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Review of the pollution threat to groundwater in Sri Lanka

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Abstract: Groundwater is an important source of potable water in Sri Lanka. However, little attention has been given to the pollution risk to the supplies despite the increasing threat posed by both modern intensive agriculture and the disposal to ground of industrial and domestic wastes. This paper attempts to review the vulnerability to pollution of the coastal sand, limestone and crystalline basement aquifers of Sri Lanka and the activities likely to generate contaminants.

Monitoring of groundwater quality has shown that some aquifers in Sri Lanka are already contaminated by agro-chemicals leached from intensively cultivated soils and by domestic wastes discharged via pit-latrine soakaways.

INTRODUCTION

Groundwater is increasingly exploited for potable water-supply in Sri Lanka, especially in the smaller towns and rural areas, as it is usually the cheapest and safest source of supply. Numerous low-yielding boreholes fitted with handpumps have been constructed in recent years over large areas of Sri Lanka, and around Colombo and Jaffna higher yielding boreholes penetrating sedimentary strata have also been constructed for both industrial land public water supply. Groundwater represents the major source of potable water in Sri Lanka.

However, too few resources have been available to investigate the aquifers themselves, particularly in the basement-rock areas. The water levels and groundwater quality of these boreholes are largely unmonitored. Yet many water-supply boreholes have been abandoned as a result of the deterioration in quality due to excessive concentrations of iron, fluoride and chloride (Anon 1987). The lack of monitoring and understanding of the groundwater systems means that the scale and precise causes of these water-quality problems are largely unknown.

Further, the threat to groundwater quality from pollution has received only limited attention, although the risk to potable supplies is increasing, particularly due to:

(a) the increasingly widespread use of on-site disposal of unsewered domestic wastes,

(b) the intensification of irrigated agriculture, and the accompanying increase in use of fertilisers and pesticides, and

(c) the uncontrolled on-site discharge of industrial effluents.

The impact of the above activities on groundwater needs to be evaluated so as to: (a) draw attention to the threats posed to the security of the quality of potable groundwater supplies, and (b) define the need for more effective pollution-control practices. Pollution of the aquifers can result in the slow deterioration of groundwater quality and, particularly when associated with the more toxic and persistent synthetic organic compounds, can affect large volumes of groundwater; the abandonment of the aquifer for water-supply may be necessary in the worst instances. In view of the limited resources available for monitoring there is an urgent need for relatively simple techniques of pollution-risk assessment. This assessment would serve to identify those areas most at risk and focus attention upon the analytical/sampling programme required, The objective of this paper is to review (a) the principal activities that pose a significant groundwater pollution risk, and (b) the vulnerability of the aquifers in Sri Lanka.

ACTIVITIES THAT GENERATE SIGNIFICANT POLLUTION RISK

The disposal of effluent from unsewered sanitation

Concern has been expressed that the construction of pit latrine soakaways may pose a threat to public groundwater supplies (Foster 1986). The most immediate threat is the microbiological contamination of groundwater, although chemical pollution, particularly nitrate, may in the longer term represent a more widespread and persistent problem in densely populated areas (Table 1). The soil is usually most effective in protecting groundwater by attenuating pollutants (through adsorption and active biological degradation), but excavations for pit latrines often by-pass this layer and thus increase the risk of fecal contamination of groundwater. Pit latrines in Sri Lanka are mostly of the water-flush type. This type of latrine increases fluid loading and hence the likelihood of microbiological contamination of groundwater.

Studies of the movement of pathogenic organisms have mostly been restricted to unconsolidated aquifers. These aquifers are characterised by slow, intergranular groundwater flow and by high porosity, favouring pollutant attenuation and dispersion. Subsurface travel times in these environments of about 20 days are usually considered sufficient to reduce indicator organism populations to acceptable values (< 1 FC/100 ml), although much longer subsurface survival times (without transport) are possible. However, where groundwater movement is mostly along joints and fractures, much higher flow velocities are possible with less opportunity for pathogen attenuation and dispersion. The microbiological and chemical pollution risk in such fissure-flow environments has not as yet been fully established, although some studies elsewhere have confirmed that rapid movement of pathogenic organisms can occur (Hutton and Lewis 1980).

Agricultural land-use

Rising nitrate concentrations in groundwater in the 1970s in the UK and other western countries focussed attention on the impact of modern agricultural practices on groundwater quality, principally the leaching of solutes (nitrate) derived from fertilisers. More recently, concern has been expressed about the leaching to groundwater of pesticides from intensively cultivated soils (Rothschild *et al.* 1982; Wehtje *et al.* 1981).

The use of fertilisers and pesticides in Sri Lanka is expanding rapidly as in other developing countries, particularly with the introduction of new high-yielding crop varieties. However, little research on the

Table 1. Chemical pollution of groundwater

Population density (per ha)	*Nitrogen generated* (KgN/ha/a)	*Maximum leachate concentrations*[1] (mg *N*/l) assuming following percentage of nitrogen in human wastes are mobilised:		
		10%	30%	70%
50	250	12.5 (55)[2]	37.5 (166)	87.5 (388)
100	500	25 (110)	75 (330)	175 (775)
200	1000	50 (220)	150 (660)	350 (1550)

1 assumes a) long-term infiltration of 200 mm/a.
b) maximum concentration at water-table with no dilution.

2 (concentration as NO_3 mg/l)

leaching losses from intensively cropped tropical soils has been undertaken, although where irrigatio is inefficient and excessive, losses can be expected to be high. The aquifers that appear most vulnerable to diffuse agricultural pollution are those covered by well-drained permeable soils, which are highly suited for irrigated agriculture. Those soils are most usually developed on limestones and some alluvial deposits.

Those pesticides that are mobile (soluble and only weakly adsorbed) and relatively persistent, such as some carbamate and thiocarbamate insecticides, are likely to be the most readily leached to groundwater. Once below the soil zone the transport and fate of these pesticides is not well understood; their persistence in aquifers is likely to be many times greater than in soils (Lawrence and Foster 1987). Further, in many developing countries, pesticides that have been banned in the industrialised countries for environmental/health reasons are often still widely used.

Irrigated agriculture may affect groundwater quality in another way, by increasing its salinity particularly where the water-table is shallow. The increasing use of surface water for irrigation (e. g. in the Mahaweli scheme) in areas where dry-land farming was previously practiced is likely to produce changes, as yet unforeseen, in groundwater quality and recharge. The impact on potable groundwater supplies is not clear. Elsewhere in the world major irrigation schemes implemented without sufficient drainage measures have had delayed but substantial salinity problems associated with them.

The disposal of industrial effluent

In recent years the groundwater pollution hazard posed by various industrial chemicals has received considerable attention following reports of their widespread occurrence at low levels in groundwater and their locally much higher concentrations close to urban and industrial centres in Europe and USA (Zoetman *et al.* 1981). In Sri Lanka, small-scale industries (such as textiles, metal processing, vehicle maintenance and tanneries) are often widely distributed in urban or urban-fringe areas. These industries will generate effluents such as oils and solvents· which are not infrequently discharged directly onto the soil or into shallow pits; the cost of transport to safe disposal sites or on-site treatment of effluent is prohibitive. The likelihood of this effluent penetrating to shallow groundwater which may be used nearby for potable-water supply must be high.

Little is known in detail about the behaviour of many of these chemicals in the subsurface environment, particularly in fissured aquifers (Lawrence and Foster 1987). The WHO drinking-water guideline concentration for most of these chemicals is low, often less than 10 ug/1 as these compounds are generally very toxic even in low concentrations when consumed over extended periods. In view of these low permitted concentrations, even a small spillage involving a few litres can contaminate a very considerable volume of groundwater.

AQUIFER VULNERABILITY

The term aquifer-pollution vulnerability describes the intrinsic characteristics that determine the sensitivity of an aquifer to being adversely affected by an imposed contaminant load. Aquifer vulnerability can be considered as an interaction of components related to the aquifer itself:

a) the inaccessibility of the saturated zone, a hydraulic sense, to penetration of pollutants,
b) the attenuation capacity as a result of physicochemical retention or reaction of pollutants.

These are determined primarily by the geology, aquifer type (confined or unconfined) and depth to groundwater. These interact with the following components of pollution loading:

a) the manner of pollutant disposition, especially in relation to by-pass of the soil and fissuring, and the magnitude of the hydraulic loading,
b) the physicochemical mobility and persistence of the pollutant to define the overall vulnerability of an aquifer to pollution.

In this paper the aquifers in Sri Lanka are subdivided into three broad geological groups (Figure 1):

(1) Coastal sands and superficial deposits,
(2) Miocene limestone,
(3) Basement Complex.

Aquifers in the Coastal Sand and Superficial Deposits

Locally significant groundwater supplies for drinking water, irrigation and occasionally, industry, are obtaind from these unconsolidated deposits. These aquifers are usually shallow and covered by permeable or very permeable soils, permitting rapid infiltration to the water-table. Groundwater movement in these porous and granular aquifers is characterised by low velocities (< 1 m/d) and limited regional flow systems. As a consequence, groundwater quality will largely reflect conditions locally within the aquifer and land-use activities practised on the immediate aquifer outcrop.

In the Kalpitiya peninsula, limited monitoring of the coastal-sand aquifer beneath intensively cultivated and irrigated soils has shown significant contamination of the aquifer by nitrate derived from fertilisers, with peak seasonal concentrations up to four times the WHO guideline (Figure 2). Groundwater concentrations beneath unfertilised land are substantially lower. In areas where groundwater nitrate

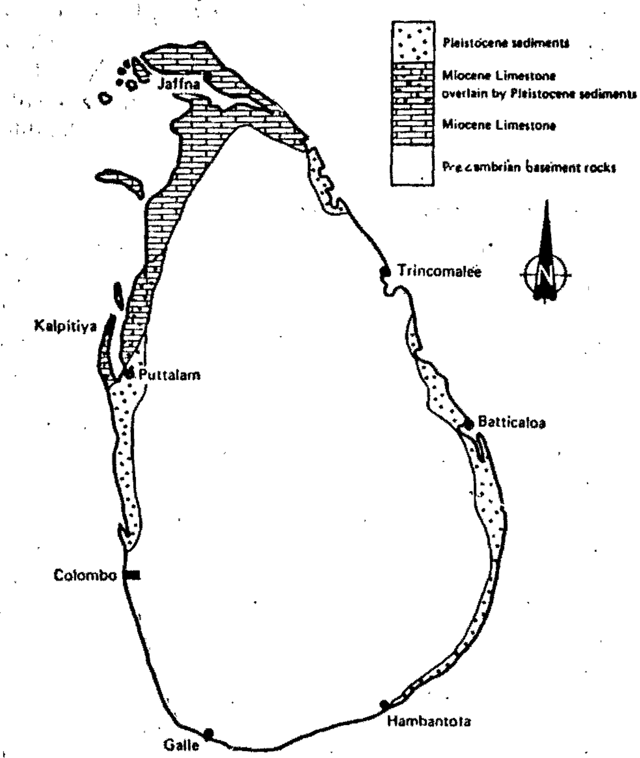

Fig 1. Simplified geological map of Sri Lanka.

concentrations are high, there is a substantial risk that potable groundwater supplies may also be contaminated by pesticides leached below the soil zone, particularly where the more mobile compounds of the carbamate group are used. A research programme on this topic, funded by the British Overseas Development Agency and involving the Water Resources Board, the Agriculture Department and the British Geological Survey, is currently being undertaken.

Contaminant transport in such porous and granular aquifers will be slow, allowing effective removal of pathogens and other less persistent contaminants over quite short distances. The pollution risk from on-site sanitation systems is, therefore, not generally considered to be high.

Miocene Limestone

The limestone which outcrops in the north-west of the island from Mannar to Jaffna (Figure 1) is the main source of freshwater for this densely populated and intensively cultivated area. Groundwater abstraction is from numerous privately owned open dug wells and shallow boreholes. Abstraction is largely uncontrolled and in places can be excessive, resulting in intrusion of salt water (Foster 1976; Gunasekaram 1983).

The limestone, which is extremely permeable and karstic with rapid groundwater flow along major fissures, is overlain by thin permeable soils, permitting very rapid infiltration to the water-table with little attenuation or degradation of contaminants.

High groundwater nitrate concentrations, in excess of the WHO guideline value, are reported to be widespread in the Jaffna peninsula (Foster 1976; Gunasekaram 1983; Dissanayake *et al.* 1984), with concentrations locally in excess of 200 mg/l. The nitrate is derived largely from fertilisers and from latrine soakaways. Fecal coliform bacteria have also been widely reported in groundwater samples and 80% of the wells monitored were of unacceptable bacteriological quality (Gunasekaram 1983). The leaching of pesticides to groundwater must also be suspected, although due to the difficulties and expense involved in sampling and analysis, no monitoring is believed to have been undertaken.

Basement aquifers

The crystalline basement outcrops over 90% of the island and aquifers within the shallow, weathered and fractured layers are widely used for low-yielding water supplies However, few detailed studies of these aquifers have been attempted and their groundwater systems and recharge mechanisms are not well understood. Aquifers vary from those in the unconsolidated weathered mantle, which are characterised by very slow intergranular groundwater flow and substantial porosity, permitting attenuation/elimination of some pollutants over quite short distances, to those in the fractured bedrock where groundwater velocities are higher and porosity lower, allowing transport of pollutants without significant retardation. Similarly, the unsaturated zones of these aquifers are variable in terms of thickness, lithology and mode of water transport.

Little work has been attempted to quantify groundwater velocities in the crystalline basement aquifers, although a tracer experiment recently carried out by the University of Peradeniya in collaboration with

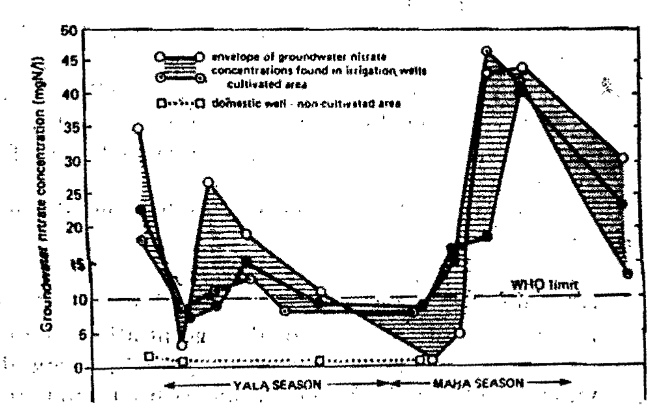

Fig 2. Seasonal changes in groundwater nitrate concentration.

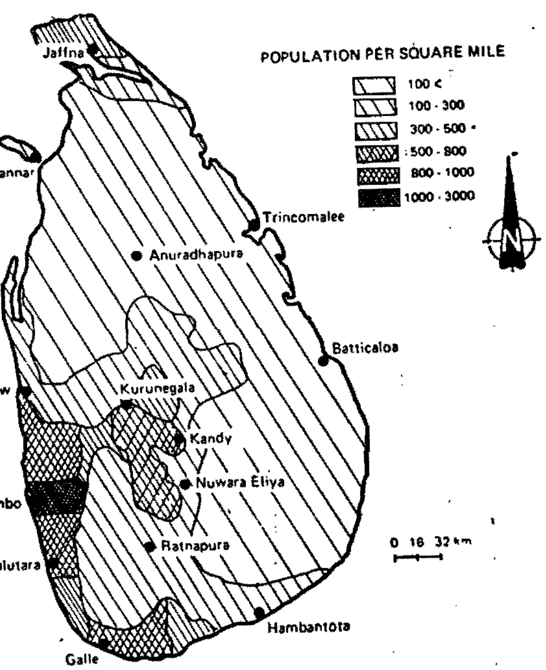

Fig.3 A. The population density of Sri Lanka.

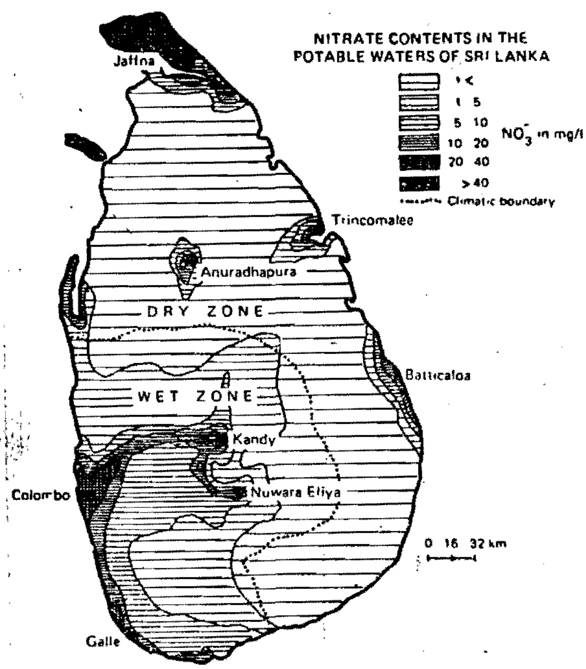

Fig. 3 B. The distribution of nitrate in the potable waters of Sri Lanka.

Luton College of Technology clearly demonstrated the very rapid travel time (2-3 days) of a lithium tracer from a pit-latrine soakaway to a water-supply borehole 20-25 m distant (G Notcutt, personal communication). Such rapid travel times would not permit attenuation or elimination of pathogens, and although not tested, water from this borehole is likely be of unacceptable bacteriological quality.

In a survey of the distribution of nitrates in potable water of Sri Lanka covering mostly the basement areas, a clear correlation was shown between nitrate concentration and population density (Fig. 3). The elevated nitrate concentrations were considered to be due to the leaching of nitrogen fertilisers from paddy land (Dissanayake *et al.* 1984). A correlation between nitrate concentration and infant mortality rate (Fig. 4) was also suggested (Disanayake *et al.* 1984). However, in this paper it is suggested that latrine soakaways are probably mostly responsible for the elevated nitrates, and that pathogens derived from the soakaways are the more likely cause of the increased infant-mortality rates.

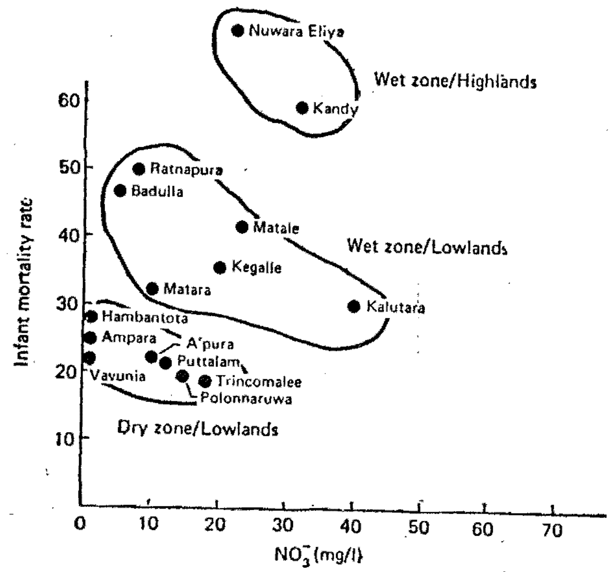

Fig. 4. Variation of the infant mortality rate with the nitrate content of groundwater. (after Dissanayake *et al.* 1984.

DISCUSSION

This paper has attempted to show that the major aquifers of Sri Lanka are vulnerable to pollution to varying extents and that limited monitoring has revealed contamination of potable water supplies due to both the leaching of agrochemicals from intensively cultivated soils and to effluents discharged from pit latrine soakaways (Gunasekaram 1983; Dissanayake *et al.* 1984; Lawrence and Kuruppuarachchi 1986). Contamination of groundwater by the casual disposal of industrial wastes has also been reported (Gunasekaram 1983), although in the absence of specific monitoring the full extent of this latter type of pollution has not been quantified.

In view of the importance of groundwater in Sri Lanka for potable water supplies it is clear that

Table 2. Vulnerability of aquifers to pollution.

Aquifer	Soil-unsaturated Zone					Aquifer Properties			Pollution risk assessment
	Soil type	*Thickness* (m)	*Water transport*	*Delay time to water-table* (days)	*Attenuation/ retardation of pollutant*	*Groundwater flow*	*Groundwater velocity* (m/d)	*Attenuation of pollutants*	
Miocene Limestone	very permeable, low organic content	5-10	fissure	1-3	slight	fissure	10-100	slight	Pollutants including pathogens likely to be transported considerable distances with only limited attenuation/retardation
Coastal sands	permeable, very permeable, low organic content	1-10	intergranular	1-20	slight—moderate	intergranular	0.1-1.0	significant	Pollutants likely to be transported quite short distances. Pathogens removed within a few metres.
Basement rocks	variable but usually less permeable than above	variable 3-20	intergranular/ fissure	very—variable	slight—major	intergranular/ fissure	<0.1-10	slight—major	Pollutant transport very variable. Little research to date on pollutant, transport in Basement aquifers.

Table 3. Pollution-risk asssessment of Sri Lanka aquifers.

AQUIFER	Vulnerability to pollution	Main activities generating pollutants			Routine groundwater monitoring recommended	Protection measures required	Type of pollution assessment investigations required
		Intensive agriculture	*On-site sanitation*	*Discharge or industrial effluents*			
Miocene Limestone	v. high	Yes major pollutants: nitrate pesticides	Yes major polutants: nitrate, chloride, pathogens	Yes major pollutants: solvents, fuels, metals	1) Nitrate 2) Bacteriological 3) Industrial chemicals* 4) Pesticides*	1) Improved land and water management 2) Improved on-site sanitation systems 3) safe disposal or treatment of industrial wastes	1) Extent of pollution 2) Nutrient and agrochemical leaching losses beneath intensively cultivated soils 3) Monitoring of impact of introduction of protection measures
Coastal Sands	moderate—high	Yes major pollutants: nitrate, pesticides	(Yes) (where pollution density high major pollutants: nitrate, pathogens)	(Yes) (major pollutants A/A)	1) Nitrate 2) Pesticides*	1) Improved land and water management	As abovc
Basement aquifers	Low—high	(Yes) (nitrates) (pesticides)	Yes major pollutants: nitrate pathogens	(Yes) (major pollutants A/A)	1) Nitrate 2) Bacteriological	1) Improved design of on-site sanitation systems	1) Research on pathogen transport in fractured rocks, 2) Monitoring of impact of improved sanitation systems.

Where brackets used = only locally important

* In view of expense and difficulties of sampling/analysis, recommended only where
  (a) pollutant suspected by other monitoring,
  (b) high-risk areas.

sensible groundwater pollution protection measures need to be introduced. In the first instance, a protection and monitoring scheme needs to consider: (a) how vulnerable is groundwater to pollution, (b) what activities occur on aquifer outcrop, and (c) once in the aquifer, what is the fate and mode of transport of the contaminat? It is recommended that pollution assessment studies should be attempted and that maps showing aquifer vulnerability to pollution be prepared covering Sri Lanka. These maps would be of use to those responsible for:-

(a) planning and installation of new water-supply boreholes,
(b) monitoring of existing water-supply boreholes,
(c) planning new housing development,
(d) planning and implementing rural development.

In those areas where the aquifer vulnerability is considered high, an assessment of land-use activities that pose a risk to the security of potable water supplies should also be undertaken. Pollution protection measures that might be considered include: (a) improved agricultural and water - management practices (more efficient irrigation, intercropping of deep- and shallow-rooted crops, banning of certain pesticides); (b) improved design of on-site sanitation systems (incorporation of sand filter at base of latrine for pathogen removal, periodic emptying of solids, increasing the spacing between pit latrines and water-supply boreholes); and (c) collection of industrial wastes for safe disposal.

A provisional assessment of the situation in Sri Lanka is shown in Tables 2 and 3, although more research is required to quantify contaminant migration to the water-table from latrine soakaways and from intensively cultivated soils. The limestone aquifer of the Jaffna Peninsula is not only highly vulnerable to pollution but also subject to land-use activities likely to generate pollutants. Protection measures, even if intoduced, are unlikely to prevent all contamination reaching the water-table and in particular, elevated concentrations of nitrate and some organic compounds in groundwater can be expected The WHO drinking water guidelines are regarded by some as unnecessarily stringent for developing countries and it may be that a relaxation of the limits should be considered for some areas, as measures designed to attain the present WHO standards would be very expensive and have a major negative impact on agriculture and industry.

There is a clear need to carry out more research to assess the following:

(a) what nutrient-leaching losses occur beneath intensively cultivated soils,
(b) what pesticides are reaching the water-table and at what concentrations, and
(c) what management practices are required to reduce these losses without a significant reduction in agricultural production?

The vulnerability to pollution of the crystalline basement aquifers is more difficult to assess as these aquifers are highly variable; however, currently the most widespread pollution threat would appear to be from on-site sanitation systems. Research is urgently required to investigate both pathogen transport in basement aquifers, particularly where groundwater flow is predominantly along fractures and joints, and also chemical pollution, principally the build-up of nitrate, especially in the more densely populated areas.

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