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Sustainable Groundwater Management and Climate Change

The supply of the world population with clean drinking water is one of the overriding goals in the community of states. The United Nations declared 2003 the International Year of Freshwater as a means of consolidating efforts towards the sustainable management of freshwater resources.

Introduction

An explicit target of the UN Millennium Development Goals is to "halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation". It is more doubtful than ever that this objective will be reached. Groundwater plays a very special role in the provision of the population with water: On the one hand, with regard to the freshwater supply, groundwater reserves can compensate for several years of drought. On the other hand, in arid and semi-arid countries with low groundwater recharge, the groundwater formed in former, even long-past geological eras is being used increasingly for agricultural irrigation and the provision of drinking water. In these cases the utilization no longer corresponds to the current recharge. The interventions in the hydrological cycle are so massive that they are leading to a distinct lowering of the groundwater level, bringing about saltwater intrusion, settlement cracks in buildings and the drying out of entire landscapes.

Germany is a country with an abundance of water. Nevertheless, even here there are distinct conflicts over the utilization of the groundwater, which make themselves felt on the one hand in the flooding of agricultural land as well as cellars in housing development areas, while on the other hand causing drought damage to forests and the drying out of wetlands. Competing forms of utilization being carried out in close proximity to one another often make it nearly impossible to find a balance of interests.

A decrease in the demands made on drinking water brought about by water-saving devices, the decline in the amount of water used by industry in its efforts to save on energy costs and sewer charges, and the development of industry away from processing and toward service, have led to a very low per-capita drinking water demand in Germany. The conflicts over damages caused by the rise in groundwater levels have shown that further water-saving measures are by no means necessarily sustainable, particularly when they go hand in hand with an increased demand for energy or the consumption of non-renewable resources. And what is perhaps most important is the fact that "water-saving" in Germany does not solve the water problem in countries characterized by water poverty on account of basic climatic conditions. In order for Germany to contribute to sustainable freshwater management in these countries, it would undoubtedly be more effective to think about our import of "virtual water" in agricultural products from arid countries. Above all the production of meat in arid countries is linked with very high demands on the water resources. When we eat this meat, we consume the "virtual water" which is then lacking for the provision of the population with drinking water in the countries in question, or is available only to those who can pay for it.

The long tradition of water management in Germany and the development of an environment characterized by intensive agricultural use as well as a dense population have led to the development of high standards in water management planning. At the basis of this achievement is intensive hydrological monitoring, which makes information on the available water supply over several decades useable nearly everywhere in Germany. In isolated cases, groundwater hydrographs were already being drawn up as early as the end of the nineteenth century. While initially there were only very few observation wells, the measuring network became denser as the utilization of groundwater increased. In the groundwater catchment area "Hessian Ried", measuring more than one thousand square kilometres and highly significant for the supply of the Rhine-Main conurbation (with Frankfurt am Main as its centre), more than two thousand observation wells are currently monitored on a regular basis. Rights for the withdrawal of groundwater are meanwhile linked with the maintenance of minimum groundwater levels specified by the authorities. Artificial groundwater recharge is carried out in relation to the weather. Infiltration control requires the prompt evaluation of all monitoring data, and an Internet-based database system has been set up to guarantee the rapid availability and exchange of data. The public is moreover kept constantly informed at www.grundwasser-online.de. As a compromise between the competing interests of forestry, nature conservation, agriculture and the protection of developed areas, the 1999 groundwater management plan ruled that the groundwater table is to be maintained at a medium level. The groundwater fluctuation is held in check by prescribing a minimum groundwater table to avoid ecological damage and the formation of settlement cracks.

The high demands placed on groundwater management have led to the further development of the technical and scientific means for making accurate forecasts about groundwater levels and successfully steering the management to the degree necessary. The means thus created are presently being used to investigate what adaptation strategies are necessary in order to take climate change appropriately into account in sustainable groundwater management.

Groundwater Recharge Due to Climate Change

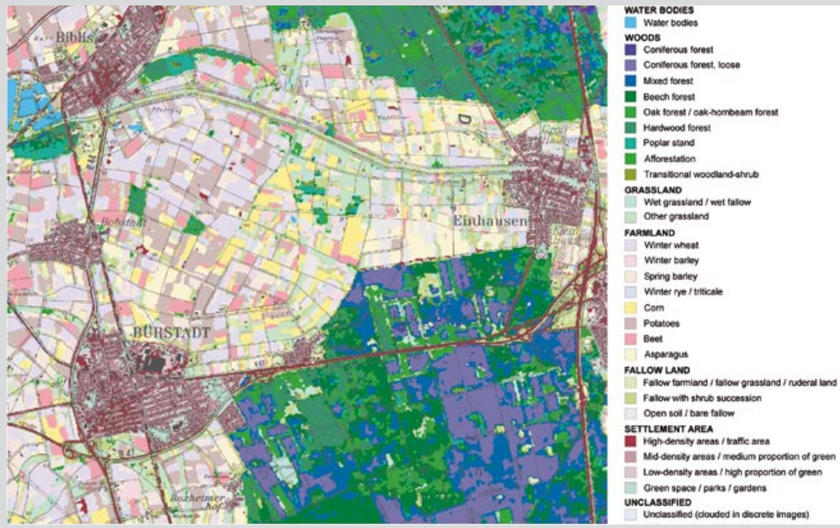
This investigation of groundwater recharge in the large catchment area of the study area "Hessian Ried", south of Frankfurt, is the prerequisite for quantifying the extent to which the climate change has affected the available groundwater supply and the development of the groundwater levels. Due to the above-described major utilization conflicts in this region, state-of-the-art methods of mathematical simulation were applied early on: A three-dimensional groundwater model and a soil-water model were constructed in order to calculate infiltration plants so as to be able to guarantee the maintenance of minimum groundwater levels over prolonged dry periods of several years. In this context, extensive experience with the continuous long-term simulation of groundwater was gained.

As input data for soil-water models, the land use has to be determined and classified according to its different categories. Due to the great number of satellites with multispectral sensor systems and high spatial resolution in operation today, land use can be identified by means of the detailed analysis of satellite image data. **Fig. 1** shows an excerpt from a multitemporal satellite image data classification. With four Landsat 7 images recorded at different times of the year, it was possible to distinguish the twenty-seven most important categories of land cover.

With the aid of geographical information systems (GIS), the soil classes and weather data have been merged with the various categories of land use on the basis of a daily soil-moisture simulation to calculate the groundwater recharge over the years.

The groundwater recharge thus ascertained on the basis of daily data was then transferred to the finite-elements of the groundwater model. The good calibration results of the groundwater model with regard to the simulation of observation periods amounting to more than thirty years have shown that the methods applied are reliable and the calculation of the diffuse groundwater recharge no longer requires adjustment within the framework of the model's calibration.

Fig. 1 | Land cover, derived by multitemporal satellite image data classification.

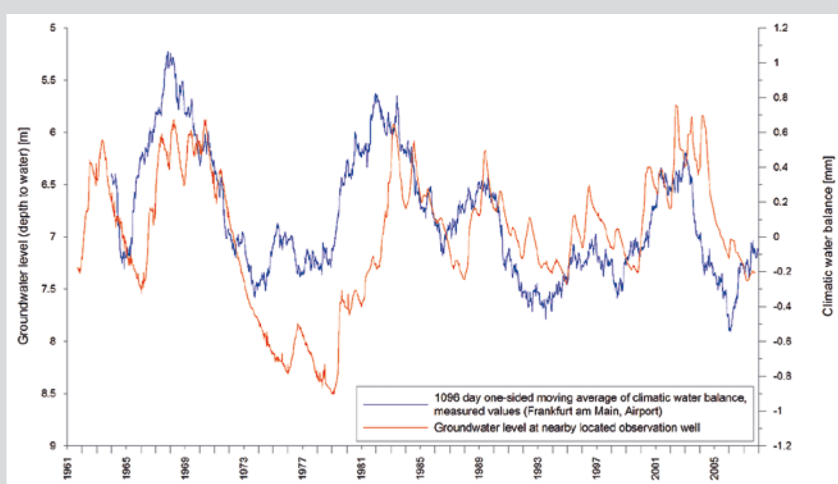


These various methods of investigation are presently being used in a research project funded by the German Federal Ministry of Education and Research. BGS Umwelt coordinates the project; project partners are HESSENWASSER GmbH & Co. KG, one of the biggest water suppliers in Germany, and the Hessisches Landesamt für Umwelt und Geologie.

The aim of this research project is long-term groundwater simulation (from 1960 to 2100) based on the scenarios of greenhouse gas emissions developed by the Intergovernmental Panel on Climate Change (IPCC).

Climate change is not only causing a rise in temperatures but is also leading to a worldwide shift in precipitation. Other factors such as the average wind conditions and the degree of cloud cover will likewise change. The decisive interplay between weather and groundwater is determined not so much by the average climate factors, however, as by the occurrence of extreme values and the variability of climate factors over long periods of time. For example, it takes a succession of

Fig. 2 | Measured fluctuation of the groundwater table compared to 1096 day one-sided moving average of climatic water balance.



several years of above-average groundwater recharge to lead to the high groundwater levels that cause utilization conflicts due to flooding. On the other hand, several dry years in succession bring about the low groundwater levels that result in settlement cracks and ecological damage brought about by dryness. Only the current regionalization of the global climate models and the availability of daily data can create the conditions under which the abovementioned effects of climate change on the groundwater can be quantified.

Fig. 2 shows the measured fluctuation of the groundwater table following a period of cyclic depletion and rise over forty years. Among the climatological data, the hydrograph curve of the measured climatic water balance has been plotted by way of example; in the scale chosen for this purpose, the curve adheres closely to the amplitude and period of the groundwater table. The global climate model regionalizations for Germany which are available to date not only the development of the weather in future, but also provide simulated weather for the years 1960 to 2000 in their control runs, allowing the comparison of various climatological data with measured levels for this time period. The results of several regionalizations have proven to be of only limited value with regard to groundwater, since they do not accurately reflect the variability during a cycle of ten years (for example) in its full amplitude. The range of soil moisture shown in its temporal development is accordingly only of limited significance. The climatic water balance depicted is a good yardstick of climatological data with regard to its relevance for groundwater.

Prospects

The impact of the climate change on sustainable groundwater management in Germany and the adaptation strategies yet to be developed require a quantification of the local changes to be expected, since the utilization conflicts are generally of a local nature. It is essential that the basis data take the unsaturated zone and groundwater recharge into account.

The methods of hydrodynamic soil-water modelling (based on daily data) and of groundwater modelling as a long-term simulation show clear trends in the development of the groundwater in dependency on climate change. Particularly, periods of low soil moisture with high demands on agricultural irrigation will increase substantially. For the first time in the study area “Hessian Ried”, a numerical simulation until 2100 is to be carried out, applying IPCC scenarios to the groundwater and reflecting utilization conflicts on the local level. Active, weather-oriented management by means of infiltration and extraction can optimize the exploitation of groundwater storage and serve as an example for regions much more strongly affected by climate change than Germany.

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