A global perspective on assessing groundwater quality

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Abstract
An assessment of global groundwater quality is needed in response to the threats posed by anthropogenic and geogenic contaminants. This essay summarises the challenges involved, including a large number of potentially relevant water quality parameters, the poor availability of data in many regions and the complex nature of groundwater systems. Direct monitoring data can sometimes be augmented by indirect methods such as earth observations, and by involving citizen science. A new web portal is being developed to complement existing databases.

Keywords Global groundwater quality · Groundwater monitoring · Hydrochemistry · Web portal

Introduction

Mandated through the United Nations Environment Assembly (UNEA), an assessment of global water quality is currently being undertaken by the World Water Quality Alliance (WWQA; UNEP 2021). The WWQA is being coordinated by the UN Environment Programme (UNEP) and includes other UN-Water agencies together with many scientific, private sector and nonstate organisations.

Providing about half of the world's drinking water and more than 40% of agricultural water, groundwater is a key freshwater resource for meeting the Sustainable Development Goals (IAH 2017), but has received less attention in previous global water quality assessments than rivers and lakes (UNEP 2016; UN-Water 2016; Damania et al. 2019). To raise the profile of groundwater in the current assessment, an informal group known as the Friends of

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Groundwater (FoG) was established within the WWQA. One of the priority actions of the FoG group was to prepare a perspectives paper on the challenges, methods and data sources for the global groundwater assessment (WWQA 2021). A summary of this perspectives paper is presented here.

Threats to groundwater quality

A range of anthropogenic activities and processes (e.g., agriculture, urbanization, industry, population growth, climate change) pose direct and indirect threats to groundwater quality. Agricultural activities employing the use of fertilisers, plant and animal protection products (e.g., herbicides, fungicides and other pesticides) are of principal concern and have been widely documented globally (Ascott et al. 2017). Another important source of anthropogenic contaminants is industrial activity, including manufacturing, processing and treatment (Lapworth et al. 2012). Domestic wastewater systems are a major source of numerous organic contaminants, as well as bacteria, viruses and macronutrients (Lapworth et al. 2017). This is a particular threat to groundwater quality where wastewater systems such as pit latrines and septic tanks are used near supply wells that access shallow groundwater (Graham and Polizzotto 2013).

Poor siting, operation and maintenance of groundwater supply infrastructure cause significant threats to groundwater quality and in severe cases render groundwater supplies unfit for consumption (Misstear et al. 2017). Pumping-induced salinity is a major threat to groundwater, particularly in coastal areas and more arid terrains, or in regions where groundwater levels are particularly shallow (e.g., due to wetlands, discharge zones) as well as areas of irrigation (Foster et al. 2018).

There are numerous direct and indirect threats to groundwater quality from climate change impacts (Barbieri et al. 2021). These include sea-level rise and more intense storm surges that affect coastal aquifers, as well as more intense precipitation and flooding which can lead to greater ingress of surface contaminants and damage to groundwater infrastructure. Land use changes linked to changing climate pose a potential threat to groundwater quality as do changes in global temperatures, e.g., changing survival times for groundwater microbes and physical and biochemical reactions linked to carbon breakdown (McDonough et al. 2020).

Groundwater quality threats also arise from the distribution of naturally occurring (geogenic) contaminants. Under certain redox conditions, ions dissolve from minerals within the aquifer matrix and accumulate in groundwater to levels that can pose a health risk, as well as operational issues for water supply. Physical characteristics of aquifers such as karstic systems, can also render them more vulnerable to surface contamination or migration of contaminants in the subsurface.

Two widely documented geogenic contaminants are arsenic and fluoride, although others include iron, manganese, chromium and radionuclides such as uranium, radium and radon. At high concentrations these can lead to serious health problems such as cancers in the case of arsenic or dental and skeletal problems in the case of fluoride. Elevated iron and manganese concentrations commonly cause aesthetic—metallic taste and staining of cloth—and operational issues such as clogging of boreholes, pumps and water reticulation infrastructure, and can be a critical factor in the success of groundwater supply systems. Naturally occurring high salinity may also compromise groundwater quality and restrict use for drinking water and irrigation.

Challenges and opportunities for a global groundwater-quality assessment

Priority contaminants for monitoring include salinity (usually monitored as electrical conductivity, EC), acidity (pH), major ions, nitrate, microbiological pollutants, some contaminants of emerging concern (CECs) and geogenic contaminants, including those mentioned previously (IAH 2017). However, a key question is: what groundwater quality parameters can be easily upscaled to a global assessment, given that many groundwater quality issues are local and considerable variations in hydrogeology exist across aquifer systems?

Challenges for assessing groundwater quality arise from the four-dimensional nature of flow systems. Groundwater systems are often highly heterogeneous, meaning that samples from wells in close proximity may produce very different results, especially if taken from different depths. Well construction may also affect groundwater quality data—for example, two wells of identical depth may produce contrasting results if one has a grouted upper well casing and the other does not.

Furthermore, long transport times in many groundwater flow systems mean that groundwater pollution and rehabilitation may involve considerably longer timescales relative to surface-water contamination—for example, nitrate stored in the unsaturated zone may cause contamination of underlying aquifers for many decades (Ascott et al. 2017).

Aside from poor sampling or analysis procedures, including a lack of suitable analytical equipment in many regions, unrepresentative groundwater-quality data can result from sampling boreholes originally designed for monitoring water levels and whose location and construction may be unsuitable for monitoring groundwater quality. Boreholes for monitoring groundwater quality must be sited carefully and constructed to allow sample collection at different depths (Misstear et al. 2017). Construction materials and procedures for sampling and handling must be designed to avoid false positives or negatives. This is especially important when the contaminants are redox-sensitive, volatile, or present in trace concentrations such as CECs, which include pharmaceuticals, personal care products, per- and polyfluoroalkyl substances (PFAS), wastewater treatment products, nanoparticles and plastics, and remain largely unmonitored in groundwater (Lapworth et al. 2012).

Groundwater quality data are relatively scarce due to the often-limited public accessibility of data from national groundwater quality monitoring networks, which themselves are lacking in many countries. With exceptions such as the European Union (EU) Water Framework Directive (European Commission 2000), many national agencies are not required to make groundwater quality data available. Even if data are publicly available, questions arise about their reliability, representability and quality, unless an internationally recognized quality assurance process is employed.

For interpretation, the context of monitoring data needs to be considered, including the locations of boreholes or springs, borehole depths, and sampling protocols as well as laboratory analyses. Often this information is not available or is kept at different institutions and not at a central location. Public accessibility of groundwater quality data is further hampered by national restrictions that make data available only for research or multilateral reporting and assessment purposes; however, international norms exist that offer guidance on improving access, for example, the Aarhus Convention (Mason 2010).

There are opportunities to engage new approaches and existing or emerging tools in assessing groundwater quality, including citizen science, earth observation data, geophysical methods and improved sensors. Only the first two will be briefly described here.

Citizen science (CS), an innovative approach to monitoring groundwater quality, is based on direct collaboration between the general public and scientists. The objective is to use smart, yet cost-effective tools to generate water-related data to support existing monitoring systems; however, several attributes of the conceptualization of CS activities can affect its success, and

results need to be validated independently (San Llorente Capdevila et al. 2020). The vast majority of CS applications for gathering groundwater quality data currently takes place in North America and Europe, though a growing number of citizen science groundwater-quality-monitoring programmes are being deployed elsewhere.

Satellite-based earth observations (EO) can produce proxies for groundwater contamination processes. Poulin et al. (2020) showed that EO on population density, road density, precipitation, temperature and landcover in Uganda and Bangladesh were strongly correlated with microbial contamination levels in shallow groundwater. Earth observations can provide variables for use in prediction modelling—for example, EO-derived information on anthropogenic activities such as landcover or population density can be used to predict nitrate, herbicide concentrations and salinity in groundwater (Anning et al. 2012; Stackelberg et al. 2012). Numerous studies have employed EO products with machine learning (ML) to develop models of geogenic groundwater contamination of arsenic (Podgorski et al. 2020) and fluoride; however, these and other ML-based approaches (e.g., deep learning) would require further development before effective use in large-scale prediction of anthropogenic-related contaminants such as salinity, chloride, microbes, other trace elements and trace organic compounds.

Data sources and the groundwater quality portal

Groundwater data exist at different scales (global, regional, national, local), and can also be derived from alternative sources (e.g., EO, modelling). Global sources include assessments, overviews, studies and data portals. Examples are the global prediction maps of arsenic concentration in groundwater exceeding 10 μg/L and the population at risk (Podgorski and Berg 2020), hosted by the Groundwater Assessment Platform (GAP; EAWAG 2021). In the European Union, the metadata repository of the KINDRA project provides a useful resource of groundwater-related scientific and applied information (Petitta et al. 2021).

Sources of open data include the Global Freshwater Quality Database of GEMStat (GEMS/Water 2020) and the SDG 6 Data Portal (UN-Water 2021), which contain groundwater quality monitoring data. Alternative sources of information can also be used to assess groundwater quality—for instance, a land-use database or a database holding commercial registrations of companies may indicate the presence of potential groundwater contamination sources. Combined with insights from the hydrogeological system, potentially impacted zones can be derived.

A global groundwater quality portal (GGWQ; IGRAC 2021) is being developed as part of the WWQA/FoG/IAH activities. The aim of the portal is to be the focal point for

global groundwater quality information and activities, to improve the global knowledge base and to link to other portals and activities relevant to groundwater quality assessment at regional to global scales. Relevant data and information collected and processed will be accessible through the portal in a structured way and updated regularly.

The GGWQ portal includes a reference database and a map viewer. The reference database will collect the most relevant sources of literature and datasets on assessing groundwater quality at global and regional scales. The map viewer is envisaged as a meta-portal or entry point to portals from different organisations, without storing/duplicating data already available elsewhere. The outcomes of FoG activities, via the groundwater quality portal, will feed other relevant portal/databases, especially the UNEP World Environment Situation Room (WESR).

The GGWQ portal will support the development of a global groundwater-quality assessment based on upscaling and regionalisation of local assessments. It will also incorporate the findings of case studies carried out by WWQA partners, e.g., the Cape Town Groundwater case study in South Africa (Riemann 2021). In the long-term, the portal will be a knowledge base for further regional assessments of groundwater quality. It will serve as an information point for scientists, policymakers, the general public and various other stakeholders.

Conclusions

A global groundwater quality assessment is needed because human activities and climate variability are increasing the pressure on groundwater resources. Protecting our groundwater resources is necessary for safeguarding human health, maintaining food supplies and conserving ecosystems. Many regions rely on naturally clean groundwater, as water treatment systems are too costly. Knowing where to source good quality groundwater, as well as understanding threats to this resource, is therefore important.

The FoG group aims to develop further as a focal point for regional/global groundwater quality assessment within WWQA and provide advice, guidance and scientific leadership. The GGWQ portal will assist in this task and be further developed, taking into account feedback from the different stakeholders. Readers wishing to find out more about the FoG group and the WWQA, and who might wish to contribute information to the portal, should contact the corresponding author of this essay.

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