International Association of Hydrogeologists

Strategic Overview Series

HUMAN HEALTH & GROUNDWATER

KEY MESSAGES

- the high quality of most groundwaters, consequent upon the self-purification capacity of subsurface strata, has long been a key factor in human health and wellbeing
- more than 50% of the world's population now rely on groundwater for their supply of drinking water – and in most circumstances a properly-located and soundly-engineered waterwell represents a low-cost, reliable and safe source
- however, a few aquifer systems are rapidly connected to the land-surface, and are thus more vulnerable to pollution from most waterborne microbiological and chemical contaminants
- intensive agricultural land-cultivation employs heavy applications of nutrients and pesticides which can be leached from soils, and thus constitute the most widely-distributed groundwater pollution threat in many aquifers
- some synthetic organic chemicals are very resistant to degradation in most groundwater systems and can constitute a long-term health hazard – and this includes certain so-called 'emerging organic contaminants'
- serious natural contamination of groundwater (especially with arsenic and fluoride) can occur through rock dissolution in some situations

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.

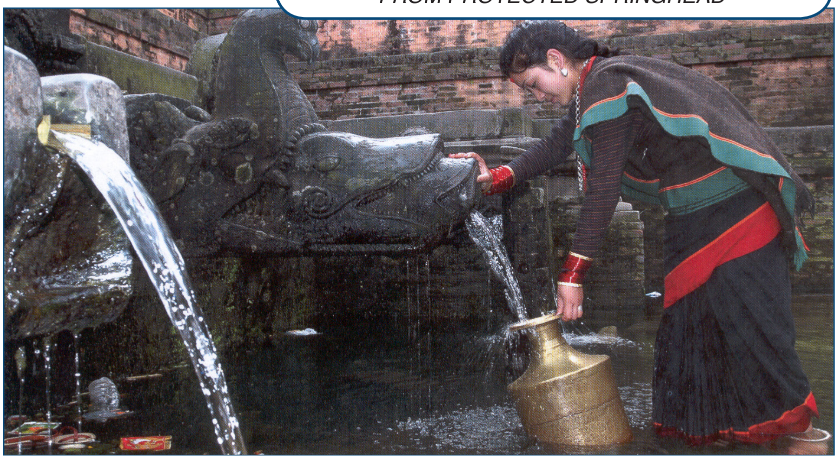
The underlying reasons for the excellent natural microbiological quality of groundwater are the :

- 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).

DOMESTIC WATER-SUPPLY COLLECTION IN ASIA FROM PROTECTED SPRINGHEAD



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 micro-filtration. 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.

PATHOGENIC ORGANISMS — SELECTION OF THOSE POTENTIALLY TRANSMITTED VIA DRINKING WATER

PATHOGENIC SPECIES	PERSISTENCE IN WATER	CHLORINE RESISTANCE
PROTOZOA		
Cryptosporidium parvum	long	high
Giardia intestinalis	moderate	high
Entamoeba histolytica	moderate	high
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

WHO GUIDELINES ON DRINKING-WATER LIMITS - VALUES FOR SELECTED CHEMICAL CONTAMINANTS ***(a)***

NATURALLY-OCCURING CONTAMINANTS		
arsenic	10	
barium	700	
boron	2400	
fluoride	1500	*(b)*
selenium	40	
uranium	30	
AGRICULTURAL POLLUTANTS		
nitrate	50,000	*(c)*
nitrite	3,000	*(c)*
alachlor	20	
aldicarb	10	*(d)*
atrazine	100	*(e)*
carbofuran	7	
chlordane	0.2	
chlorotoluron	30	
2.4D	30	
dichlorprop	100	
dimethoate	6	
DDT	1	*(f)*
fenoprop	9	
isoproturon	9	
lindane	2	
MCPA	2	
mecoprop	10	
methoxychlor	20	
metolachlor	10	
simazine	2	
INDUSTRIAL & COMMUNITY POLLUTANTS		
cadmium	3	
chromium	50	*(g)*
mercury	6	*(h)*
benzene	10	
carbon tetrachloride	4	
dichloromethane	20	
ethylbenzene	300	
pentachlorophenol	9	
tetrachloroethene	40	
toluene	700	
tricholoroehthene	20	
xylenes	500	

(a) expressed as µg/l (ppb), although some determinands are usually given in mg/l (value in ug/l is divided by 1000 to report in mg/l) - note some countries have lower and/or higher values for certain contaminants
(b) but consider all intake
(c) can also be wastewater derived
(d) both sulfoxide and sulfone
(e) hydroxyatrazine 200 µg/l
(f) now mainly non-agricultural use
(g) as total chromium
(h) as inorganic mercury

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

AGRICULTURAL PESTICIDE APPLICATION TO A PERMEABLE SOIL

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).

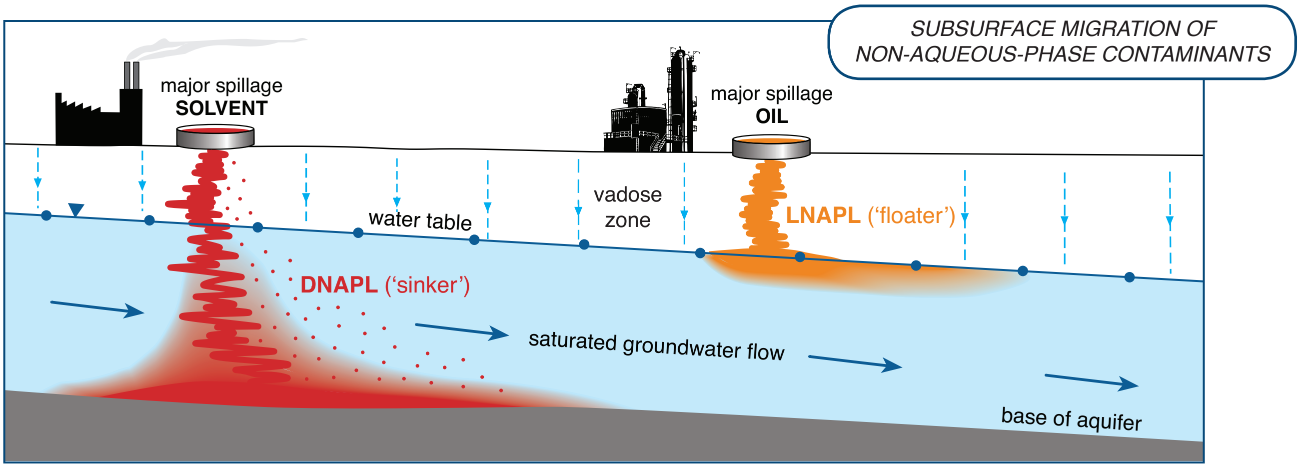
(B) Industrial Chemicals & Hydrocarbon Fuels

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.

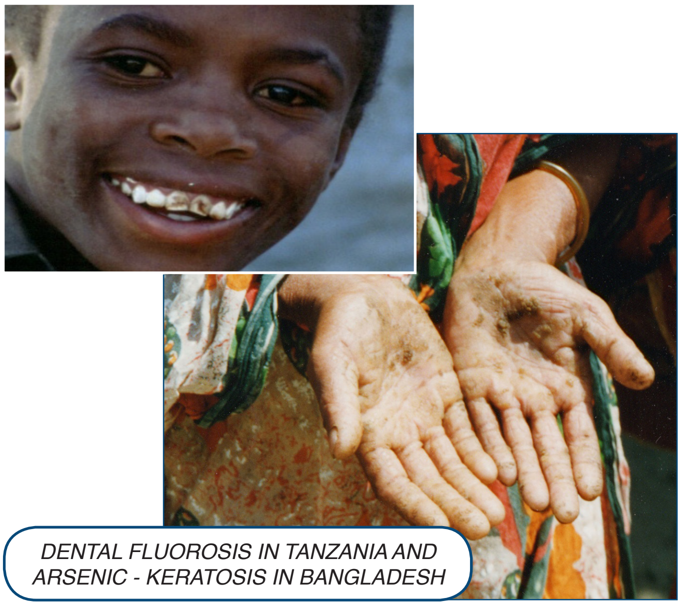
The limited water-solubility of these compounds means that subsurface accumulations persist for decades or centuries. But their mobility in the dissolved phase poses a long-term threat to groundwater quality, with point sources creating long definable plumes. If plume position is known, groundwater pumping 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, nitroso-dimethylamine 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).



DENTAL FLUOROSIS IN TANZANIA AND ARSENIC - KERATOSIS IN BANGLADESH

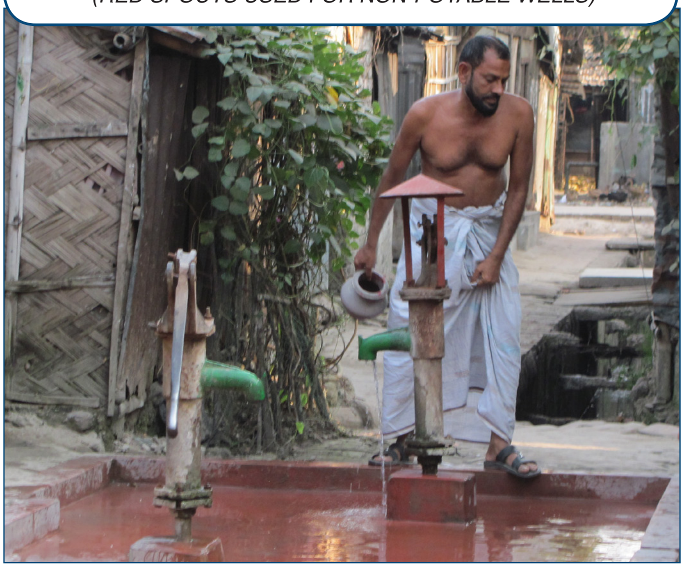
The trace pollution of groundwater with synthetic organic chemicals by this route can include endocrine-disrupting and carcinogenic compounds in pharmaceuticals, plastics and epoxy-resins,the so-called emerging organic contaminants (EOCs), whose fate has not been widely studied in groundwater compared 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.

HAND-PUMP WATERWELLS IN BANGLADESH WITH GREEN SPOUT INDICATING ARSENIC-FREE GROUNDWATER (RED SPOUTS USED FOR NON-POTABLE WELLS)



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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.

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**

Supported by:

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SELECTED BIBLIOGRAPHY

- Daughton C G 2004 Groundwater recharge and chemical contaminants - challenges in communicating the connections and collisions of two disparate worlds Ground Water Monitoring & Remediation 24:127-138
- Edmunds W M & Smedley P L 2013 Fluoride in natural waters. Essentials of Medical Geology 311-336. Springer (Berlin).
- Fendorf S et al 2010. Spatial and temporal variations of groundwater arsenic in South and South-East Asia. Science 28 : 1123-1127.
- Foster S & Candela L 2008 Diffuse groundwater quality impacts from agricultural land-use: management and policy implications of scientific realities. RSC Groundwater Science & Policy 457-474. CRC Publishing (London).
- Morris B L & Foster S S D 2000 Cryptosporidium contaminant hazard assessment and risk management for British groundwater sources. Water Science Technology 41 : 67-77.
- Poch-Massegú R et al 2014 Irrigation return flow and nitrate leaching under different crops and irrigation methods in western Mediterranean weather conditions. Agricultural Water Management 134 : 1-13.
- Pankow J F & Cherry J A 1996 Dense chlorinated solvents and other DNAPLs in groundwater. Waterloo Press (Ontario).
- Sorensen J P R et al 2015 Tracing enteric pathogen contamination in Sub-Saharan African groundwater. Science of Total Environment 538 : 888-895.
- WHO 2011 Guidelines for Drinking-Water Quality–4th Edition. World Health Organisation (Geneva).
- Zogorski J S et al 2006 Volatile organic compounds in the nation's groundwater and drinking-water supply wells. US Geological Survey Circular 1292 (Virginia).

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