Sustainability **2011**, *3*, 1792-1795; doi:10.3390/su3101792

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Editorial

A Summary on the Special Issue "Sustainability of Groundwater"

Veith Becker [1],*, Anssi Myrttinen [1], Johannes A.C. Barth [1] and Peter Bayer [2]

[1] GeoZentrum Nordbayern, Friedrich-Alexander Universität Erlangen-Nürnberg, Schlossgarten 5, 91054 Erlangen, Germany; E-Mails: anssi.myrttinen@gzn.uni-erlangen.de (A.M.); barth@geol.uni-erlangen.de (J.A.C.B.)

[2] Geological Institute, ETH Zürich, Sonneggstr. 5, NO G5, 8092 Zürich, Switzerland; E-Mail: bayer@erdw.ethz.ch

***** Author to whom correspondence should be addressed; E-Mail: veith.becker@gzn.uni-erlangen.de; Tel.: +49-9131-8522660; Fax: +49-9131-8529294.

Received: 5 October 2011 / Accepted: 7 October 2011 / Published: 10 October 2011

One of the most common denominators for almost any form of life is the existential need for water. This need has recently received much attention in the frame of sustainability discussions [1,2]. In addition, environmental sustainability and safe access to fresh water is one of the eight United Nation's millennium development goals, and ultimately most conditions of life rely on water. Expected higher water demands for irrigation, industrial and household purposes outline the need for more investment in freshwater characterization and quantification. In addition, factors including climate change, large-scale reservoirs, re-channelling of streams, expansion of urban centres as well as chemical and microbial loading need to be taken into account.

Within this framework groundwater plays an important role, because it is a compartment that has received little attention due to its hidden nature. This is particularly important for continental groundwater that is estimated to make up between only 0.3 and 1.6% of the global water budget [3]. From this small proportion, only a fraction is useable due to high salinity of mostly deeper groundwater. Nonetheless, groundwater is by far the most mined resource worldwide and is used in irrigation, industry and households [4,5]. For instance, Foster and Chilton [6] evaluated that groundwater globally provides 50% of drinking water, 40% of industrial water and 20% of the water used for irrigation. Other figures produced by the United Nations Environment Programme [7] indicate that today more than 25% of the world population (*i.e.* 1.5 to 2 billion people) rely on groundwater with expected future rapid growth. This growth in demand is partially due to better technologies that become available to access deeper groundwater systems. Also groundwater is often the only local freshwater resource available.

On the other hand, groundwater often suffers growing pressures through input of pollutants and pathogens. Due to long residence times and slow flow velocities of groundwater, any changes to this valuable resource must be considered with great care. With most subsurface processes being slow they memorize impacts over generations so that only far-sighted groundwater use and protection is sustainable. For such investigations, technologies of detailed and affordable monitoring still remain a challenge. Another reason to devote more scientific attention to sustainable management of groundwater is the fact that in many parts of the world it is extracted at a greater rate than it is being replenished. "Man-made-rivers" can be found in northern Africa and are good examples of the increasing overexploitation of groundwater bodies [8].

This special issue assembles some key studies in the field and covers aspects of coastal aquifers, as well as sustainability and monitoring issues in Africa and India.

The groundwater study in India focuses on the Maheshwaram Catchment in Central India [9]. In this region a growing demand for groundwater is registered for agricultural activities. This is linked to concerns about potential water contamination and triggered a local groundwater-quality monitoring program. It relies on cost-effective sampling strategies and combined field observations together with geostatistical analyses to develop optimized monitoring using statistical analyses.

Another study presented in this special issue describes a case study from Mali in East Africa [10]. This study modeled effects of population growth as well as urban and industrial development together with climate variability. The work tested four separate scenarios that projected increasing abstraction of groundwater. Results may help to narrow down areas of groundwater decline by comparison to local precipitation rates.

This work is nicely complemented by an article on sustainable groundwater removal in relation to groundwater storage [11]. The dynamics of the latter depend on induced recharge and reduction of groundwater discharge that can balance pumping rates. This in turn depends on aquifer-wide pumping rates that may prevent such equilibria and can exhaust groundwater storage capacities. The authors suggest improved decision making by including the need for domestic water supply and constraints by local water balances as well as natural or induced changes in groundwater levels.

A similar topic is covered in the contribution by Roumasset and Wada who considered optimal sustainable groundwater extraction in the context of climate change [12]. They state that minimizing adverse effects of groundwater scarcity requires optimal patterns of groundwater management. With this, the work reviews several paths for groundwater extraction from a coastal aquifer. This is further detailed by a description of exploitation of multiple aquifers and usage of recycled water and then linked to changing frequency, duration, and intensity of precipitation. The factors are tested on a case study in South Oahu, Hawaii, where climate potentially improves gains of integrated groundwater management.

Groundwater resources in coastal regions are highly sensitive to salt and chloride intrusions. This issue is further discussed on a case study in Benin, West Africa [13]. These are weighed between inputs from the Atlantic Ocean and a shallow lake that has elevated chloride contents. Better characterization of the local groundwater system suggests appropriate management practices and sustainability of groundwater via a series of numerical models. These include characterisation of flow and density-driven transport of water from the lake. The findings were combined with field investigations that included groundwater chemistry, hydraulic responses to pumping tests of the aquifer and distribution of electrical resistivity as well as installations of multi-level piezometers. These combined techniques outlined management strategies on adverse impacts from salt water and anthropogenic contaminants entering this important local source of fresh water.

The special issue closes with a European case study that outlines a time and cost analysis for restoration of a contaminated aquifer [14]. It investigated long-term contaminations that are planned to be restored with active sustainable technologies. This is weighted versus natural attenuation capacities of the aquifer and its pollutants. The analysis yields an estimate of at least 20 years for the duration of remediation and attributes costs to public resources over current and future generations.

All studies presented here are of local nature, but reflect a good overview of groundwater issues that can occur globally and on a daily basis. These studies are therefore indicative for a several issues of sustainable groundwater use and its protection including salt-water intrusion, agricultural use, sustainable abstraction and remediation. They lay foundations for future debates on similar studies and help to protect a highly important resource for the environment and humans.

Acknowledgments

We thank all contributors of this special issue as well as the editorial staff of MDPI Sustainability Journal to make this special issue a success.

References and Notes

1. Fishman, C. *The Big Thirst: The Secret Life and Turbulent Future of Water*. Free Press: New York, USA, 2011.
2. Catley-Carlson, M. Environment: Water, water everywhere... *Nature* **2011**, *473*, 27-28.
3. Barth, J.A.C.; Viachaslau, F.; Bayer, P.; Struckmeier, W.; Grathwohl, P. Global Water Balance. In *Linkages of Sustainability*; Graedel, T.E., van der Voet, E., Eds.; MIT Press: Cambridge, MA, USA, 2010; pp. 221-232.
4. Struckmeier, W.; Rubin, Y.; Jones, J.A.A. *Groundwater – reservoir for a thirsty planet?* ; Report of the Earth Sciences for Society Foundation, The Year of Planet Earth Project; Leiden, The Netherlands, 2005.
5. Zekster, I.S.; Everett, L.G. *Groundwater and the environment*. Lewis Publishers: Boca Raton, FL, USA, 2000.
6. Foster, S.S.D.; Chilton, P.J. Groundwater: the processes and global significance of aquifer degradation. *Phil. Trans. Roy. Soc. London B Biol. Sci.* **2003**, *358*, 1957-1972.
7. UNEP *Groundwater: a threatened resource*. UNEP: Nairobi, 1996; Vol. 15.
8. Elhassadi, A. Views on Libyan national plan (LNP) to resolve water shortage problem (WSP). Part Ib: Great Man-Made River (GMMR) project–Capital cost with interest rates. *Desalination* **2008**, *220*, 184-188.
9. Nabi, A.; Gallardo, A.; Ahmed, S. Optimization of a groundwater monitoring network for a sustainable development of the Maheshwaram Catchment, India. *Sustainability* **2011**, *3*, 396-409.
10. Lutz, A.; Thomas, J.M.; Keita, M. Effects of population growth and climate variability on sustainable groundwater in Mali, West Africa. *Sustainability* **2010**, *3*, 21-34.

11. Van der Gun, J.; Lipponen, A. Reconciling groundwater storage depletion due to pumping with sustainability. *Sustainability* **2010**, *2*, 3418-3435.
12. Roumasset, J.A.; Wada, C.A. Optimal and sustainable groundwater extraction. *Sustainability* **2010**, *2*, 2676-2685.
13. Silliman, S.E.; Borum, B.I.; Boukari, M.; Yalo, N.; Orou-Pete, S.; McInnis, D.; Fertenbaugh, C.; Mullen, A.D. Issues of sustainability of coastal groundwater resources: Benin, West Africa. *Sustainability* **2010**, *2*, 2652-2675.
14. Schirmer, M.; Niemes, H. Sustainable technologies and social costs for eliminating contamination of an aquifer. *Sustainability* **2010**, *2*, 2219-2231.