Introduction

Stefan Zerbe
Giuseppe Tommaso Cirella
Niels Thevs

1. Water resources: On top of the world's global change agenda

Water is one of the main natural resources. Without water, no life could exist on Earth. Water is also an issue of global change and related to environmental problems and human health. For example, 13 % of humanity, globally, do not have access to clean drinking water and about 3.5 million deaths are related to inadequate water supply and sanitation annually (UNESCO 2012). Due to the over-utilisation of water for agriculture, industry and in the large urban agglomerations, surface water as well as groundwater in many regions of the world has decreased in quantity. It is projected that climatic changes will enhance extreme water related events like floods and droughts (UNESCO 2009). About 25 % of all terrestrial ecosystems are degraded with drylands being the most vulnerable ones (FAO 2011). The most common degradation processes in drylands are destruction of vegetation, soil salinisation and soil erosion. A major driver for those degradation processes is water shortage. Central Asia is one of the world's largest dryland regions. There, inadequate water resource management has resulted in large-scale ecosystem degradation. The desiccation of the Aral Sea and degradation of adjacent terrestrial ecosystems are a well-known example.

Central Asia has an extremely continental-arid climate and is largely covered by deserts, semi-deserts, steppes and alpine ecosystems. In arid environments, agriculture and settlement development depends on large-scale irrigation. Water sources are melting water from glaciers and snow as well

Part of
Cirella, G. T. & Zerbe, S. (Eds.). (2014). *Sustainable water management and wetland restoration strategies in Northern China* bu,press. https://doi.org/10.13124/9788860461094

as precipitation in the high mountain areas that is Tianshan, Qilianshan, Kunlun, Pamir and Hindu Kush, which often are only temporarily transported by rivers to mostly peripheral desert areas. Large river systems in Central Asia include the Syr Darya, Amu Darya, Ili and Tarim (Giese et al. 1998; Kuzmina & Treshkin 1997; Treshkin 2001). There, the irrigated water is diverted from the rivers and lakes to the surrounding settlements with their agricultural lands.

In recent decades, water increasingly is taken from groundwater reservoirs (e.g. Song et al. (2000) for the Tarim River, northwest China) as the main water source for the natural as well as the anthropogenic ecosystems (Thevs 2007). In particular, growing settlement populations and subsequent agricultural food production in Central Asia (Zerbe et al. 2006) are responsible for this transposition. Growing populations have an increasing demand for food, raw materials and energy. Agriculture is one of the main drivers in Central Asia for land development; however, agriculture is also one of the main drivers for environmental problems, such as decreasing resource water and water pollution – via fertiliser and pesticides. In the past decades, in particular cotton plantations have been increasingly introduced throughout Central Asia. For example, 11 % of the world's cotton production comes from the arid and semi-arid regions of Xinjiang (USDA 2012). The irrigation of cotton fields has led to severe water shortages in those regions. The change of the Aral Sea from an "inland ocean" into a salt desert in only two decades is reflective of this (Breckle et al. 2012).

Currently, also the glaciers throughout the bordering mountains are in retreat due to climatic changes (Unger-Shayesteh et al. 2013). Thus, the river run-off from glacier melt has increased during the last two decades (NDRC 2006). It is generally expected that, due to climate change, the river run-off will decrease and become more variable, once the glaciers have shrunken (Hu et al. 1994; Jiang et al. 1997; Giese & Moßig 2004; Barnett et al. 2005). Therefore, in such a continental-arid climate and against the background of climatic changes water must be used efficiently, in particular for agriculture and in the urban-industrial environments.

Another issue of global water change is pollution (UNESCO 2012). Pollution strongly affects the quality of river water and river sediments (Borin et al. 2009). The latter behaves as a sink of pollution, especially for heavy metals and aromatic compounds. Sediments in rivers may be transported to the sea, spread over riverbanks and tidal marshes or managed, that is actively dredged and disposed of on land. Once deposited on tidal marshes or alluvial areas, the polluted sediments may enter semi-terrestrial ecosystems or agro-ecosystems and may pose a risk by accumulating along the food chain and finally end up in the human body. In order to prevent this, phytoremediation through plants is considered as a management option to clean both water and flooding sediments (Pilon-Smits 2005). Thus, pollutants are removed in an early stage of the food chain. In particular, phytoremediation with reed (*Phragmites australis*) is considered an effective technique to clean up waters and sediments from organic and inorganic pollutants. The release of industrial and municipal waste products in freshwater ecosystems has been become a dramatic issue for the condition of the environment and for human health (Taisan 2009).

2. Wetland and river restoration: A task for the 21st Century

In recent decades, the restoration of degraded and damaged ecosystems has become a challenge for landscape management, nature conservation and sustainable land-use development throughout the world (Bradshaw & Chadwick 1980; Jordan et al. 1987; Urbanska et al. 1997; Perrow & Davy 2002; Temperton & Kirr 2004; Lüderitz & Jüpner 2009; van der Zanden & Cook 2011; Hampicke 2009; Zerbe & Wiegleb 2009). Already in 1995, Daily (1995) stated that about 45 % of the terrestrial land surface has a reduced land-use capacity due to a history of unsustainable management. The restoration of floodplains and related settlement ecosystems in arid and semi-arid environments becomes especially difficult with the increasing limitation of water resources. As rivers and their floodplains provide many ecosystem services, for example the purification of water, combating desertification, the accumulation of carbon, production of biomass and providing habitats for plants and animals, there is a particular focus on restoration (Mant & Janes 2006; Lüderitz & Jüpner 2009). Sound restoration science and practice integrates a multiplicity of disciplines. Additionally, it supports decision-makers towards a better assessment, via integrative components of local community knowledge, stakeholders and scientific tools. The task for the 21st Century will be to harmonise these components, at a local level and the augmentation of educative processes, so wetlands and river systems alike can be promptly recognised as central to a productive natural ecosystem.

3. Alternative land-use systems: Reed as a multi-service species

Against the background of increasing agriculture (e.g. crop cultivation, pastures) in Central Asia and, in particular, unsustainable land-use with subsequent negative consequences of the natural resources, alternative land-use systems have to be taken into account. Drivers for these alternative land-use systems can be key species, which are indigenous and adapted to the local and regional environments. Those key species, trees, shrubs as well as herb or grass species, might provide a bundle of ecosystem services. This has been proven for a number of plant species throughout the world. In central and southern Europe, for example, the tree *Castanea sativa* Mill. is such a multi-service species, providing timber, fruits, honey and also cultural services (Conedera et al. 2004). Sustainably managed, it also provides a habitat for a vast number of organisms and serves for environmental education and recreation. In Central Asia, the genus *Apocynum* has been pointed out by Thevs et al. (2012) as a multi-functional species by, in particular, stressing the possible alternative to non-sustainable cotton production in those arid regions.

Reed (*P. australis*), occurring as cosmopolitan species throughout the world, is also considered a promising species which could serve many and diverse demands for the society (Köbbing et al. 2013). It can play an important role within a water-saving and resource-efficient sustainable land-use strategy. Reed can grow on a great variety of sites with regard to different ground water levels, water level changes in floodplains, nutrient availability, and salinity (Thevs 2007; Lambertini et al. 2008; Haslam 2010). Using its ability for phytoremediation, reed can be placed downstream of irrigated land or settlements so that it can use the drainage water and work on the self-purification of wastewater. Thus, by drain-water utilisation or wastewater treatment, reed will produce biomass, which can be used for a neutral CO_2 energy production and which accumulates carbon in the belowground biomass and organic layer, respectively (Kerschbaumer et al. 2014). Furthermore, reed can grow on sites along the lower reaches of rivers, which only receive water during the summer floods of some years. Such sites pose problems for irrigation because a dry period during spring and early summer, e.g. as encountered at the Tarim River in recent years, results in crop failure. Reed can deliver rather stable biomass yields because it takes up water from the groundwater and thus survives periods during which the river, i.e. surface water, is dry. Reed is used as pasture and fodder as well as it is harvested, in order to use the biomass as raw material for paper production and construction materials. If reed is used as pastureland or as fodder plant, it is grazed or harvested during summer, which might result in a certain export of nutrients. For the biomass utilisation as raw material, reed is harvested during winter. The harvested reed biomass is used as raw material for paper production and for the production of chipboards (Hansmann 2008a). As a natural plant, perfectly adapted to the environment, reed does not require treatment like irrigation, seeding, weeding or herbicide or pesticide treatment. Therefore, *P. australis* offers a huge potential as a valuable resource for rural people especially in developing countries. The potentially available reed biomass is lacking reliable data and it is difficult to quantify because as a natural plant it is not part of official statistics such as agricultural crops and residues.

In the recent past, increasing research has been carried out on assessing the advantages of the energy valorisation of biomass (Mckentry 2002; Koziński et al. 1996; Friberg & Blasiak 2002). Some of those studies have analysed biomass combustion technologies or co-firing options with coal. In addition, reed has been considered as an energy source in northern Europe (Graneli

1984). Also in Spain, it is known that some farms could be dedicated to cultivate plant varieties for bioenergy use, such as Giant Cane (*Arundo donax* L.). In the combustion research, an interesting option is the domestic heating by means of conventional boilers, whose efficiencies using reed as fuel has been also compared with the one obtained with traditional fuel, e.g. wood logs, briquettes and pellets.

4. The culture of water

Water is not valued the same in different cultures. There is a strong interlinkage between water and culture. Religion, ethnic, education, environmental laws, etc. influence the individual behaviour towards as well as the society's management of the resource water. Waste of water and water pollution is often related to a low cultural value of water as one of the most important natural resources. Water has always played a more or less prominent role in cultures, depending on the environmental conditions people had to face. Indigenous cultures are still renowned for their ingenious and sustainable water practices. For example, the Karez well system under the extreme continental-arid climate of northwest China was built by the indigenous people to divert water from the mountains in underground channels to the oasis as a perfect adaptation to this dry environment (UNESCO 2014). Modern practices, however, have often disturbed and overruled these traditional practices, with undesired consequences such as the loss of water by evaporation (Schelwald-van der Kley & Reijerkerk 2014). As an example, the water reservoirs along the Tarim River in China evaporate between 0.1 and 0.21 km^3 per year, which is 10 to 25 % of the water used for irrigation along the Tarim River (Thevs et al. 2015). Moreover, according to Schelwald-van der Kley & Reijerkerk (2014), a cultural impact assessment can be a useful tool in assessing and subsequently mitigating adverse cultural impacts of innovations and developments. They state some important points that incorporate a review process in which predictive methods are used in whether or how an action should proceed, monitoring the impacts that occur and acting on the results of such a monitor-based process.

Within environmental ethics, the concept of culture entails perceptions, values, attitudes and institutions. Culture has a long record in history and has undergone different changes. This is also true for "water cultures". Culture shapes the way that society copes with environmental problems. It also shapes the relation between Western scientists and local communities. Success of conservation objectives must therefore properly address the background of culture. This is true especially if different cultures merge at specific sites, such as in Central Asia. The general concept of sustainability has been addressed by Ott and Döring (2008) and Döring (2009). In a more recent study, the role of water culture has been emphasised from different perspectives, e.g. by Balaji et al. (2009). Concepts of social research in developing countries with respect to nature and environmental conservation have been designed in a large scope of literature. One can choose between different tool kits according to specific local circumstances. One step is to reflect upon the problem, which looks at tools and their appropriateness to the study area.

Most experts will agree that water culture needs some sort of comprehensive approach that takes into account past, present and future use. The use of technical solutions in coordination with integrative social-environmental goals, from a comprehensive perspective, is an urgent matter. The culture of water, from a critical analysis of ecocentrism leads us to move away from such an ecocentric stance, and instead, take a visionary look at strong sustainability as a more encouraging, or alternative, path for water use and its maintainability (Kerschbaumer & Ott 2013). Firmly founded, as a result, environmental improvements are grounded in environmental ethics and the relationship connecting value, or the understanding of worth that keeps human beings in equilibrium with the environment. As water is one of the fundamental needs for human survival, water culture via its use and reuse is an exemplar indicator, and starting point, to develop an equilibrium between society and the resource water.

5. Interdisciplinary research on environmental problems in northern China: The SuWaRest consortium

The overall goal of our international and interdisciplinary research consortium was to provide the scientific basis for a comprehensive water management in settlements and on agricultural lands in Central Asia by considering aspects of the natural as well as social sciences. We investigated settlements and irrigation agriculture in northern China with case studies in the Gansu Province and Inner Mongolia Autonomous Region (Inner Mongolia). One of our focal species which we investigated with this multi-disciplinary approach was reed (*P. australis*). As already stated above it occurs along rivers, at lakes and on wetlands in general and is widespread in our investigation areas in the northern Chinese settlements. Reed is utilised there, in particular, as raw material for paper. Additionally, we focused on its potential to be used as biomass for energy production, in particular at the local level. Despite the fact that animal herding on reed stands is a traditional land use all over Central Asia, which is an important income source and an important feature of the various cultures and ethnics (e.g. Turk and Mongolian people), we hypothesised that reed might offer alternative utilisation options in this region. Additionally, ecosystem services such as, e.g. water purification, nutrient extraction and sand fixation in deserts and steppes, it may also provide income opportunities during winter when other agricultural activities are reduced. Moreover, the perception of water by the local stakeholders was analysed which marks the first study of this kind in continental-arid northwest China.

Within this holistic view on water in settlements and irrigation agriculture, we thus address the following issues:

- environmental ethics and arguments in favour of a strong sustainability viewpoint in Chapter 1;
- describe, in detail, our two investigation areas in Chapter 2, i.e. the Heihe River Basin and Wuliangsuhai Lake with the Hetao Irrigation District;
- the use of microbial communities as bioindicators for land-use systems is outlined in Chapter 3;

- water allocation along the Heihe River and Tugai forest conservation in Ejina is described in Chapter 4;
- the physiology of reed (*P. australis*) with regard to nutrient content and allocation is analysed in Chapter 5 by comparing aquatic and terrestrial habitats;
- with regard to our focal plant species reed, diversity and the role of rhizobacteria associated to *P. australis* is investigated in Chapter 6;
- with regard to reed as a renewable energy source, an insight into possible conversion pathways is given in Chapter 7;
- the economic perspective is shown in Chapter 8 by investigating the livelihood and economy of reed-dominated wetlands; and
- the subject of sustainability is addressed with an index of sustainable functionality derived from data on the Urat Front Banner in Chapter 9, and a comparative look at alternative development scenarios on the Hetao Irrigation District and Wuliangsuhai Lake in Chapter 10.

In a final summary, Chapter 11 discusses our findings against the background of our multi-disciplinary approach and derives management recommendations for waters and wetlands in northern China.

Key references

Bradshaw, A.D. & Chadwick, M.J. 1980. The restoration of land. University of California Press, Berkeley, Calif.

Daily, G.C. 1995. Restoring Value to the World's Degraded Lands. Science, 269(5222): 350–354.

Döring, R. 2009. Natural capital – What's the difference? In: R. Döring ed. Sustainability, natural capital and nature conservation. Marburg: Metropolis-Verlag, 123–142.

Köbbing, J.F., Thevs, N. & Zerbe. 2013. The utilisation of Reed (*Phragmites australis*) – A review. Mires and Peat, 13: 1–14.

Mant, J. & Janes, M. 2006. Restoration of rivers and floodplains. In: J. van Andel & J. Aronson eds. Restoration ecology: The new frontier. Malden, Mass: Blackwell Science, 141–157.

Ott, K. & Döring, R. 2008. Theorie und Praxis starker Nachhaltigkeit. Metropolis-Verlag.

Zerbe, S. & Wiegleb, G. 2009. Renaturierung von Ökosystemen in Mitteleuropa. Spektrum Akademischer Verlag, Heidelberg.