



THE INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS



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HYDROGEOLOGY: BACK TO THE FUTURE!

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ABSTRACT BOOK

T1 - GROUNDWATER, FOOD AND HEALTH

148 - HYDROGEOLOGICAL CRITERIA FOR SANITATION SITING – A CHECKLIST FOR NON-HYDROGEOLOGISTS

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In a poll of health professionals in the British Medical Journal, sanitation was voted as the most important medical advance since 1840. "Improved sanitation" is a term used in the monitoring of the Millennium Development Goals (and probably will be applied to the Sustainable Development Goals as well). Whilst the criteria of what improved sanitation entails are debatable, it is quite clear from the hydrogeologist's perspective: the sanitation system should not contaminate the local groundwater resources it comes into contact with. Once pathogens have infiltrated into groundwater, e.g. through open defecation or leaking sewerage systems, it takes varying amounts of time for the different types of pathogens to die off, during which they are transported in the groundwater system, perhaps to a drinking water source.

The working group on sustainable sanitation and groundwater protection of the Sustainable Sanitation Alliance has come up with a checklist for the siting of onsite sanitation systems. This document provides a set of criteria for planning small scale sanitation systems in areas that allow for concepts like separation distances to be realized. The criteria included in the checklist are horizontal and vertical distance between the drinking water source and the sanitation system, aquifer type, groundwater flow direction, impermeable layers, slope and surface drainage, volume of leaking wastewater, and superposition.

The siting criteria are simple enough to be applied in a semi-automated analysis to a larger number of sanitation systems with the help of a geographic information system (GIS). Users of the checklist are nevertheless encouraged to seek guidance from local hydrogeologists in establishing the values for the criteria. If larger groundwater-based supply structures are concerned, it might be appropriate to establish groundwater protection zones around the major well fields with appropriate land-use planning.

The poster will also summarize initial feedback from users of the checklist which will be distributed firstly via the Susana online Forum, used by up to 30,000 practitioners from 152 countries.

832 - INCLUDING GROUNDWATER RESOURCES PROTECTION INTO THE IWRM PRINCIPLES IN BASIN MANAGEMENT IN THE CUVELAI- ETOSHA BASIN (CEB), NAMIBIA

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As in many arid and semi- arid areas, groundwater plays a major role for the water supply in the endhoreic Cuvelai- Etosha Basin (CEB) shared by Namibia and Angola. As a reaction to changing conditions in terms of rapidly growing demand and measurable increases of climatic extremes, the Namibian Government seeks to better protect the known groundwater resources while in the same time tries to identify further, less vulnerable aquifers to grant long term supply with safe water.

Through an ongoing cooperation project with the German Federal Institute for Geoscience and Natural Resources, the Namibian Division of Geohydrology could widely describe the complex system of groundwater resources in the CEB and their interaction with surface water. While the increased appearance of the so called "Efundja", a flood coming from Angola into the Namibian part of the CEB both in terms of frequency and intensity are vital to recharge the shallow aquifers, more and more incidences of especially faecal contamination of the hand dug wells have been reported as a result of the flooding in combination with inadequate sanitation installation. The deeper water layers are less prone to contamination and have a high potential to buffer years of drought. They are however far more difficult to access and technical procedures for borehole design must be developed and adhered to. To determine the needs and means to protect the various water bodies a vulnerability mapping and risk assessment has been carried out. Applying a version of the PI- method adapted to the local conditions and a survey of potentially hazardous sites, an overview of critical areas is available for water practitioners and land-use planners. A specifically developed guideline for the delineation of groundwater protection zones along with an improved monitoring network allows setting the right measures for safekeeping the water resources. But how can government officials control the compliance of the guidelines in a vast country with the world's second lowest population density? The answer lies in the spirit of Integrated Water Resources Management (IWRM). Water users, organized in Basin Management Committees, are actively involved in the development process of the guidelines and the monitoring networks. Thus they become aware that for securing future development, people must be guardians of their own water resources. The Namibian approach can hence serve as a good example for stakeholder participation while setting the technical and scientific frame for applied IWRM.

T2 - GROUNDWATER FLOW SYSTEMS BEHAVIOUR

165 - TRACES OF THE DIFFERENT LEVELS OF PALAEO LAKE CHAD ON GROUNDWATER RESOURCES

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Hydrogeological field campaigns were carried out between 2009 and 2013 in the Kanem and Bahr el Ghazal regions, north of Lake Chad to gain information on groundwater quality and flow paths in the Quaternary aquifer. Water levels were recorded and samples for chemical analyses and environmental isotopes were collected.

The groundwater contour map shows a mound in the Kanem region that leads to groundwater flow in south and south-east direction. A second mound appears to the southeast of the lake in the Bahr el Ghazal sill. It impedes the water from the Lake Chad to flow into the Bahr el Ghazal, if the lake's level is lower than 286 m asl.

Chemical analyses prove that groundwater in the Kanem region is of good drinking quality. Groundwater in the Bahr el Ghazal region shows sodium, chloride, sulphate, fluoride, and arsenic at very high concentrations. The first four ions can be explained either by evaporation processes, ion exchange, or the mineral composition of the underground. The elevated concentration of sulphate needs an additional source besides gypsum. This could be the palaeo Lake Chad in the Holocene. Similar to the actual Lake Chad, this palaeo lake was very shallow and mainly covered by massive aquatic flora. Its drying out led to extinction of the plants that were covered by fine material (clayey sands to clay) transported by the Bahr el Ghazal in posterior flowing events. A rather anaerobic milieu developed and the genesis of sulphide was enabled, which remained in the underground. Its subsequent oxidation in groundwater induces the presence of sulphate.

The environmental isotopes confirm this theory. While the ^{18}O and ^2H excess along the shore of the actual Lake Chad is explained by recharge with evaporated water from the lake, this cannot be the reason for excess in the Bahr el Ghazal region. This area has not been occupied by lake water since the Holocene, when the lake level reached 290 m NN, and groundwater is of fossil origin.

770 - IDENTIFICATION OF POTENTIAL RECHARGE AREAS USING A MULTI-METHOD APPROACH. THE MULTI-LAYERED OHANGWENA AQUIFER SYSTEM, CUVELAI-ETOSHA BASIN, NAMIBIA-ANGOLA

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The newly discovered transboundary Ohangwena-Groundwater System (OGS) and its freshwater resources are of very high importance for the strategic planning of future water supply in the North of Namibia. Demographic growth leads to an increasing pressure on existing water resources. Therefore the understanding of water availability and quality are key aspects for further investigations. A recently established observation well network provides hydraulic and hydrochemical information for the three main aquifers of the OGS. Key issue in the whole investigation process is the undeveloped northern part of the OGS, which is on Angolan territory, without the existence of climate stations, stream gauges or borehole information.

The identification of recharge areas and recharge values are key factors in groundwater management. Reliable figures for recharge are an essential requirement for the estimation of sustainable available groundwater resources.

Several methods were applied to identify groundwater flow patterns and recharge areas. Water level monitoring information in combination with climate data provides the first information on regional groundwater flow and distinguish recharge mechanisms and potential recharge areas for the three aquifers. Groundwater age distribution support flow regime explanation and the determination of the origin of water resources. General groundwater chemistry is displaying the main active processes in the aquifers but not necessarily indicating origin of the water resources. In this case the general hydro-chemistry information supports the delineation of the alluvial Cubango Megafan.

Specific patterns in Rare Earth Element concentrations and stabile isotope results seem to be very useful to identify potential recharge areas.

The results reveal that recharge occurs locally only in the uppermost aquifer of the OGS (KOH 0). The deeper aquifer (KOH 1 and KOH 2) are fed by waters from the northern parts of the eastern sand zone of the Cuvelai-Etosha basin.

T3 - SUSTAINABLE USE OF GROUNDWATER

164 - ESTIMATION OF GROUNDWATER POTENTIAL OF A LOCAL AQUIFER IN BURUNDI

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The city of Gitega is located in the central part of Burundi some 100 km to the east of Bujumbura, the capital city. The area is characterised by Precambrian hills composed of alternating schist, quartzite, and phyllite, which is common in the entire country. Typical for this environment are the numerous springs that are traditionally used for rural water supply.

Local porous aquifers composed of sandstone and clay layers appear along the valleys, as a product of rock-weathering. Although the groundwater potential of these aquifers is unknown, some of them have been tapped to comply with increasing water demand. Various wellfields seemed to show effects of over-pumping, although no systematic measurements were available to confirm this hypothesis.

To overcome the situation, a study was performed regarding the most important wellfield of Gitega water supply composed of six continuously pumped wells. Remote sensing and geophysics were applied to site three new piezometers. Drilling followed by borehole logging and pumping tests led to a better understanding of the geology. Chemical and isotope analyses indicated good water quality and recent recharge.

Automatic water level measurements in the three new piezometers since February 2014 confirmed over-pumping. The curves show a continuous decrease of water levels over 8 months at a rate of 1 to 2 m/month, despite the fact that one well was out of production since June. In November 2014 another well was shut down, due to problems with the pump. Water levels recovered promptly to reach within 2 months the values of February. It was concluded that the sustainable extraction of the wellfield would be that of the four wells still pumping.

Based on water balance, recharge was calculated at 264 mm/yr, or 23% of the mean annual precipitation of 1150 mm. With this recharge and considering the sustainable pumping rate, a catchment area for the wellfield was estimated.

Now the wellfield can be pumped in a sustainable manner and groundwater protection measures can be established.

T4 - URBAN AND CONTAMINANT HYDROGEOLOGY

149 - GROUNDWATER QUALITY ASSESSMENT IN THE LUSAKA URBAN KARST AQUIFER

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Lusaka, the capital of Zambia, is situated in a tropical continental highland climate on a karst aquifer. Half of the city's drinking water supply stems from this highly vulnerable groundwater source. The slightly more than 2 million inhabitants (2010 population census) use approximately 50 million cubic meter of groundwater from public supply wells. As sanitation coverage only reaches 65% of dwellers and consists mainly of unlined pit latrines sitting directly on top of or within the carbonate rocks, the main water quality issues Lusaka faces are microbiological and nutrient pollution.

In two water quality assessment campaigns carried out in the framework of a bilateral Technical Cooperation project in 2008 and 2010 a total of 107 boreholes and 32 springs were sampled. Both studies show that microbiological contamination is widespread in the city area. Only one third of samples stay below the Total Coliform limit given in the Zambian Drinking Water Standard. From the chemical analyses it can be concluded that natural (unpolluted) groundwater from the karst aquifer should have an electrical conductivity (EC) of less than 800 $\mu\text{S}/\text{cm}$ and concentrations in sodium, chloride, nitrate and sulphate below 10 mg/L. Anthropogenic pollution showed in higher levels of EC (up to 1450 $\mu\text{S}/\text{cm}$) and nitrate concentrations (up to 260 mg/l NO_3). Concentrations of heavy metals and iron are low throughout the study area. Under the prevailing pH (median = 7.0) in the calcareous environment concentrations of Pb, Cd and As are far below toxic levels in all samples analysed. Lack of certified laboratories in Zambia renders it necessary for scientific studies to send samples abroad for analysis (Germany in this case). Storage time of up to 20 days and transport still allowed for Chlorinated Volatile Organic Carbons (CVOCs) to be analyzed and corrected by a recovery function. Analysis gave positive results for 10 out of 81 samples. Elevated Mangan-concentrations above 0.1 mg/L could be a result of anoxic oxidation of fuel and point to the possibility that BTEX (Benzene, toluene, ethylbenzene, xylene) might be found near the groundwater surface in the vicinity of filling stations and fuel depots.

171 - CHEMICAL FE-CLOGGING IN WELLS FOR OPEN-PIT DEWATERING: EXPERIMENTAL MODELLING AND PREVENTION MEASURES

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Chemical Fe-clogging is a major factor affecting the hydraulic and therefore energetic and economic performance of vertical filter wells in drinking water supply and aquifer dewatering for mining or construction purposes alike. It is, therefore, worthwhile to identify hydrochemical and hydraulic parameters relevant to the progression of Fe-clogging and resulting change in hydraulic conductivity as well as the influence of different filter pack materials, conditions of well operation and flow of air and water. In this study, the process of Fe-precipitation was therefore reconstructed in an unscaled experimental model of a 200x200 mm section of a dewatering well filter in an accelerated manner.

Parameters controlling location, progression, type and intensity of Fe-incrustation buildup as well as its influence on the hydraulic conductivity of the gravel pack were found in pH, temperature, bicarbonate-concentration, and the aeration situation. A kinetic Fe-oxidation model with PhreeqC fit reasonably well to the experimental results and allowed for sensitivity analyses of the concentrations of Fe(II) and dissolved oxygen, temperature, and the dominating anion in solution.

With respect to macroscopic and microscopic distribution, mineralogy, specific surface area and organic carbon content, the Fe-precipitates produced in the model showed certain differences but also distinct similarities in comparison to field samples that had been taken at excavated wells in the open-pit Garzweiler (Rhenish lignite district, Germany, RWE Power AG).

Four different filter pack materials (including natural Tertiary and Quaternary gravel and artificial glass beads) were tested in the model, none of which showed any relevant disadvantages or benefits with respect to Fe-clogging affinity.

Based on tracer experiments at test wells in the field and experiments in the model, a new scheme for design and operation of dewatering wells was found to work properly, and to successfully prevent chemical Fe-clogging.

As main conclusions from the experiments, it can be said that the choice of filter pack material does not play a major role, but that screen pipe aeration has to be strictly avoided from the beginning of well operation to prevent chemical Fe-clogging.

T5 - GROUND / SURFACE WATER: AN INTEGRATED VIEW

163 - SURFACE WATER - GROUNDWATER INTERACTION – THE CASE OF THE LOWER LOGONE WETLAND IN THE LAKE CHAD BASIN

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Hydrogeological studies in the Lake Chad basin have shown that wetlands are of great importance for the recharge of the Quaternary aquifer in the area. Due to climate change and mismanagement of water resources, nowadays only the Lower Logone wetland at the border between Chad and Cameroon is active. It is annually inundated by outflow from the Logone River. The amount of water it receives depends on the discharge from the river and thus, from the precipitation at the Mandara Mountains in Cameroon.

In March to May 2013 and April to June 2014, studies have been performed to understand the inundation mechanisms, demonstrate the relationship between surface water and groundwater, and evaluate the amount of groundwater recharge in the area.

Discharge was measured in the Logone and its tributaries. Groundwater levels were recorded and samples for quality and isotope evaluations were collected.

Discharge measurements show that flooding of the Chadian part of the wetland takes place when the discharge at Bongor surpasses 1100 m³/s and towards the Cameroonian part when discharge at Katoa rises above 360 m³/s.

The size of the wetland was mapped for the period 2001-2014 using remote sensing. It varies significantly, depending on the precipitation in the Mandara Mountains. The minimal flooded area for the considered period reaches 2,720 km².

The groundwater contour map show flow to the north along the Logone River and to the north-east along the wetland.

Chemical analyses indicate groundwater of good drinking quality.

The isotopic analyses demonstrate two different recharge sources. Boreholes near the Logone River receive recharge from river water while those situated in the wetland are recharged by surface water that has been exposed to evaporation.

Calculations prove a mean annual recharge of 10 mm from the wetland. Taking in consideration the minimal surface of the wetland, at least 27 million m³ are recharged annually in the area.

T8 - NEW TOOLS AND NEW FRONTIERS

630 - GROUNDWATER RECHARGE, ROOTING DEPTH AND UPWARD WATER VAPOR TRANSPORT: INVESTIGATIONS IN THE UNSATURATED ZONE USING ARTIFICIAL DEUTERIUM (²H) IN SEMI-ARID ENVIRONMENTS

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The stable isotopes of water, in particular deuterium (²H) have been proven to be suitable tracers within soil-vegetation-atmosphere interface (Koeniger et al., 2010 ; Beyer et al., 2015). However, little experimental evidence exists on the persistence of artificially introduced ²H₂O (deuterated water) in the unsaturated zone of dry climates, and the necessary input concentrations and methods of application are poorly understood (Becker and Coplen, 2001).

We present different field applications of labeling studies using ²H that were carried out in the framework of the project SASSCAL (Southern African Science Service Centre for Climate Change and Adaptive Land Management) in the semi-arid Cuvelai-Etoshia Basin, Namibia. The aims of our investigations are threefold : i) The quantification of groundwater recharge through the unsaturated zone ; ii) the determination of maximum rooting depths and iii) the investigation of upward water transport.

Our results suggest that even under extreme climatic conditions deuterium is a suitable tracer for process studies within the unsaturated zone. Results of the field experiments contribute to extend the portfolio of methods for estimating groundwater recharge in data scarce environments and support the parameterization of SVAT models. A major advantage using artificial ²H is the ability to obtain quantitative, not purely qualitative results. Since a relatively low amount of tracer is required which makes labeling experiments economically feasible. In combination with recently developed insitu measurement techniques of stable isotopes, potential for further process based research is promising.

Koeniger, P., Leibundgut, C., Link, T., & Marshall, J. D. (2010). Stable isotopes applied as water tracers in column and field studies. *Organic Geochemistry*, 41(1), 31-40. doi:10.1016/j.orggeochem.2009.07.006

Becker, M.W., Coplen, T.B. (2001). Use of deuterated water as a conservative artificial groundwater tracer. *Hydrogeology Journal*, 9(5), 512-516.

Beyer, M., Gaj, M., Hamutoko, J., Koeniger, P., Wanke, H., & Himmelsbach, T. (2015). Deuterium labeling for the estimation of annual groundwater recharge in semi-arid regions. *Isotopes in Environmental and Health Studies* (submitted)

636 - MODELING UNSATURATED ZONE STABLE ISOTOPE DEPTH PROFILES IN AN EVAPORATION DOMINATED ENVIRONMENT

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Common modeling approaches of water fluxes in the unsaturated zone use computer models solving the Richards-Equation. Hydraulic parameters are derived from infiltration tests, grain size analysis, bulk density and pedotransfer functions (PTF). Calibration is further done using soil moisture and suction tension measurements. Recent developments in modeling techniques allow an additional incorporation of stable isotope depth profiles.

A field experiment was conducted in a semi-arid area in the Cuvelai-Etoshia-Basin, Namibia within the SASSCAL project (Southern African Science Service Centre for Climate Change and Adaptive Land Management). A bare plot of 1 m² was irrigated with 60 mm water of known isotopic composition and the dry-out was monitored. Soil moisture, suction tension and soil temperature were measured during the entire experiment. In addition a climate station was established and evaporation was measured using a CGI-pan.

For the estimation of parameter uncertainty 5000 Monte-Carlo-Simulations were performed. As a measure of model performance the Nash-Sutcliffe-Efficiency (NSE), the volumetric efficiency (VE) and the R²-values were compared. A reduction of parameter uncertainty by incorporating isotope depth profiles in the calibration process can be shown.

799 - CAVE-DRIP WATER STUDIES ON STABLE ISOTOPE COMPOSITION TO IMPROVE CATCHMENT ELEVATION ESTIMATIONS IN THE JEITA SPRING CATCHMENT, LEBANON

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The Jeita spring catchment in Beirut, Lebanon was investigated in detail recently within a technical cooperation project of the Council for Development and Reconstruction (CDR), Lebanon and the Federal Institute for Geosciences and Natural Resources (BGR), Germany. In addition to multiple artificial tracer experiments with fluorescein, which were mainly conducted to investigate catchment extension and boundaries as well as underground flow connections (Margane et al., 2014) rain, snow and spring water stable isotope composition was studied for the characterization of spring catchment elevations. An additional sampling of cave-drip water over one melting season was conducted (March 2014 to September 2013) at six collectors in the upper part and three collectors in the lower part of Jeita cave.

The isotope values of Jeita spring samples show a seasonal variation and clear influence of snow melt with mean values at -7.19 ‰ and -35.7 ‰ for d18O and d2H (n = 483), respectively. In contrast all nine drip samplers show relatively enriched values (between -6.48 ‰ and -3.79 ‰ for d18O and -30.6 ‰ and -13.0 ‰ for d2H (n = 128) in comparison to the Jeita spring water. All samples (springs and cave) plot close to the local meteoric water line established for the Jeita spring catchment (Jeita-LMWL $y = 6.04x + 8.45$; $R^2 = 0.92$). This indicates that the collected cave-drip water clearly reflects shorter pathways and potentially source areas that are different from the majority of the spring water. Such findings might foster more detailed drip-water source studies in caves and are potentially interesting for studies of cave development and speleothem dating techniques.

381 - A COMBINED HYDROGEOLOGICAL, HYDROCHEMICAL, AND GEOPHYSICAL INVESTIGATION AT RUMONGE, BURUNDI, TARGETING GROUNDWATER WITH LOW IRON CONTENT

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Rumonge is located on the eastern edge of the sedimentary basin of Lake Tanganyika at the foot of the mountains that constitute the Kongo-Nile water divide which lies to the east. The water supply of the town is based partly on several springs prone to contamination and on wells showing elevated concentrations of iron. As part of the bilateral Project "Management and Protection of Groundwater Resources" between the Burundian Ministère de l'Eau, l'Environnement, l'Aménagement du Territoire et de Urbanisme (MEEATU) and the German Federal Institute for Geosciences and Natural Resources (BGR), a combination of hydrochemical, hydrogeological, and geophysical methods was applied in order to understand if groundwater in other parts of the area could provide water with a lower iron content.

Transient electromagnetic soundings were applied along two profiles and the existing observation wells were geophysically logged using natural gamma and flow meter logs. The results showed that the groundwater is drawn either from basin sediments overlying granitic bedrock or from the fractured weathered bedrock at the edges of the basin. The TEM profile showed a deepening of the sedimentary basin toward the lake. The groundwater chemistry revealed a general low mineralization in the whole basin. The iron concentration however, is high within the basin and low close to the mountains. The interpretation of the water levels is consistent with the idea of a sedimentary aquifer system composed of probably interconnected layers of sand and clay extending from the mountains toward the lake with groundwater flowing toward the lake. The presence of dissolved iron in groundwater within the basin is explained by iron-containing material in the underground and the prevailing anaerobic conditions. The reason why the iron concentration decreases towards the edges of the basin is not clear yet and hypotheses are discussed.

142 - A NEW GIS LAYER OF THE UPPERMOST EUROPEAN AQUIFER SYSTEMS BASED ON THE "INTERNATIONAL HYDROGEOLOGICAL MAP OF EUROPE 1 : 1,500,000"

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The International Hydrogeological Map of Europe in a scale of 1:1,500,000 (IHME1500) is a map series composed of 25 map sheets, finalized in August 2013. The main feature of that overview map of groundwater resources across Europe provides a seamless spatial distribution of the uppermost aquifer systems. The aquifers are classified into six types distinguishing between porous and fissured rock types as well as between four grades of groundwater productivity including non-aquifers. Moreover the groundwater resources are characterized by lithological descriptions and stratigraphic assignments. This main topic was digitized in a Geoinformation System (GIS) containing the attributes aquifer type, lithology and areas with groundwater affected by saltwater intrusion.

The content was revised and harmonized. Implementing a spatial modulation the spatial information was adapted to the uniform drainage system and coast line of the Vector Map level 0 (vmap). Abundant mismatches of characteristics and offsets of profile outlines across map sheet borders were corrected and missing information added. The result is an advancement of the former printed edition of the IHME1500.

With respect to the hydrogeological content 1065 heterogeneous lithological descriptions were aggregated introducing a new methodology. The resulting five aggregation levels with a declining class number from 204 to a ternary distinction of consolidated, unconsolidated and mixed materials are included in the database. This coherent hydrogeological map in a digital manner allows processing by GIS or groundwater models as well as assessments beyond hydrogeological issues in a European scale.

The vector data will be publicly available from April 2015 on BGR Homepage. Beside the above mentioned IHME data the download will comprise an additional data set of tectonic fractures, metadata and technical notes.