put into operation in the 1960s and relies entirely on groundwater abstractions by 18 wells located along the Kharaa up to 8 km upstream from the city. One major problem is leakage, which accounts for about 40% of the water supplied (MoMo Consortium 2009). As much of the distribution system was placed at least 3 m below the ground because of low winter temperatures, the localization of leaks is a rather difficult task. In Darkhan, wireless multi-parameter probes and hydraulic modelling are used in order to locate and quantify water losses (Scharaw & Westerhoff 2011). A detailed description is provided by Scharaw & Westerhoff in this volume.

Figure 6: Water kiosk in an urban ger district

Figure 7: State of Darkhan's central WWTP

Darkhan's central waste water treatment plant was commissioned in 1968. It was designed mainly to reduce COD, and equipped for mechanical, biological and chemical sewage treatment. About 40,000 out of 74,000 inhabitants are connected to the waste water treatment plant, which currently uses only one third of its capacity, mainly because equipment has become dysfunctional over time (see figure 7). Because of low winter temperatures, some processes (mainly the biological treatment) become impossible (MoMo Consortium 2009; Hofmann et al. 2011).

Building local capacity for IWRM implementation

Strategies to solve existing water problems are in the long term only effective if the knowledge generated is available in the target region itself. An important prerequisite for attaining sustainable effects in the IWRM process is the ability of individuals, organizations and societies to act competently. In the IWRM framework, important elements for capacity development include a strengthening of individual responsibilities, the propagation of a participative approach and the provision of training related to water technologies to be implemented. Finally, the acceptance of national IWRM strategies requires a sensitization of the general public for sustainable handling of water.

The MoMo project follows a multilevel Capacity Development approach addressing a wide range of target groups (see table 2).

Table 2: Capacity Development in the IWRM MoMo project

Level	Science	Administration	Business	General Public
Target Group	University students in Mongolia and Germany	- Water Authority - National Water Committee - River Basin Council	Local water supplier (USAG Darkhan)	- schools (teachers and students) - residents of ger settlements - general public
Instruments	- seminars and lectures - practical courses - excursions and study tours - joint mentoring and supervision	- seminars - workshops - study tour	- practical courses - seminars - stakeholder workshops - study tour	- development of teaching units - Mongolian school networks - Mongolian-German school partnerships - teacher training - workshops and seminars for the public
Topics	- hydrology and land use - application of GIS and RS - (urban) water management	- IWRM concept - planning of interventions - decision systems - quality assurance - information management	- centralized wastewater treatment - decentralized wastewater treatment - management of matter fluxes	- environmental education - sustainable water use - participative planning
Sources: modified after MoMo Capacity Development webpage (http://web.me.com/mwaltherub/MoMo-Capacity_Development)				

Reconsidering the institutionalization of IWRM

Traditionally, water management in Mongolia has been highly centralized, but at the same time, there is a multitude of government agencies involved. In fact, “more than 20 organizations have some responsibility for aspects of the water sector under existing legislation” (Livingstone et al. 2009:20). While aimag (province) and soum (district) governors are responsible for the management of water exploitation and protection, the main responsibility for water policy lies with the Ministry of Nature, Environment and Tourism. However, five other ministries (Mining and Energy; Road, Transportation, Construction and Urban Development; Food, Agriculture and Light Industry; Defence) play a role, too. In order to coordinate and integrate their activities, the National Water Committee and the Water Authority were founded in 2000 and 2005, respectively (Horlemann & Dombrowsky 2010).

Because administrative boundaries do not represent hydrological units, 29 river basins were defined in 2009 for which River Basin Councils (RBCs) are to be set up. This can be understood as a response to the spatial mismatch between aimag borders and river basins (Horlemann & Dombrowsky 2010). Nevertheless, it remains unclear what exactly the role of the RBCs will be. A lack of implementation capacity and financial resources remain important constraints (Horlemann & Dombrowsky 2012). The statutory meeting of the Kharaa RBC took place in early 2012, but the exact role and effectiveness of the council’s work are yet to be awaited.

CONCLUSIONS

The results and conclusions presented in this paper are to a certain degree still preliminary as both research and implementation measures in the study area are still in progress. As a region where near-natural conditions and considerable anthropogenic influences on water resources and aquatic ecosystems co-occur with high dynamics, the Kharaa catchment is a suitable model region for (a) further developing the scientific basis of IWRM, (b) implementing IWRM elements and (c) evaluating their impact. Important issues related to regional water availability include the effects of climate change (which will most likely reduce the availability of ground and surface water in the future) and land use change driven by agricultural activities, mining and urbanization (resulting both in rising water demand and changes in surface runoff and infiltration). The physico-chemical water quality in the catchment ranges from very good in the headwater region to moderately polluted (with heavy metals and nutrients) in the middle and lower reaches of the Kharaa. Hydromorphological deficits are mainly related to intensive land use in the riverine floodplains. The ecological state of aquatic habitats as evidenced by the diversity of their flora and fauna reflects both water quality and hydromorphological structures, indicating disturbances of natural ecosystem functioning in the mid- and downstream sections of the Kharaa.

For several reasons, urban water management is a core issue for the implementation of an IWRM in the region. Firstly, in the past two decades urban growth was neither paralleled by an adequate modernisation of infrastructures nor adequate capacities of water management. Therefore, a considerable amount of wastewater remains untreated or poorly treated, constituting the most important source of nutrient influx into the Kharaa River. At the same time, problems linked to the distribution of drinking water, sanitation and waste water treatment are linked to potential risks to human and animal health. In the light of data scarcity and insufficient monitoring routines on the one hand and several indications for infectious diseases caused by waterborne pathogens, including viral agents, on the other hand, both an assessment of the situation and the derivation of recommendations for hygiene monitoring are indicated. This needs to be paralleled by interventions which are obviously necessary, including an indepth assessment of appropriate technologies for the water sector and the perspectives for their successful implementation beyond the pilot stage.

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