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Hydrogeography – linking water resources and their management to physical and anthropogenic catchment processes

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1. Introduction to the thematic issue

The sufficient availability and quality of water is a prerequisite not only for all forms of plant, animal and human life, but also for socioeconomic development, with particularly strong links to the agricultural, mining and industrial sectors. As one of the most fundamental sub-disciplines of geography, hydrogeography does not only describe the uneven distribution of water resources at the regional and global scale, but also seeks to explain such differences on the basis of the physical environment and human interferences with nature. Hydrogeography (in contrast to a purely physical hydrology) has therefore turned into a truly geographical science – considering the complex interlinkages between the physical and the human environment – more than half a century ago (*Winkler* 1970; *Uhlig* 1971). Hydrogeography continues to be a highly relevant geographical subdiscipline, as is for example evidenced by the existence of the *Commission for Water Sustainability* (for details, please see https://iguwater.wordpress.com) within the *International Geographical Union*.

This thematic issue was initiated by the working group on hydrology within the German Geographical Association (for details, see http://www.ak-hydrologie.de) ahead of its 50th anniversary meeting in 2018, and follows up on several other thematic issues (co-)organized by the working group in the past few years (*Chifflard* and *Karthe* 2014; *Cyffka* and *Karthe* 2013; *Karthe* et al. 2017; *Sun* et al. 2018). The working group also publishes annual conference proceedings in the series *Geographica Augustana*.

2. State of the Art

2.1 Hydrology in the geographical perspective

Both at the global and regional scale, hydrology is influenced by physical and anthropogenic drivers. However, in the era of the Anthropocene (*Crutzen* 2002), the distinctions between 'natural' and 'anthropogenic' processes have become less clear, because human influences are now manifested in all parts of the natural environment. Global change "is marked by the in-

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terdependence of physical, biogeochemical, economic, social, cultural, demographic and political processes" (*Germer* et al. 2011: 1). In this context, water plays a prominent role in two ways: on the one hand, significant shifts in global and regional water distribution are expected; on the other hand, various earth systems (e.g. climates, soils, vegetation) are connected by oceanic currents and hydrological flows (*Steffen* et al. 2005), and are thus affected by the changes. It is therefore not surprising that the *International Association of Hydrological Sciences* (*IAHS*) underlines the importance of interdisciplinary research efforts in the context of the scientific decade "Panta Rhei – Everything flows: changes in hydrology and society" (*Montanari* et al. 2013).

Historical hydrology reconstructs past river courses or specific discharge events based on different types of evidence, such as sediment records, historical documents on meteorological conditions, river basin conditions and flood events, photographs, official documents, news reports, personal accounts and local historians' research (*Deutsch* et al. 2010; *Ruiz-Bellet* et al. 2015; *Roggenkamp* and *Herget* 2014, 2016).

Hydrology investigates water flows both on the surface and below the surface, often looking at the scale of river catchments or meaningful subunits (*Rogger* et al. 2017). The different flow pathways are governed by various drivers which include (a) the characteristics of a precipitation event, (b) the hydraulic properties of subsurface layers (soils and underlying rock formations) (*Chifflard* et al. 2018a; *Horton* 1933) and (c) surface cover properties such as vegetation or artificial surface sealing, including any anthropogenic modifications thereof (*Germer* et al. 2010; *Pistocchi* et al. 2015).

Today, the majority of the world's large rivers are dammed in at least some sections. Dams, no matter for which purpose they are erected, do not only modify the temporal pattern of discharge (*Hauer* et al. 2016), but also affect physico-chemical water characteristics (*Hahn* et al. 2016; *Mack* et al. 2013), sediment transport regimes (*Chalov* et al. 2016; *Wohl* and *Rathburn* 2003) and the connectivity of river systems (*Vörösmarty* et al. 2010). Moreover, in dry regions, dams lead to significant evaporation losses which may result in the evaporation of half the storage volume during a single year (*Barbier* 2006).

2.2 Water quality and river ecology in the geographical perspective

In a hydro-ecological perspective, riparian floodplains are an integral part of river systems, despite the fact that their environment may seem more terrestrial than aquatic, except for flood periods. The state of river and riparian ecosystems is shaped not only by natural hydrology, hydromorphology and water quality, but also by many other external effects.

From a hydrogeographical perspective, it is important to understand that hydrology, water quality and river ecology are closely interlinked. For example, water quality in a river depends not only on the amount of pollutant influx, but also on its hydrology (i.e. its dilution capacity) and ecological state (i.e. the functioning of biogeochemical filtration mechanisms) (*Chalov* et al. 2017; *Völker* et al. 2013). Despite all progress in agricultural, mining, industrial and municipal water management, a good chemical status of rivers remains a challenge in many parts of the world, including Germany (*Karthe* et al. 2017; *UNEP* 2016; *Völker* et al. 2013). In mining regions throughout the world, water, sediment and soil pollution are often particularly problematic, even after mining activities have ceased (*Winde* et al. 2004; *Thorslund* et al. 2012).

The ecological assessment of water bodies requires the monitoring not only of hydrological, hydro-morphological and physico-chemical water quality parameters, but also function-oriented biological indicators (*Borchardt* and *Richter* 2003). Because aquatic ecosystems depend on functioning riparian ecosystems, the ecological restoration of floodplains has received increasing attention in recent years (*Aishan* et al. 2015; *Stammel* et al. 2016), in particular regarding the provision of regulating ecosystem services (*Tomscha* et al. 2017).

2.3 Water management and hydro-geography

In the context of efficient water usage and management, hydrogeography turns into a more applied and solution-oriented science. Maximizing water use efficiency is a prominent goal for water managers in dryland regions such as the continental parts of Central and Eastern Asia (*Karthe* 2018). Very important water users in this region include agriculture, and other forms of vegetation such as trees planted for erosion control, in oasis or for urban greening (*Feike* et al. 2015; *Guo* et al. 2016).

Because many major rivers cross international borders, river basin management often requires a transboundary perspective (*Boklan* and *Janusz-Pawletta* 2017). In such cases, a common understanding about water management goals is essential, as it is practically exemplified by the European Water Framework Directive (*Völker* et al. 2013) which is being considered a reference even outside the EU (*Heldt* et al. 2017).

Despite all (justified) criticism of purely technocratic approaches, water management in the anthropocene also requires the development and implementation of water-related technologies. Wastewater treatment is a point in case: while water quality in many rivers of the developed world continued to deteriorate until the 1950s, the widespread construction of wastewater treatment plants and their continuous upgrading have led to significant water quality improvements in receiving water bodies (*Seeger* 1999). However, technical solutions should always consider the environmental and socioeconomic and demographic framework conditions. Demographic developments (both growth and shrinkage) have the potential to significantly modify the dimensioning requirements of water infrastructures over their lifetime (*Karthe* et al. 2016; *Londong* et al. 2011).

3. This special issue's focus

3.1 Hydrology

The study presented by *Mathias Deutsch, Tobias Reeh* and *Daniel Karthe* investigates historical floods for the River Roda in Thuringia, Germany. The authors combine different sources of information to reconstruct past flood events for the 16^{th} to 19^{th} century. For the severe flood events of the late 19^{th} century, they identify interesting parallels to more recent floods (e.g. the role of land use change). Ultimately, they concluded that historical accounts are an important basis for future flood preparedness, particularly with regard to heavy regionalized rainfall for small watersheds.

Three manuscripts in this collection deal with the relevance of near-surface and land cover properties for the generation of runoff, interflow and infiltration. The study presented by *Peter Chifflard, Dennis Moulding, Jann-Thorben Petri, Julian J. Zemke and Martin Reiss* addresses the surface runoff of horse grazed pasture areas. Special focus is given on the antecedent soil moisture as this is indicated to be one of the key factors of surface runoff generation due to its high spatial and temporal variability. A self-constructed rainfall simulator is used to compare the runoff generation of four horse and cattle grazed pastures, respectively, with different antecedent soil moisture but homogeneous geological underground and soil types. The experimental approach reveals distinctively higher runoff coefficients for sites grazed by horses than by cattle and confirms the strong importance of the antecedent soil moisture.

The paper by *Christian Reinhardt-Imjela, Katja Maerker, Achim Schulte* and *Arno Kleber* investigates the role that periglacial cover beds play for near-surface water flow processes in the Ore Mountains (Germany), which like most Central European mountains were glaciated during the Pleistocene. One important hydraulic property of these near-surface layers is their anisotropy, which plays an important role for modelling surface and below-surface water flows during heavy rainfall events. In a case study on the Upper Flöha watershed and using the *NASIM* rainfall-runoff model, the authors show that periglacial cover beds are very important elements for flood model parameterization, and that their correct representation is essential for the efficiency of flood models. The manuscript by *Julian J. Zemke* assesses the alteration of runoff processes in a headwater catchment in the Hunsrück-Hochwald National Park in Germany. In the study region, slope bogs and waterlogged soils have been drained by a dense network of trenches in order to support forestry. The author shows that the moisture content of former slope bogs has decreased significantly (even after short dry periods), but also argues that his findings can support a future rehabilitation of the bog land.

The article by *Ahmed El-Shazli, Georg Hörmann, Paul D. Wagner* and *Nicola Fohrer* analyzes the suitability of different methodological approaches to estimate evaporation losses from the Aswan High Dam Reservoir in Egypt. According to the authors' findings, simple water balance approaches yield suitable results over longer periods of time. However, for more short-term investigations, especially during the hot summer months, water balance-based estimates differ significantly from calculated evaporation rates. Given the very high evaporation losses of about 5.5 mm/day (annual average), the authors conclude that for vast reservoirs such as that of the Aswan High Dam, the usage of water balance equations can lead to substantial biases in the estimation of evaporation losses.

3.2 Water quality and river ecology

The article by *Jens Hahn, Nina Zitzer* and *Gabriela Laufenberg* presents a case study on heavy metals in the former mining region around Braubach in Germany. Forest soils of this region are characterized by acidic pH-conditions and local enrichments of Pb (strong), Cd and Zn (moderate). In river channel sediments, the authors find the more mobile elements (Cd, Zn) in more strongly elevated concentrations, as they did for surface water. They conclude that this results from the mobilization of both elements from catchment soils to water courses, but also from the relatively high sorption capacity of channel sediments. Contrastingly, Pb appears to be retained in forest soils.

The study presented by *Barbara Stammel*, *Mira Amtmann*, *Marion Gelhaus* and *Bernd Cyffka* investigates anthropogenic impacts on riverine floodplains on ecosystem services at the example of a 35 km stretch along the Danube river in Germany. Following river course rectifications in the late 19th century and the construction of dams for flood protection, the development of a navigable channel and the erection of a hydropower plant in the 20th century, the river's active floodplain was reduced to one-fifth of its original size. The authors show that this coincided with a significant decrease of ecosystem functions such as water storage, carbon sequestration and nutrient retention (which were reduced by 40% to 80%). Similarly, they observe a notable loss of habitats (which is much more difficult to quantify, though).

3.3 Water use and management

The contribution by *Fabian Krengel, Christian Bernhofer, Sergey Chalov, Vasily Efimov, Ludmila Efimova, Liudmila Gorbachova, Michal Habel, Björn Helm, Ivan Kruhlov, Yuri Nabyvanets, Natalya Osadcha, Volodymyr Osadchyi, Thomas Pluntke, Tobias Reeh, Pavel Terskii* and *Daniel Karthe* analyzes the challenges for transboundary river management in Eastern Europe using the example of three specific river basins, namely that of the Desna (shared by Russia and Ukraine), the Western Dvina (shared by Russia, Belarus, Lithuania, Estonia and Latvia) and the Western Bug (shared by Ukraine, Belarus and Poland). Despite similarities regarding size, climate and hydrological characteristics, the authors find considerable differences regarding pollutant discharge, hydrological modifications, monitoring routines and legislation in the up- and downstream riparian subbasins (countries).

The article by *Maierdang Keyimu, Ümüt Halik, Zongshan Li, Abdulla Abliz* and *Martin Welp* investigates the suitability of three different tree species (*Morus alba* L., *Fraxinus sogdiana* Bunge and *Platanus acerifolia* (Aiton) Willd.) for urban greening in Aksu, an arid oasis city in northwestern China. The authors identify considerable differences regarding the water consumption by these species (more than factor four), but also regarding their water-use efficiency. They conclude that the native tree species (*Morus alba* L.) was best adapted to the arid environment and thus best suited for urban greening projects.

The study presented by *Christian Opp, Bastian Ziebolz* and *Michael Groll* discusses the factors to be considered for upgrading and renewing wastewater treatment plants (WWTPs) in rural areas, considering wastewater composition, receiving water characteristics, life cycle assessment of the WWTP, and regional socio-economic and demographic trends. For their specific study area (which is characterized by relatively unpolluted receiving water bodies and a shrinking population), the authors conclude that maintaining existing WWTPs is preferable to upgrading them to more state-of-the-art technologies (which are more costly and do not result in notable net benefits for receiving water ecology).

4. Conclusions

In the early 21st century, hydrogeography is still based on fundamental hydrological insights that were gained by geographers and hydrologists around a century ago (and sometimes even before). While the understanding of most hydrological processes has more or less gradually evolved over the years, hydrogeography has developed very dynamically in more recent decades. This is largely due to the following trends: (1) there has been a (renewed) focus on interdisciplinary approaches, thus linking human and physical geography; (2) various phenomena related to global change (e.g. climate change, demographic change, technogenic developments) directly alter regional hydrology and water quality; and (3) the arrival of modern monitoring and modelling techniques related to hydrological processes and their drivers have catapulted hydrogeography into the age of 'big data'. Despite all these advances, and a vast range of perspectives ranging from microscopic and local to the entire hydrosphere, modern hydrogeography still considers water resources and their management in the context of physical and anthropogenic catchment processes.

Special Dedication

The three editors of this thematic issue do not only share a passion for hydrogeography, but all of us have just become fathers. We would therefore like to dedicate this thematic issue to our beloved children: Lukas Minho Karthe; Lukas Büche; Joshua Nicolas and Zoe Louisa Chifflard. We sincerely hope that the research presented here contributes not only to a holistic understanding of hydrogeography but also towards the sustainable use and management of the aquatic and terrestrial environment.

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401

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