Why are groundwater supplies of major significance for human health and how do quality hazards arise?

The naturally high microbiological and chemical quality of groundwater, captured at springheads and in shallow galleries and dugwells, has been vital for human survival, wellbeing and development from our earliest history – and remains so today. The purity of groundwater, coupled with its mineral content, is such that many springs historically have been attributed medicinal value.

The underlying reasons for the excellent natural microbiological quality of groundwater are the:

- capacity of subsoil profiles to retain and eliminate fecal parasites, bacteria and viruses in percolating recharge
- generally long residence times (decades to millenia) compared to the subsurface survival of pathogenic organisms (usually < 50 days and rarely > 300 days).

There are a few potentially-important exceptions since some geological formations can result in:

- much less capacity for self-purification of pathogens, imparting high levels of aquifer pollution vulnerability
- natural contamination of groundwater with trace elements that create a health hazard (arsenic and fluoride) or nuisance to users (dissolved iron and/or manganese).

This Series is designed both to inform professionals in other sectors of key interactions with groundwater resources and hydrogeological science, and to guide IAH members in their outreach to related sectors.
Other problems can arise through:

- poor design and/or misuse of in-situ sanitation units and drainage soakaways with direct discharge of pollutants to groundwater
- some pollutants being very persistent in most groundwater systems (such as salinity, nitrates and some man-made chemicals)
- contaminant loading beyond natural self-purification capacity (eg. from over-application of animal manures and urban wastewater)
- inappropriate waterwell design allowing cross-connection of shallow contaminated zones with deeper groundwater.

The increasing incidence of chemical groundwater pollution gives rise to long-term health concerns of a chronic type, whereas if microbiological contamination reaches a potable groundwater source it can cause an immediate acute health concern.

**How can fecal groundwater pollution be prevented?**

Waterwells and springheads must be soundly designed and constructed to exclude fecal contamination from humans or animals at (and very close to) the source. Failure to do this can result in serious direct contamination, such as that which caused the fatal waterborne disease outbreak in Walkerton (Ontario) Canada in May 2000.

The flow characteristics of some geological formations (fissured/fractured rocks, notably karstic limestones, and very coarse alluvial deposits with shallow water-table) result in rapid connectivity between their groundwater and the land-surface. They are thus much more vulnerable to pathogenic contamination (from fecal bacteria /viruses, and even protozoa like Cryptosporidium and Giardia).

Drinking-water sources in such formations can be hazardous to human health unless they are appropriately defended by protection zones and by routine water-supply disinfection as a second barrier. But some pathogens, notably Cryptosporidium (which is very common in the excreta of young farm animals) are not removed by routine disinfection and require advanced microfiltration. Careful construction and protection are thus essential to prevent fecal pollution of groundwater sources. They need to be based on detailed understanding of groundwater flow, adequately-dimensioned and vigilated zones (with fencing to exclude animal grazing from swallow holes and areas without soil cover), and appropriate in-situ sanitation design and septage management.

Particular care is needed where waterwells and springs are used for domestic water-supply – this occurs in rural areas of all countries and in fast developing cities. The large numbers of individually small sources involved do not lend themselves either to protection zoning or treatment plant. In such circumstances improved sanitation is a high priority, in conjunction with maintaining adequate vertical and horizontal separation between the base of in-situ sanitation units and the intake zones of waterwells.

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<tr>
<th>PATHOGENIC SPECIES</th>
<th>PERSISTENCE IN WATER</th>
<th>CHLORINE RESISTANCE</th>
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<td><strong>PROTOZOA</strong></td>
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<tr>
<td>Cryptosporidium parvum</td>
<td>long</td>
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<td>Giardia intestinalis</td>
<td>moderate</td>
<td>high</td>
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<td>Entamoeba histolytica</td>
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| **BACTERIA**             |                      |                     |
| Campylobacter jejuni     | moderate             | low                 |
| Escherichia coli         | moderate             | low                 |
| Leptospira spp           | long                 | low                 |
| Salmonella typhi         | moderate             | low                 |
| Shigella spp             | short                | low                 |
| Vibrio cholerae          | short/long           | low                 |

| **VIRUSES**              |                      |                     |
| Enteroviruses            | long                 | moderate            |
| Hepatitis A & E          | long                 | moderate            |
| Noroviruses              | long                 | moderate            |
| Rotaviruses              | long                 | moderate            |
Not enough is known about subsurface pathogen survival, but new methods in molecular biology (qPCR techniques) are facilitating research. There are also emerging concerns about the appearance of antibiotic-resistant pathogenic strains.

What are the main threats of chemical groundwater pollution?

(A) Agricultural Land-Use
Agricultural production based on the extensive use of inorganic fertilisers, organic manures and plant protection products has seen rapid development over the past 30-60 years, with the most intensive applications being on irrigated land. Fertiliser applications frequently exceed crop needs (after taking into consideration nitrate generation by soils and that already contained in irrigation water) and/or are unfavourably timed. On permeable soil profiles this leads to widespread leaching of nitrate in groundwater recharge to levels greatly in excess of 50 mg/l.

Similar can be said of plant protection products. Pesticides in particular are designed to be toxic to weeds, insects and rodents, and more than 1700 active ingredients are believed to be in current use in over 45,000 brands. This, together with manufacturer’s confidentiality, make it difficult to obtain accurate application data. A great number of pesticides (or their partial breakdown products called metabolites) have been detected...
locally in groundwater at concentrations greater than WHO drinking-water guidelines. Increasingly pesticides are designed to have shorter soil half-lives (and thus would not be expected in groundwater), but unfortunately their persistence in the deep subsurface can be many times longer (as a result of many fewer microbes for breakdown than in the soil), and the more soluble compounds are readily leached in groundwater recharge.

Measures to protect groundwater in use for potable water-supply include:
- excluding some types of intensive agricultural land-use from source protection zones
- banning the sale of the most persistent pesticide compounds in groundwater
- improved agricultural cropping, husbandry and irrigation practices to avoid excessive agrochemical applications (such as crop rotation, avoiding fallow by use of cover crops, direct drilling to reduce soil aeration, not fertilising if irrigation water high in nitrate).

(B) Industrial Chemicals & Hydrocarbon Fuels
Groundwater pollution may also be caused by spills and leakages from storage tanks, landfills, fuel-filling stations, dry cleaners, chemical manufacturers and numerous other sources. Industrial contaminants have a wide range of properties resulting in complex migration behaviour in sediments and rocks. Those most common in groundwater are dominated by man-made chlorinated hydrocarbons and petroleum hydrocarbons, and can be classified into two major groups:
- Light Non-Aqueous Phase Liquids (LNAPLs or ‘floaters’ such as gasoline and diesel compounds), which move through the vadose zone, and accumulate at the water table
- Dense Non-Aqueous Phase Liquids (DNAPLs or ‘sinkers’ such as the chlorinated solvents trichloroethene and chlorobenzene, etc.), which move downward by gravity through permeable layers accumulating on an impermeable contact 10’s to 100’s of metres below the ground-surface and the water-table.

The limited water-solubility of these compounds means that subsurface accumulations persist for decades or centuries. But their mobility in the dissolved phase poses a long-term threat to groundwater quality, with point sources creating long definable plumes. If plume position is known, groundwater pumping may be designed to prevent these contaminants entering drinking-water capture zones. Moreover specific aquifer properties (such as reduction/oxidation conditions) may play an important role in their in-situ breakdown.

Although these compounds are hydrophobic (only weakly water soluble) their solubilities are still several orders-of-magnitude greater than drinking-water and ecosystem health guidelines. Since they exhibit a wide spectrum of toxicity, solvents such as tetrachloroethene, trihalomethanes (e.g. chloroform), and gasoline compounds such as toluene and methyl-tertbutyl-ether (MTBE), are the most common groups of volatile organic contaminants detected in groundwater. Many are considered
carcinogenic to humans on ingestion, inhalation, or dermal contact. New (emerging) industrially-derived contaminants are being identified in groundwater, including 1,4 dioxane, nitrosodimethyamine and perfluorinated compounds.

(C) Wastewater Disposal & Re-Use
In and around cities with significant mains sewerage cover, wastewater disposal and reuse practices can result in a health hazard through various potential routes of wastewater infiltration to groundwater, resulting in pollution with ammonium, nitrate, community and industrial chemicals (especially to unprotected waterwells).

The trace pollution of groundwater with synthetic organic chemicals by this route can include endocrine-disrupting and carcinogenic compounds in pharmaceuticals, plastics and epoxy-resins, the so-called emerging organic contaminants (EOCs), whose fate has not been widely studied in groundwater compared to other anthropogenic contaminants. Potentially important EOCs include carbamazepine, sulfamethoxazole, ibuprofen and bisphenol, entering groundwater from leaking sewers or in-situ sanitation. Significant concentrations (100 ng/l) of a range of EOCs are being detected in groundwaters globally – and many of these are among high priority substances for regulation in terms of their potential environmental and human-health effects.

Which are the main concerns in terms of natural groundwater contamination?

The interaction between percolating water and host rock can itself, sometimes, lead to water-quality problems, since a number of natural contaminants can dissolve in groundwater. Fluoride and arsenic are by far the greatest concern in terms of regional extent, population affected and human impact – although elevated water-supply salinity can affect maternal health and the presence of dissolved iron and manganese imparts an unpleasant taste and stains laundry (and is often unacceptable to consumers).

The more arid regions with granitic and volcanic terrain are particularly vulnerable to groundwater fluoride contamination and associated endemic fluorosis. Globally some 200 million are thought to be drinking water with fluoride above the WHO guideline value of 1.5 mg/l (1500 μg/l) and fluoride problems are a constraint on rural water supply provision in many water-stressed regions. High groundwater arsenic concentrations have been identified at shallow depths in large areas of South & East Asia and some parts of Latin America following 20 years of investigation.
The health impacts of chronic arsenic exposure in drinking-water include skin disorders and cancer. Large deltaic and alluvial plains, and arid inland basins, are particularly prone to elevated groundwater arsenic, with Bangladesh being very badly affected. Despite major mitigation efforts, significant exposure among the national population remains (estimated at 45 million above the WHO drinking-water guideline) some 20 years after its initial discovery.

The mitigation of arsenic and fluoride problems in groundwater requires a combination of measures:
- detailed hydrogeologic investigation to understand their distribution and mobilisation, and to locate non-contaminated groundwater
- labelling of hazardous waterwells to advise users on the need for use constraints
- provision of treatment plants of widely-varying scale according to the type of waterwell source involved.

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**PRIORITY ACTIONS**

- all groundwater sources used for drinking-water need to have sound sanitary completion to exclude the possibility of direct pollutant entry (for example by pathogenic organisms, hydrocarbon fuels/lubricants or other contaminants)
- aquifer systems exploited for drinking-water supplies should be subject to systematic survey, monitoring and assessment of potential pollution vulnerability and actual pollution hazard, which then needs to be managed by establishment of appropriately-dimensioned and vigilated source protection zones
- all groundwater sources used for drinking-water supply require quality surveillance in relation to perceived pollution/contamination risks – and if used untreated those at serious risk (or already impacted) should be marked as ‘only suitable for non-potable uses’
- the UN-Sustainable Development Goals for 2030 require greatly increased sanitation of peri-urban areas and rural villages, which if not soundly-designed will constitute an increased threat to potable groundwater quality
- research must continue and intensify on the subsurface fate (and persistence) of pathogenic organisms and some organic compounds to guide groundwater use and protection policy