Historic Mining Infrastructure as An Opportunity for Regional Water- & Energy Supply (Harz Mountains, Germany)

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Abstract

High precipitation, dams, and waterworks make the Harz Mountains a large freshwater supplier. But, challenges arise based on climate change and extreme weather events. Old mine working can support water management if integrated into the system. Successful planning and integration need a holistic understanding of the regional water cycle, the current situation of the mine workings and the interaction. The development of a hydro-analytical water management tool establishes a link to analyse excavation utilisation enabling adaptive water management. A hybrid model approach is used to simulate and forecast regional water quality developments using AI systems supporting the decision-making for additional measures and identifying chances to adapt to climate change.

Keywords: Mine Heritage, Harz Mountains, AI, Digital Technologies, Climate Change

Introduction

More and more regions have to adapt to extreme weather events in the course of climate change. sudden heavy rainfall or prolonged heavy overland rainfall followed by flooding or increasing dry periods are a challenge for many regions. Mountain regions are particularly important for the water balance (Viviroli and Weingartner 2007), as the average precipitation levels are often up to 1600 mm per year or higher due to the uphill rainfall. Regions in the rain shadow of the mountains often only have annual mean precipitation in the range of only 500 mm per year or even less. At the same time, there is a risk of flooding in the surrounding countryside (Tonn 2002). Climatically, the Harz Region is one of the areas with the highest precipitation rates in Germany with its annual precipitation of 1326 mm on the Clausthal plateau. Furthermore, its storage capacity based on six dams in the western Harz and four groundwater works from the interconnected system of the Harzwasserwerke GmbH (HWW) supplies around two million people and numerous important industrial companies from the Harz Mountains to Bremen with drinking water every day (Harzwasserwerke GmbH 2022). The low mountain range not only has a special status due to the UNESCO World Heritage the "Upper Harz Water Regale", but the water quality also stands out in comparison to many other areas in northern Germany (Niedersächsischer Landesbetrieb für Wasserwirtschaft Küsten- und Naturschutz 2019) and is therefore not only of special water management relevance for areas with nitrate-polluted aquifers but also for regions in the rain shadow of the Harz Mountains with an annual average of only 481 mm precipitation over 50 years (Harzwasserwerke GmbH 2022). If the current supply system is not expanded, the HWW see the challenge that as a result of climate change and the simultaneously increasing demand of the user region, the supply and quality of water will be limited in the medium and long term and flood events such as those in Goslar in 2017 will increase. The demand in terms of quantity and quality concerns not only the (drinking) water supply but also the provision of sufficient (cooling) water for industry, such as the chemical plants in Langelsheim, the sewage treatment plant pipelines, and agricultural operations in the foreland. In addition to quantity, temperature trends, microbiological parameters, pH and potentially toxic elements are of particular interest for regional water management. Due to the high annual precipitation rate and the already existing underground cavities due to the centuries of mining history, their potential as water reservoirs should be investigated to actively integrate them into the current water supply network. Therefore, the Clausthal University of Technology (CUT), the Harzwasserwerke GmbH (HWW), and the Federal Institute for Geosciences and Natural Resources (BGR) have set the goal of developing the potential of the Harz Mountains as a water and energy management region in a holistic, digital way and thus establishing a basis for further research into water and energy storage in above- and underground spaces around the area.

Geology and hydrogeological features of the study area

With a length of about 90 km in an NW-SE direction and a width of about 30 km in a NE-SW direction, the Harz is the northernmost low mountain range in Germany. It is essentially built up of Palaeozoic rocks (Devonian and Carboniferous) and is uplifted by several 100 m compared to the surrounding foreland (Figure 1). Striking marginal fractures separate it from the Harz foreland, which is characterised by the Germanic Triassic. For example, the "Harznordrand" fault runs from NW to SE. Here the Harz block drops suddenly from altitudes of around 600 m to 200-400 m at the Harz rim. Altogether, the Harz Mountains can be subdivided into four geographical units. This geological description focuses on the north-western Upper Harz, as the economically most important mining districts with their drainage systems are located in this area. Silver bearing galena sphalerite and chalcopyrite were the main minerals mined from the hydrothermal veins. The Upper Harz belongs to the geological unit of the Clausthaler-Kulmfaltenzone, which is a plateau of folded Lower Carboniferous siliceous and clayey shales with thick greywackes (turbidites) at about 600 m above sea level (Liessmann 2010). This unit occupies most of the Upper

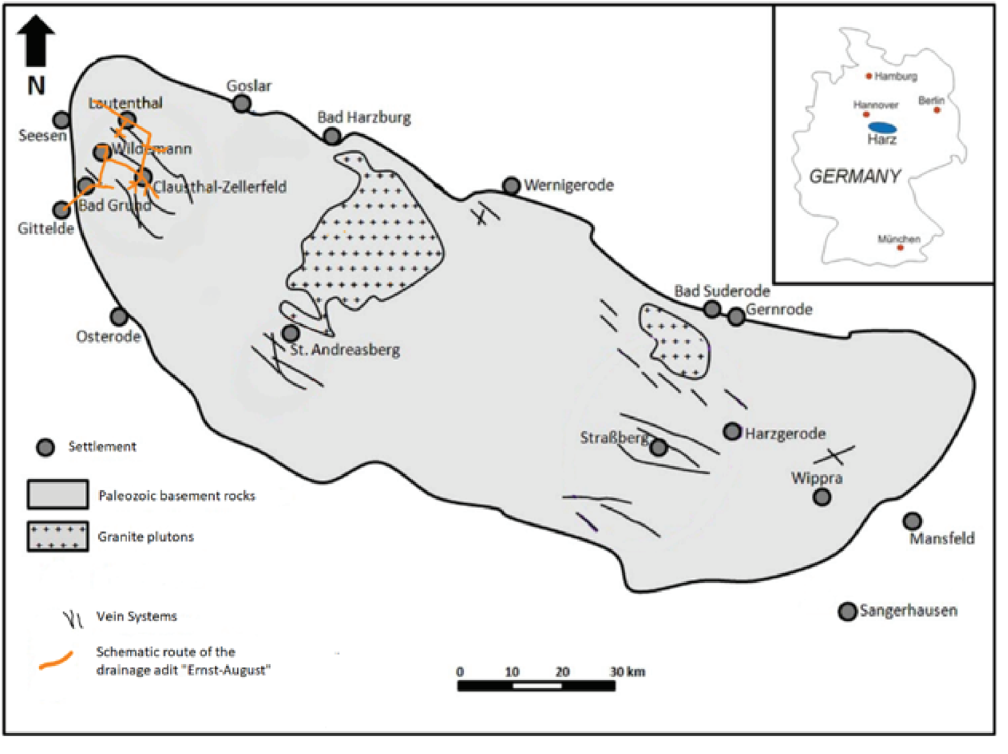

Figure 1: Overview of the location of the study area and the geological framework (Modified after Bozau et al. 2017).

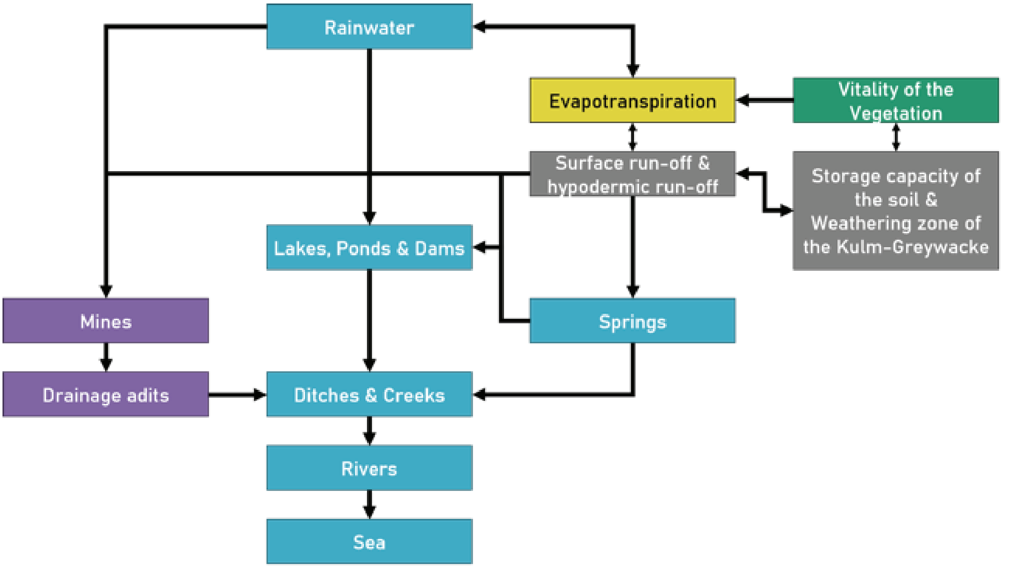

***Figure 2:** Schematic overview of the waterway network in the Upper Harz Mountains (Modified after Bozau et al. 2017).*

Harz (Müller and Franzke 2014). As these formations have low permeabilities, only a small part of the precipitation contributes to groundwater recharge. A large part is discharged as surface runoff into the surrounding receiving waters and ditches, abandoned mine buildings, drainage adits, lakes, and dams (Figure 2). Water movement occurs mainly along hercynian (SE-NW) fissure and fault systems at depths of tens of meters. The near-surface aquifer is fed mainly from accumulating precipitation water. This leads to rapid water exchange processes and thus to short residence times of the water within the Paleozoic bedrock, which results in less mineralisation of the Harz waters (Alicke 1974). The percolating part of the precipitation water moves as hypodermic runoff within the weathering zone and can escape as infiltration water due to the partly steep morphological conditions and flow to the receiving waters. The near-surface groundwater flow direction is oriented to the morphological conditions. The outflow is from the highlands to the receiving waters in the lowlands. The runoff is controlled by two large watersheds in the Harz Mountains. One watershed runs NNE - SSW across the High Harz, between Wernigerode and Braunlage, and separates the catchment areas of the Weser and Elbe. Another watershed runs parallel to it, separating the runoff to the S and the N respectively (Müller and Franzke 2014).

Methodology and previous research

The idea of WSH 2050 is to optimally utilize and, if necessary, expand the storage capacity of the Harz Mountains to specifically buffer sudden rainfall and store it for later demand. Since the hydrography of a region has a mutual interaction with geological, morphological, climatic, and pedological factors, these must be analyzed together. Additionally, there are numerous mines and drainage adits from the mining history, as well as the effects of biotic and abiotic forest dieback in the Harz Mountains, which must be included in the considerations. Although there is information on the individual components, there are currently no digital tools that allow all parameters to be linked and interacted for holistic water management of the region. The project has so far been pre- and funded by the Lower Saxony Ministry of Science and Culture (MWK) to develop a concept within one year, check the technical feasibility, identify challenges and limitations of the project, select suitable technologies and involve further project partners. A strongly interdisciplinary consortium is working together to bring all hydrographic factors together in one database (single source of truth). The consortium currently consists of six interdisciplinary institutes of CUT, the Leichtweiß Institute (LWI) of TU Braunschweig, the Northwest German Forest Research Institute, the Department of Mining Archaeology of the Lower Saxony State Office for the Preservation of Monuments, the Federal Institute for Geosciences and Natural Resources (BGR) and the HWW. As part of the previous project "Energy and Water Storage Harz" (EWAZ), the Hydrogeology, Water Management, and Water Protection (HYWAG) department of LWI has already combined a spatially high-resolution hydrological water balance model with a model for the operation of individual reservoirs or interconnected storage systems in the Western Harz with climate models to simulate the system services: Flood protection, low water elevation, drinking water supply as well as power supply using energy storage to simulate. The planning version of the hydrological software PANTA RHEI developed at HYWAG was used for the hydrogeological modelling. This is a deterministic semi-distributive model in which the overall catchment area is subdivided into high-resolution sub-areas. These sub-areas are also subdivided into the smallest hydrological calculation units (hydrotropes) according to land use, soil attributes, and topography. Although the leaf area index is included here in the annual cycle and the crop rotation of the long-term economy, current changes in the forest stand due to the *bark-beetle* and the last dry summers and storms would have to be added. The linked storage operation model IGOmod is based on the software Gecko and is used to model arbitrary interconnected systems and operation rules for multi-purpose storage. PANTA RHEI provides the natural inflows of the reservoirs, while IGOmod is used to simulate the water volume operation of individual reservoirs and interconnected reservoirs and their transfers. Parameters taken into account in the combined model are meteorological time series, processed as spatial data fields from data of the water management authorities, the HWW, and results of the project Climate Impacts on Inland Water Management in Lower Saxony (KliBiW) (Nistahl et al. 2021). Furthermore, the storage model also includes single areas of underground mining cavities. In the WSH 2050 project, this already existing combined model is to be extended to include the entire underground system. This expanded model is intended to serve as a management tool that enables targeted forecasts about holistic, adaptive water management of the region while reducing conflicts of use by generating various options for action for different issues

***Figure** 3: Overview of the aspects of WSH 2050 as a holistic model of the water management region of the Harz* and simulating and comparing their influence on water quality and quantity so that the current water demand by the Harz can also be ensured in the future (Figure 3).

A total of five constructive and operational variants of water and energy management (new constructions, extensions, transfers) are considered in the EWAZ project to investigate possible effects on the water balance of the region for the four previously mentioned and partly competing target variables. In an interim result, it was shown that already a multifunctional (pumping) storage coupled with an existing dam would significantly improve flood performance in the future, in addition to improvements in the other system performances mentioned. Therefore, the connection of underground storage systems offers significant added value for the region, especially considering the climate change adaptation strategy (Specificity of underground storage) (Nistahl et al. 2021). However, the utilization of the already existing historical mining cavities as water reservoirs is restricted by the following requirements:

1. No degradation of the water qualities due to former mining activities during storage (e.g. due to convection from deeper flooded mine areas)
2. Sufficient knowledge about the whole underground system consisting of mine buildings, drifts, and drainage adits to make statements about system interrelationships and stability
3. Economically viable implementation

At present, only isolated data by (Bozau et al. 2017) on water quality exist for the system of water drainage adits in the Upper Harz Mountains due to the difficult accessibility and the complex sampling conditions. Information on the geometry of the adits, drifts, and mine buildings is available in the form of partially digitized vertical sections, but the current condition of the cavities is not sufficiently known to make statements about the actual storage volume, the hydraulic connection of the adits and mine buildings to each other or to investigate the effects of hydraulic engineering measures on the overall system and its stability. These challenges must be met with the help of the latest sensor technology, which is adapted to the difficult environmental conditions underground. To meet these challenges, the two largest drainage adits of the Upper Harz ("Ernst-August- und Tiefer-Georg-Stollen") as well as the above-ground catchment area of the "Dammgraben", which receives its water from the area of six Harz rivers, are to be investigated and several sub-projects are currently being proposed. One project seeks to determine the condition of the underground flooded mine workings using a diving robot. In another project, a long-term monitoring network with the help of AI-based "virtual" sensors of the longest and youngest water drainage adit in the Harz Region is to be developed. In addition to the difficult accessibility of the underground systems, a particular challenge in WSH 2050 is the fusion of heterogeneous data sources and their sustainable management and the fact that not all subject areas are at the same level of digitization.

Conclusions and Outlook

Due to its geographical location, the Harz region is of particular water management relevance for Lower Saxony. To design efficient water management for the region, all hydrographic parameters must be considered together. At present, no technology enables a holistic approach. In the first phase of the project, the following challenges arose:

1. Development of a uniform data management for a multitude of heterogeneous data
2. Restricted digital availability of data
3. Insufficient data density for water quality resulting in a long-term need for a measurement data network
4. Form and actuality of geometric data of underground systems

To meet these challenges, different state-of-the-art technologies and sensor techniques need to be combined into one model. Currently, various works are taking place at the Institute of Mining to create a digital model of the underground system and support it with different technologies. The wholistic model can support actions against different regional, national, and global challenges and the methodology of its development is transferable to other regions.

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References

Alicke R (1974): Die hydrochemischen Verhältnisse im Westharz in ihrer Beziehung zur Geologie und Petrographie. Clausthaler Geol. Abh. 20: 1-233

Bozau E.; Licha T.; Ließmann W (2017): Hydrogeochemical characteristics of mine water in the Harz Mountains, Germany. In *Geochemistry* 77: 614–624

Harzwasserwerke GmbH (2022). Available online at https://www.harzwasserwerke.de/ueber-uns/portrait/.

Liessmann W (2010): Historischer Bergbau im Harz. Kurzführer. 3., korr. und erg. Aufl., Springer Berlin Heidelberg, ISBN 978-3-540-31328-1

Müller R; Franzke HJ (2014): Oberharz. Tiefe Gruben und hohe Rücken. Streifzüge durch die Erdgeschichte Ed. Goldschneck im Quelle-&-Meyer-Verl, Wiebelsheim, ISBN 978-3-494-01531-6

Niedersächsischer Landesbetrieb für Wasserwirtschaft Küsten- und Naturschutz (Ed.) (2019): Grundwasserbericht Nidersachsen. Sammlung-Parameterblätter-Datenbestand 2018. With assistance of Annette Kayser. 1.th ed. Available online at www.nlwkn.niedersachsen.de.

Nistahl P; Müller T; Lange A; Meon G (2021): Modellierung von vernetzten Speichern unter Mehrfachnutzung und Klimaänderung im westlichen Harz. In *KW Korrespondenz Wasserwirtschaft* 14 (11): 711–718.

Tonn R (2002): Ein Gebirge als Wasserspeicher. In *Natur und Landschaft zwischen Küste und Harz-Begleitheft zur Projektwoche von Preisträgern in den Landeswettbewerben von Jugend forscht 2002* (20): 110–119.

Viviroli D; Weingartner R (2007): Wasserschloss in einer durstigen Welt: Bedeutung der Gebirge für den Wasserhaushalt. In *Die Alpen*: 34–37.