WELL Study

Groundwater, latrines and health

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EXECUTIVE SUMMARY

Background

On-site sanitation systems dispose of human excreta, with or without treatment, on the residents' housing plot. Examples include pit latrines and septic tanks with drainage fields. This study reviews the risks to health posed by groundwater contamination from on-site sanitation (particularly latrines). Detailed understanding of groundwater contamination is complicated by a host of factors, broadly grouped into substantial and often unknown variations in subsurface conditions, contaminants, and the mechanisms of their movement. The problem is further complicated by the multiplicity of *other* pathways by which contaminants may be ingested, the variation in human response to a given dose, and the variety of approaches that may be taken to reduce such risks.

Pathogen characteristics

Pathogens are defined as disease-causing organisms, of which human excreta may contain four major types: worm eggs, protozoa, bacteria and viruses. Eggs and protozoa are effectively screened by soil during groundwater flow, so bacteria and viruses, which are much smaller, are the main focus of concern. Individuals excrete around 10^9 bacteria/gram of faeces, the vast majority of which are not pathogenic. An infected individual can excrete up to 10^6 viruses per gram of faeces.

Groundwater pollution from on-site sanitation

The risks of aquifer pollution are substantially affected by groundwater hydrology. Aquifers (water-bearing layers of soil) lie in the saturated zone below the water table. Soil above the water table is unsaturated with water, and is classified as part of the unsaturated zone. ***Pathogens do not travel farther or faster than the water in which they are suspended.*** Water flows very slowly in the unsaturated zone, as flow is along a thin and tortuous path along the surface of soil particles. Flow is much more rapid in the saturated zone, as water flows directly through the soil pores. Most on-site sanitation systems depend upon the capacity of the soils in the unsaturated zone to accept and purify effluent. ***The key factor that affects the removal and elimination of bacteria and viruses from groundwater is thus the maximisation of the effluent residence time between the source of contamination and the point of water abstraction. Because of the very low velocities of unsaturated flow, the unsaturated zone is the most important line of defence against faecal pollution of aquifers.*** Commonly used guidelines in many soil conditions keep the bottom of the pit at least 2 m above the water table, and at least 15 m from any well used for drinking purposes. In some areas, however, such criteria cannot be met, or the soil conditions (such as fissured limestone) do not assure groundwater protection when such guidelines are followed. In these cases, the choice of sanitation technology depends upon a number of factors, including the relative risks of alternatives.

Health aspects

There are two main health risks commonly associated with water quality degradation from on-site sanitation: faecal-oral disease transmission, and nitrate poisoning. Nitrate standards may be violated from latrine leachate, especially in arid areas where dilution of nitrogen loadings is consequently limited. High nitrates can lead to methaemoglobinaemia, (also known as "blue baby" syndrome.) This condition, in which oxygen cannot be effectively transported or released by the bloodstream, occurs mostly in children under 3 months of age. Methaemoglobinaemia is a rare condition; between 1945 and 1972, only 2000 cases were reported worldwide, most of which were not fatal. This contrasts markedly with diarrhoeal disease (the second main health risk associated with contaminated groundwater), which causes up to 3 million deaths annually. Methaemoglobinaemia is also much less of a risk where breast-feeding is common, as breast-fed children are less likely to ingest high-nitrate water.

The epidemiology of faecal-oral disease, water, and sanitation is fraught with conceptual difficulties. Nevertheless, a number of studies summarised by Esrey (1991, 1996) point to (a) the greater impact of improved sanitation upon health relative to improved water supply, and (b) the greater importance of water quantity to health when compared with water quality. Studies by Moe et al. (1991), and Kirchoff et al. (1982) pointed to a lack of significant response to "moderate" contamination, and raise questions about both dose-response relations for faecal contamination and water quality standards.

Options and choices

The common reaction to regard pit latrines "unacceptable" in dense urban areas because of the risks of groundwater contamination needs to be considered more critically. As outlined in Section 5, this response is often based on a number of unstated, untested, and in many cases, improbable assumptions about the causal chain of disease and the choice of sanitation technology. In practice, the choice of technology is more tightly constrained by issues of water supply and sullage removal than by hypothetical balances of risks. Where large quantities of water require disposal, sewerage becomes more attractive and pit latrines are likely to be inadequate; where only small or irregular quantities of water are available, sewerage will prove difficult to support as an option. Data from urban settlements in India are presented which support the hypothesis that it may be cheaper to combine on-site sanitation with public water supplies drawn from outside the contamination zone, than to combine on-site wells with off-site sanitation (i.e. sewerage). In the final analysis, planners should understand that any decision to ban on-site sanitation that leads, as a practical consequence, to a reduction in sanitation coverage and use is, in fact, a step backwards for public health.

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Abbreviations, acronyms and glossary

aeration zone — same as **unsaturated or vadose zone**.

aquifer — layers, or a group of interconnected layers, of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to borehole(s) and/or springs. (A supply rate of 0.1l/s is considered as a usable quantity) (see Box 5, page 12) (Anonymous 1997).

a productive aquifer is a bed of rock with high porosity which is capable of transmitting large quantities of water (Shaw 1994).

aquifer system — a heterogeneous body of intercalated and less permeable material that acts as a water-yielding hydraulic unit of regional extent (Anonymous 1997).

attenuation — the removal, breakdown or dilution of contaminants as they pass through the earth's material (Anonymous 1997).

BOD — Biochemical Oxygen Demand: the mass of oxygen consumed by organic matter during aerobic decomposition under standard conditions, usually measured in milligrams per litre during five days: a measure of concentration of sewage (Cotton, Franceys et al. 1995). This measure is of environmental significance for aquatic species, but is not a direct measure of public health hazard.

confining layer — a layer of low permeability material, overlying an aquifer, restricting the vertical movement of water (Anonymous 1997).

contamination — the introduction into the environment of any substance by the action of man (Anonymous 1997).

cyanosis — blue discoloration of skin due to presence of deoxygenated blood (Concise Oxford Dictionary,1984).

host response — how an individual reacts to a given dose of an infectious agent. Acquired immunity and the relation of age to pathology are important for predicting the effects of sanitation (Feachem, Bradley et al. 1980). The balance between exposure to infection and the **host response** to infection is a significant determinant of the pattern of excreta-related diseases.

infective dose — The number of ingested pathogens required to induce infection in a new host. Most pathogens have a variable infective dose and are unevenly distributed in the environment. It is, therefore, difficult to state the mean infective dose, the number of pathogens an infected person will excrete or the extractive efficiency of the excreta treatment process. Although the minimal **infective dose** is a difficult number to estimate it is crucially important. The difficulties are greatest for the major excreted bacterial infections and for protozoa. There is experimental evidence of low **infective doses** for some viruses (Feachem, Bradley et al. 1980).

latency — the interval between the excretion of a pathogen and the time at which the pathogen becomes infective to a new host. Excreted viruses, bacteria and protozoa are immediately infective i.e. they have no **latent** period (Feachem, Bradley et al. 1980).

pathogen — disease-causing micro-organism (Anonymous 1997).

percolation rate — the rate at which liquids move through the soil (Cotton, Franceys et al. 1995).

permeability (*aka* hyraulic conductivity) refers to the ease with which water can pass through a porous medium and is defined as the volume of water discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as $m^3/m^2/d$ or m/d) (Anonymous 1997). An hydraulic loading of 1 mm/d is equivalent to 1 litre/m^2/day.

persistence The survival time of the pathogen in the environment. This is a measure of how quickly the pathogen dies after it leaves the human body. It is the single property most indicative of the faecal hazard, as a very **persistent** pathogen will create a risk throughout most treatment processes and the reuse of excreta (Feachem, Bradley et al. 1980).

piezometric level the free-surface elevation to which the water level rises in a borehole penetrating confined or semi-confined conditions (Anonymous 1997).

pit latrine latrine with a pit for accumulation and decomposition of excreta and from which liquid infiltrates into the surrounding soil (Cotton, Franceys et al. 1995).

pollution the introduction into the environment of any substance by the action of man which is, or which results in, significant harmful effects to health (Anonymous 1997).

pollution plume area of degraded water in a stream or aquifer resulting from migration of pollution (Anonymous 1997).

sanitation the means of collecting and disposing of excreta and community liquid waste in a hygienic way so as not to endanger the health of individuals or the community as a whole (Cotton, Franceys et al. 1995).

saturated zone that part of the geological stratum in which all voids are filled with water under pressure greater than that of the atmosphere (Anonymous 1997).

semi-confined aquifer An aquifer overlain by a semi-porous layer *(aquitard)* of intermediate conductivity.

septic tanks watertight chamber for the retention, partial treatment and discharge for further treatment, of sewage (Cotton, Franceys et al. 1995).

sewage wastewater that usually includes excreta and that is, will be, or has been carried in a sewer (Cotton, Franceys et al. 1995).

sewer pipe or conduit through which sewage is carried (Cotton, Franceys et al. 1995).

sullage wastewater from bathing, laundry, preparation of food, cooking and other personal and domestic activities that may be expected to contain considerably fewer pathogenic organisms than sewage (Feachem, Bradley et al. 1983; Cotton, Franceys et al. 1995).

unconfined aquifer An aquifer in which the water is not pressurised by an overlying (confining) layer of low conductivity. Pressure in an unconfined aquifer is determined by the free surface of the water table within the aquifer.

unsaturated zone that part of the geological stratum above the saturated zone in which the voids contain both air and water (Anonymous 1997).

vadose zone same as **unsaturated or aeration zone.**

virus any group of sub-microscopic (invisible by ordinary microscope) entities consisting of a single nucleic acid surrounded by a protein coat and capable of replication only within the cells of animals and plants (Anonymous 1997).

1. Introduction

In 1986 a WHO Study Group defined sanitation as ‘the means of collecting and disposing of excreta and community liquid wastes in a hygienic way so as not to endanger the health of individuals and the community as a whole’ (WHO 1987). Hygienic disposal of human wastes that does not endanger health should be the underlying objective of all sanitation programmes (Franceys, Pickford et al. 1992).

On-plot sanitation systems dispose of human excreta, with or without treatment, on the residents' housing plot. Examples include pit latrines and septic tanks with drainage fields. Off-plot sanitation systems (e.g. sewerage) move excreta off the plot for treatment and disposal. On-plot systems are commonly considered an appropriate option for sanitation in developing countries, even in densely populated urban areas. On-plot sanitation systems will remain a popular form of low-cost sanitation for the foreseeable future, as conventional off-site options are usually much more expensive.

On-plot sanitation systems naturally raise a concern about the pollution of groundwater. Research over the years has shown that bacteria can be transported some distance through the ground by liquid leachate from a pit latrine or septic tank, and could thus contaminate local drinking water supplies drawn from groundwater. In 1980, Lewis et al. performed a major review of the literature available at the time, and offered some guidelines for siting latrines. Current work by BGS involves a similar review of the issues.

This study reviews the risks to health[1] posed by groundwater pollution from on-site sanitation (particularly latrines) and attempts to consider it in the light of realistic alternatives. The study focuses on microbiological contamination because this is the most widespread and direct threat to health from on-site sanitation. There is little documentation of the threat to water supply from unsafe disposal of household chemicals, and in fact this remains an issue not yet realistically addressed in industrialised societies. The risks from nitrate contamination (the most frequent chemical contaminant of concern from pit latrines) are summarised in section 4.1.1.

Fourie et al. (1995) write that pollution from on-site sanitation is influenced by a variety of complex factors:

- **Varying subsurface conditions.** In addition to the variety of subsurface soils encountered, within any soil the most critical distinction is between the saturated and the unsaturated zone;
- **Varying contaminants.** Different contaminants have different characteristics (e.g. mobility and persistence) which are affected differently by conditions in the subsurface; and
- **Varying mechanisms of movement** through different materials and which vary with scale.

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[1] WHO defines health is as " a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." Under such a broad definition, the health benefits of sanitation in terms of dignity and convenience are significant, (as indeed they are to users!) For the purposes of this report, however, health is defined in a classic epidemiological sense as “the absence of disease”.

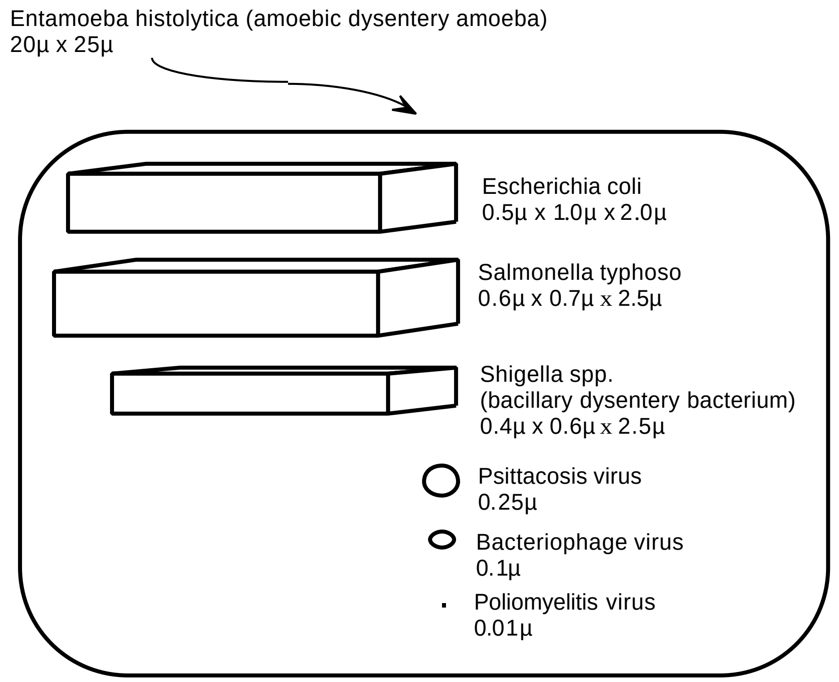
2. Pathogen characteristics

Human excreta may contain four types of pathogens (Lewis, Foster et al. 1980):

- eggs of helminths (worms)
- protozoa
- bacteria and
- viruses

Helminths and protozoa are larger than bacteria which in turn are larger than viruses. The comparative sizes of micro-organisms are shown in Box 1.

Box 1 Comparative sizes of selected micro-organisms

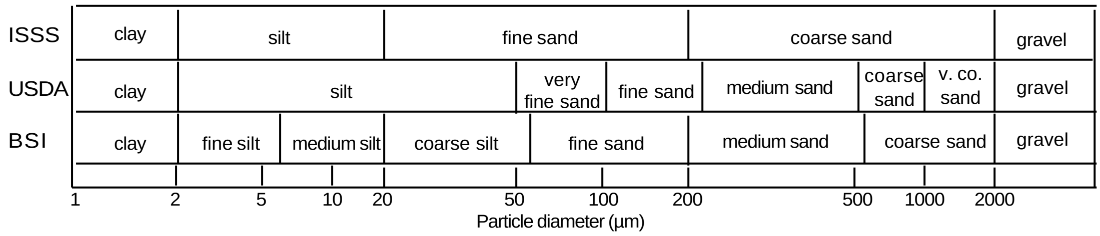


From McNabb (1977), quoted in Lewis et al. (1980)

Helminths and protozoa are not considered further. As they are relatively large (> 25µ) they are removed efficiently through physical filtration in the soil and it is unlikely they will pollute groundwater (Lewis, Foster et al. 1980).

Bacteria and viruses are much smaller. The percolating effluent from sanitation systems can transport bacteria and viruses into the groundwater and these organisms may be ingested and cause infection. Soil consisting predominantly of clay will probably filter most bacteria, including those in Box 1. However, even the finest grained clays have only a slight filtration effect on viruses (Fourie and van Ryneveld 1995) (see Box 2).

Box 2 Soil particle size classification



ISSS: International Society of Soil Science, USDA: US Department of Agriculture, BSI: British Standards Institution

After Shaw (1994)

The number of bacteria and viruses someone excretes depends on their age and state of health. All individuals excrete bacteria in vast numbers, the majority of which are not pathogenic (disease-causing). Faecal matter contains an average of 10^9 bacteria per gram, while an infected individual can excrete up to 10^6 viruses per gram of faeces. (Lewis, Foster et al. 1980) The rate of inactivation by natural or artificial processes depends on both the efficiency of removal and the numbers initially present. Excreted bacteria and viruses are transmitted by many other routes including, fingers, flies and food transmission.

Whether or not an individual becomes infected will depend on the concentration and persistence of the pathogen in the groundwater and the infectious dose required to initiate disease. In general excreted viruses have low infectious doses (<100 organisms) whereas the median infectious dose for bacteria is typically 10,000 or more. Bacteria, however, can multiply outside their host.

Box 3 Diseases and their agents which might be spread by faecally contaminated groundwater

Viral Disease	**Pathogen**
Infectious hepatitis	Hepatitis A virus
Poliomyelitis	Poliovirus
Diarrhoeal diseases	Rotavirus, Norwalk agent, other viruses
Varied symptoms and diseases	Echoviruses and Coxsackievirus
Bacterial Disease	**Pathogen**
Cholera	*Vibrio cholerae*
Typhoid fever	*Salmonella typhi*
Paratyphoid fever	*Salmonella paratyphi*
Bacillary dysentery	*Shigella spp.*
Diarrhoeal diseases	Enterotoxigenic *E. coli*
	Enteroinvasive *E. coli*
	Enteropathogenic *E. coli*
	Salmonella spp.
	Campylobacter petus spp*. jejuni*

Source: Lewis, Foster et al. (1980)

3. Groundwater pollution from on-site sanitation

Most on-site sanitation systems depend upon the capacity of the soils in the unsaturated or aeration zone (see Box 4) to accept and purify effluent. These functions may be in conflict under certain conditions but they both relate, directly or indirectly, to the regime of groundwater movement. Groundwater movement itself is largely controlled by the hydraulic characteristics of the soil. These hydraulic characteristics determine the moisture content, flow path and residence time of pollutants (Lewis, Foster et al. 1980).

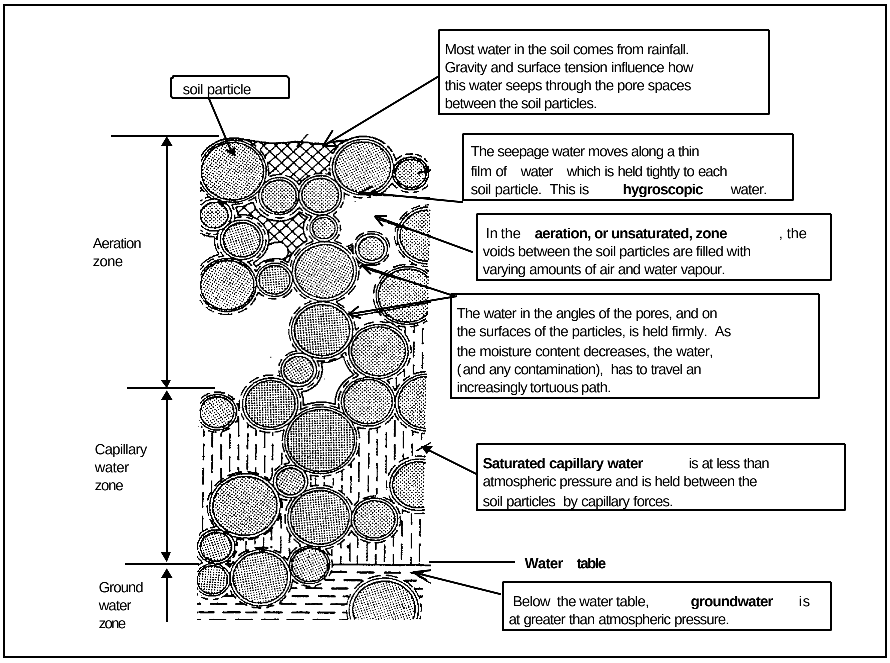
3.1 Basic groundwater hydrology

Soil can dispose of water and human wastes very effectively. While organic material for plants and other organisms is an important constituent of soil, the original parent material of soil is solid rock from the Earth's outer skin. Weathered and eroded by wind or water, the loose deposits may have moved great distances. Soil depths and composition are, therefore, variable and may be directly related, or bear no relation, to the underlying weathered rocks.

Most water in the soil comes from rainfall. Water seeps through the pore space by gravity and surface tension and its pathways are smoothed by a thin film of hygroscopic water on each of the soil particles. The hygroscopic moisture is held tightly by electrostatic forces and is not readily moved by other forces, including plant roots (Shaw 1994). These forces are measured as the moisture potential (ψ) or soil tension. The soil is saturated when ψ is equal to zero.

There are three zones of varying degrees of water saturation in soil, and these are shown in Box 4. In the **unsaturated, or aeration zone** the voids in the soil are filled with varying amounts of air and water vapour. The aeration zone is a complex mixture of solid particles, liquids and gases. Below the aeration zone lies **the saturated capillary zone,** a layer of saturated soil where all the pore space is occupied by water. In this zone, the water is at less than atmospheric pressure and is held by capillary forces between soil particles. The **water table** is defined as the surface over which the pressure equals atmospheric pressure. In the **saturated or groundwater zone** below the water table, the water pressure exceeds atmospheric pressure. The extent of the capillary zone depends on the composition of the soil and the packing of the soil particles, and can range from a few centimetres in a coarse sandy soil to a few metres in a clay soil (Shaw 1994).

Box 4 Water in the soil

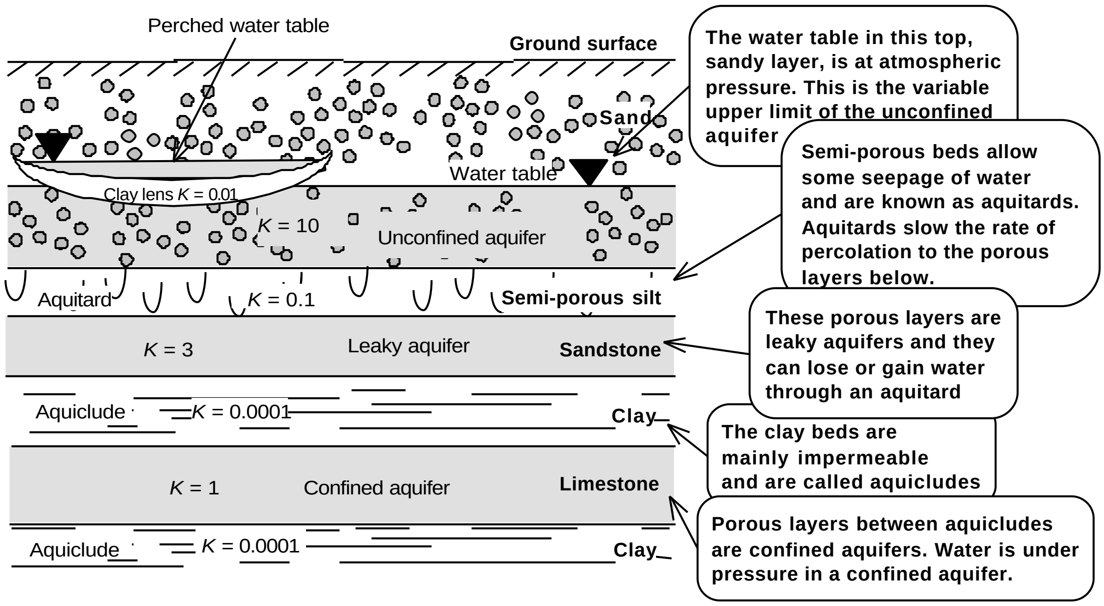


After Wiesner (1970) as shown in Shaw (1994)

The rate at which soil dries is a function of the pore size of the soil or rock. Sandy soils and certain sandstones have relatively large pores which drain at quite low tensions (negative pressures). Clays and silts, however, do not drain well but retain water and have relatively large moisture contents over a wide range of tensions. The actual distribution of pore size is expensive to determine, so descriptive soil classifications are based on the distribution of grain sizes (Lewis, Foster et al. 1980).

In sands and sandy soils the pore size is usually the size of the void between individual grains. Groundwater velocities in unsaturated soils do not normally exceed 0.3 m/d. If the soil has a high clay content and/or a lot of organic matter the soil particles can aggregate. Voids can form under these conditions, which can be promoted or accentuated by plant roots. At shallow depths all rocks contain sub-planar voids known collectively as fissures. The water is usually at low tensions within these voids, as their aperture is relatively large compared to the intergranular pores. At moisture tensions below 0.2m the larger fissures can conduct water and the hydraulic conductivity increases enormously. Velocities can exceed 5m/d and the potential for groundwater contamination increases (Lewis, Foster et al. 1980). As the soil reaches saturation, liquid flows directly through the pores, rather than along the circuitous layer adjacent to the particles.

Box 5 Aquifer definitions



sample *K* values md^{-1} of conductivity or permeability

In this simplified diagram layers of porous sands or limestones are subdivided by less porous material, such as silt or clay, which inhibit water movement. From: Shaw (1994)

3.2 Pathogen movement and removal in soil

Pathogens do not travel farther or faster than the water in which they are suspended. During their travel through the soil, a fraction will die off or be collected (adsorbed or screened) on the soil matrix as they travel. ***The key factor that affects the removal and elimination of bacteria and viruses from groundwater used for drinking is thus the maximisation of the effluent residence time between the source of contamination and the point of water abstraction. Because of the very low velocities of unsaturated flow, the unsaturated zone is the most important line of defence against faecal pollution of aquifers***. This can be achieved by keeping the pit or infiltration surface well above the water table, maintaining a low hydraulic loading rate or by restricting the infiltration rate, which will occur naturally when the infiltration surface becomes clogged. Soil type will also affect the movement and removal of micro-organisms; sandy and organic soils are poor adsorbers whilst soils with a clay content are better.

Box 6 Viruses and bacteria…survival

	Saturated	Unsaturated
Virus	Little is known about virus survival in groundwater so rough estimates are based on data relating to their survival in surface waters. It appears that temperature is the single most important factor in die-off (Lewis, Foster et al. 1980). A 99.9% reduction may be expected at 20^{o}C within about 10 days, although a few enteroviruses may survive for many months (Feachem, Bradley et al. 1983).	Virus survival increases with degree of viral adsorption to the soil so those soils which are most effective in removing viruses also enable them to persist for the longest periods. In shallow soil viruses are affected by higher temperatures and evaporation and they also face competition from aerobic soil micro-organisms. They thus tend to survive longer at deeper levels (see Box 12) (Lewis, Foster et al. 1980). Viruses may sometimes be isolated from samples containing no detectable faecal bacteria indicator organisms; this applies mainly to anaerobic conditions (Lewis, Foster et al. 1981).
Bacteria	Information on bacterial survival in groundwater is limited. It is generally accepted that survival is longer in groundwater than in surface water due to the absence of sunlight and because competition for available nutrients is not so great (Lewis, Foster et al. 1980). Temperature is important: the bacteria survive longer at lower temperatures. The chemical nature of the groundwater will also affect the survival capabilities of any bacteria present. Enteric bacteria are usually intolerant of acid conditions and, to varying degrees, are also intolerant of saline groundwaters (Lewis, Foster et al. 1980).	Moisture and temperature are the dominant factors controlling the survival of bacteria in soil, however, reported survival times vary widely and the data are complicated by the possibility of regrowth (see Box 12) (Lewis, Foster et al. 1980).

Box 7 Viruses and bacteria…movement

	Saturated	Unsaturated
Virus	Since the porous media are saturated, immobilisation of the organisms will be less in all cases The linear travel of pollution is governed primarily by the velocity of the groundwater flow and the viability of the organisms (Lewis, Foster et al. 1980)	Viruses are much smaller than bacteria. Removal appears to depend almost entirely on adsorption which is not an irreversible process (see Box 11) (Lewis, Foster et al. 1980).
Bacteria	It is important to take site conditions into account. Bacteria travel up to 3m in the direction of groundwater flow. They diminish with distance and are virtually absent in the final period. There is a general rule of 15m between a pit latrine and a well (see Box 13). The distance over which enteric bacteria are traced depends on more than their death rate and the velocity of the groundwater. It also depends on the initial concentration of enteric bacteria, their dispersion within the groundwater body, the volume of the sample which is tested and the sensitivity of the detection method. The maximum linear diffusion appears to be that distance which the groundwater flows in about 10 days. This contrasts sharply with laboratory studies and controlled field studies which suggest enteric bacteria can survive for 100 days or more (Lewis, Foster et al. 1980)	The main mechanism limiting the movement of bacteria through soil appears to be filtration at the infiltration surface (Lewis, Foster et al. 1980). This is most effective at the surface of the organic mat of the clogged zone (see Box 9). The removal of bacteria and viruses is essentially a biological process; for example, a slow sand filter consists of a very large surface area populated by micro-organisms. These micro-organisms remove other bacteria, small particles and chemicals dissolved in the filtering water. The sand is merely a support for the biological film (Poynter and Slade 1977).

Box 8 Factors influencing movement of bacteria and viruses through soil

Factor	Effect
Rainfall	Micro-organisms retained near the soil surface may be eluted after heavy rainfall because of the establishment of ionic gradients within the soil column.
pH	Low pH favours virus adsorption; high pH results in elution of adsorbed viruses.
Soil composition	Bacteria and viruses are readily adsorbed to clays under appropriate conditions, and the higher the clay content of the soil, the greater the removal. Sandy loam soils and other soils containing organic matter are also favourable for removal.
Hydraulic loading / flow rate	As the flow rate increases, micro-organisms penetrate deeper. The hydraulic loading is naturally increased during periods of groundwater recharge by infiltrating rainfall.
Soluble organic matter	Soluble organic matter has been shown to compete with organisms for adsorption sites on the soil particles, resulting in decreased adsorption or elution of already adsorbed viruses.
Cations	Cations, especially divalent ones, can act to neutralize or reduce repulsive forces between negatively charged micro-organisms and soil particles, allowing adsorption to proceed.

Source: Lewis, Foster et al. (1980)

3.2.1 Filtration

Box 9 Studies of the filtration of bacteria at the infiltration surface

Author	Indicator	Findings
Ziebell et al. (1974)	bacterial population	• within 30cm of the clogged zone the bacterial population below and to the side of a septic tank seepage bed fell close to the population level in a control soil sample.
Caldwell and Parr (1937)	faecal coliforms	• faecal coliforms were detected 10m away from a newly constructed latrine which penetrated the water table • within three months – i.e. after clogging - pollutant dispersion was considerably curtailed.
Krone et al. (1958)	E. coli	• while investigating the removal of E. coli in sand columns it was found that the effluent concentration rose gradually and then declined. • investigators concluded that accumulating bacteria at the soil surface enhances the straining mechanism.
Butler et al. (1954)	coliform bacteria	• measurements of coliform bacteria in sandy soils used to dispose of settled sewage showed a dramatic reduction in coliforms in the first 50mm of soil and a subsequent build-up of bacteria at lower levels

Reviewed in Lewis, Foster et al. (1980)

Box 10 Preliminary results from pollution studies in Uganda

As part of a larger project to develop systems of water supply monitoring in Uganda, groundwater supplies have been tested in 4 major towns in the country to date. These are Kampala, Mbale, Soroti and Tororo. In a second study, a more detailed investigation of groundwater quality in 2 urban centres in Uganda is being carried out with Makerere University. The second study, 'Assessing risks to groundwater from on-site sanitation' (ARGOSS), with sites in Iganga and Kampala, aims to establish the impact of on-site sanitation on groundwater quality under contrasting hydrogeological conditions and in areas of contrasting population density.

As part of the first project, an initial assessment of 171 protected springs (out of 259 total) in Kampala carried out during December 1997 and January 1998 (wet season) showed that only 2% were free of contamination and that 65% had coliform counts in excess of the Ugandan guideline for drinking water supplies (50cfu/100ml). Spring water quality varies with rainfall; with average microbial loading significantly increasing during high rainfall periods (though some supplies remain at very high levels of contamination throughout the year). Increased contamination may result from direct contamination from surface runoff due to inadequate protection or from rising water tables that permit flooding of latrines and, therefore, a greater likelihood of microbial transport to the spring outlet.

Sanitary inspection data for 259 samples collected between December 1997 and May 1998 show a strong association between the degree of faecal contamination and the frequency of recorded faults in sanitary completion of the spring. No strong association was observed for latrines within 30m and/or uphill and degree of faecal contamination.

These preliminary data suggest the principal route of contamination of protected springs in Kampala is the immediate area surrounding the protection works and that localised sources of faeces derived from surface water drains and watercourses are the major contributors to groundwater quality deterioration (Howard, Luyima et al., 1998).

Source: Barrett et al. (1999)

3.2.2 Adsorption

Viruses are much smaller than bacteria, and their transport and removal are therefore influenced by different mechanisms. Removal appears to depend almost entirely on adsorption, which is a reversible process (see Box 11).

Box 11 Studies of adsorption

Author	Study	Conclusions
Burge and Enkiri (1978)	• laboratory study of adsorption of bacteriophage ∅ X-174 on 5 different soils	• as the pH falls the virus particles become more positively charged and are more easily adsorbed • good correlation found between adsorption rates and cation exchange capacity, specific surface area and concentration of organic matter (r = 0.89, 0.85, 0.98 respectively) • negative correlation between adsorption rate and the pH (r = -0.94)
Green and Cliver (1975)	• single doses (50 mm/d) of septic tank effluent were applied to 60cm columns of Wisconsin soil for more than a year • the effluent doses had been inoculated with polio virus type 1 (10^5 plaque forming units per litre) and the soil columns removed all viruses	• viruses broke through at loading rate of 500 mm/d • the virus detention within the soil varies with pore saturation; there is less opportunity for contact with surfaces as the soil becomes more saturated • large hydraulic surges and uneven distribution of waste reduce the rate at which viruses are removed
Goldschmid et al. (1973)	• sterile sand columns were loaded at a constant rate of 1,200 mm/d to investigate the adsorptive behaviour of E. coli	• changes in ionic strength can reverse the process of adsorption • bacterial removal was greater with tapwater than with distilled water • when triple distilled water was used as the medium there was virtually no bacterial removal
Landry et al. (1979)	• flooding soil columns with de-ionized water caused viruses to be desorbed • adding calcium chloride to the de-ionized water before applying sewage effluent enabled the viruses to penetrate the bed; the viruses were eventually re-adsorbed	• large reductions (99.9% or more) of viruses could be expected if secondary effluent is passed through 0.25m of calcareous sand at rates of up to 550 mm/d • viruses would only move through calcareous sand if heavy rains fell within one day of applying the sewage
Landry et al. (1979)	• sand cores studied in the laboratory	• the number of viruses mobilized by simulated rainfall ranged from 24% to 66% and depended upon the strain of the virus • different strains of viruses have varying adsorptive properties
Lance and Gerba (1976)	• rate and depth of virus penetration • virus adsorption in soil is increased above some breakpoint velocity • flow rate changes above and below the breakpoint do *not* affect virus adsorption	• postulated that the breakthrough velocity corresponds with the velocity where some water begins to move through the large soil pores allowing little or no contact between viruses in the water and adsorptive surfaces • the velocity of the water moving through pores may be most important factor affecting depth of virus penetration; this implies adsorption is not an important factor of removal in the saturated zone, especially when the groundwater velocity is high

Author	Study	Conclusions
Wellings et al. (1974)	• a site was irrigated with secondary sewage at a rate of 1-5 cm a day • viral penetration of up to 6 m in sandy soil was attributed to heavy rainfall (711 mm)	• bacteria and viruses which had been adsorbed could be desorbed after heavy rain (see also (Martin and Noonan 1977; Sinton 1980))

Reviewed in Lewis, Foster et al. (1980)

3.3 Applied field investigations of pollutant movement

Box 12 Factors influencing the survival of bacteria and viruses in soils

Factor	Effects
Moisture content	Greater survival time in moist soils and during times of high rainfall
Moisture holding capacity	Survival time is less in sandy soils than in soils with greater water holding capacity
Temperature	Increased survival at lower temperatures
Adsorption	As virus adsorption to soil increases, viral survival is prolonged
pH	Shorter survival times in acid soils (pH 3-5) than in alkaline soils (bacteria)
Sunlight/evaporation	Shorter survival time at soil surface
Organic matter	Increased survival of bacteria and possible regrowth when sufficient amounts of organic matter are present
Antagonism from soil microflora	Increased survival time in sterile soil, soil microflora compete with bacteria for nutrients; aerobic soil micro-organisms adversely affect virus survival while anaerobic micro-organisms have no effect

Source: Lewis, Foster et al. (1980)

As noted above, residence time is the key factor in eliminating groundwater contamination by pathogenic bacteria and viruses; it is thus important to maximise the residence time of liquid in the unsaturated zone. Early researchers concentrated on establishing the lateral separation between wells/boreholes and on-site sanitation systems (chiefly pit latrines) to protect the groundwater. From this work, a general rule of 15m or 50 ft of separation between a pit privy and a well became widely accepted as an acceptable standard. Unfortunately, the applicability of this rule depends a great deal upon local soil and groundwater conditions (see Box 12).

As noted by Lewis et al. (1980), the linear travel of bacterial pollution is governed primarily by the velocity of the groundwater flow and the viability of the organisms. The initial concentration of enteric bacteria, their dispersion within the groundwater body, the volume of the sample which is tested and the sensitivity of the detection method also influence the distance over which bacteria can be traced.

According to Lewis et al. (1980), the maximum linear diffusion appears to be that distance which the groundwater flows in about 10 days. This contrasts sharply with laboratory studies and controlled field studies which suggest enteric bacteria can survive for 100 days or more.

Box 13 Bacteria in the saturated zone

A review of studies conducted in India and America concluded that:

- bacterial travel depends mainly on the velocity of groundwater flow.
- the probable survival time for coliforms in the anaerobic groundwater environment is 4-7 days. The distance the groundwater will travel in 4-7 days is thus the extent to which bacteria will penetrate the saturated zone
- the spread of pollution reduces when a gelatinous membrane is established on soil particles. This membrane acts as a physical barrier to the bacteria and the soil becomes a real biological filter comparable to a slow sand filter in water treatment
- the safe distance between a borehole latrine or leaching cesspit and a well is represented by about 8 days travel of the groundwater
- in the study areas in India where the hydraulic gradient is less than 0.01, and the soil is sandy (effective size less than 0.25mm), the groundwater velocity is unlikely to exceed 0.9m/d and a horizontal distance of 7.5m will provide an ample margin of safety against bacterial pollution.

Subrahmanyan (1980) quoted in Lewis, Foster et al. (1980)

4. Health aspects

4.1 Drinking water, sanitation and health

What is the risk to health of groundwater contamination from latrines relative to the benefits of improved sanitation? Much care is required in attempting to assess the relative potential benefits and impacts of sanitation and water interventions. A number of studies have attempted to estimate the separate and joint health effects of improvements to water supply and sanitation in developing countries. However useful it may be to measure the separate effects of different interventions, there are a number of serious conceptual issues in the attempt to do so (see Box 13) (Lewin, Stephens et al. 1999). This chapter presents risks in terms of the two most wide-spread groundwater contaminants attributed to latrines: nitrates and microbiological contamination.

Box 14 Difficulties in estimating benefits and impacts from sanitation and water interventions

- Faecal-oral diseases have multiple transmission routes which can result in significant interactions between water and sanitation interventions. These are rarely accounted for satisfactorily. For example, the health impacts from an improved water supply may depend on whether household sanitation conditions are good or poor, and vice versa, and on household hygiene practices (Cairncross and Kochar 1994).
- Latrine owners tend to be (a) better off than non-owners, (b) more likely to use improved water sources and larger quantities of water and (c) more likely to report good hygiene practices (Daniels, Cousens et al. 1990). Furthermore, households which access one form of environmental improvement are probably more likely to access others, leading to cumulative health benefits.
- Interactions between interventions are difficult to measure as they can vary from setting to setting. Where interactions are present, but not taken into account, too little impact may be attributed to early interventions, and too much to the later intervention. The later intervention will pick up the separate and joint effects of all interventions.

Source: Lewin, Stephens et al. (1999)

4.1.1 Nitrates

Nitrates are considered significant as a health indicator for water quality for 3 reasons:

- high levels are directly associated with methaemoglobinaemia, or "blue baby syndrome" an acute condition which is most frequently found among bottle-fed infants of less than 3 months age.
- Nitrates and nitrites have been suggested as possible carcinogens by a number of researchers
- Nitrates can be used as a crude indicator of faecal pollution where microbiological data are unavailable.

The WHO Drinking Water Guidelines (WHO, 1993) suggest an upper limit of 10 mg-l as nitrogen, or 50 mg-l as NO_3. WHO notes that "the epidemiological evidence for an association between dietary nitrate and cancer is insufficient, and the guideline value for nitrate in drinking-water is established solely to prevent methaemoglobinaemia, which depends upon the conversion of nitrate to nitrite. Although bottle-fed infants of less than 3 months of age are most susceptible, occasional cases have been reported in some adult populations."

Methaemoglobinaemia can occur when nitrates are converted to nitrites (e.g. by non-pathogenic organisms commonly found in the mouth, pharynx and colon). When this occurs, haemoglobin may be oxidised to methaemoglobin, thus preventing the transport and release of oxygen. If the rate of mathaemoglobin production exceeds the rate of its reduction, and the proportion of methaemoglobin rises to about 10%, cyanosis becomes apparent. (Johns and Lawrence 1973)

Actual morbidity and mortality statistics for methaemoglobinaemia are not easily found. In their early article calling attention to the potential hazard of high nitrate waters in Australia, Johns & Lawrence (1973) note that "There do not appear to be any recorded cases in Australia of methaemoglobinaemia caused by the ingestion of water which contains nitrate, but the condiition may have occurred without being diagnosed." Writing in 1972, Hillel Shuval (Shuval 1972) noted that, since the original observation of the phenomenon of high nitrates causing methaemoglobinaemia in 1945, only 2000 cases had been identified worldwide. More recently, Jackson (1997) notes that methaemoglobinaemia has not been reported in South Africa despite the presence of areas with high nitrates, and that Hungary, the only country where methemoglobinaemia is a notifiable disease, reported 562 cases and 7 fatalities in the decade 1981-1990 out of a population of 10 million. Johnson & Kross (1990) noted that "A 1950 report listed 144 cases of infant methemoglobinemia with 14 deaths in one 30-month period in Minnesota. Infant deaths resulting from misdiagnosis of this preventable, treatable intoxication were still occurring as recently as 1986 in South Dakota. In this state, about 39% of dug or bored wells were unsafe due to high nitrate content, compared with 22% of drilled wells and 16% of driven wells." While a very serious condition for those who contract the disease, the available data indicate that the condition is a rare one, especially in comparison with the estimated 3 million deaths a year from diarrhoeal disease.

There has also been some debate about the linkage between "high" nitrate concentrations in water, and the development of methaemoglobin in children. Craun et al. (1981) report evidence from Washington County Illinois which did not show that ingestion of water with a nitrate concentration of 22-111 mg/l NO3-N was related to increasing methaemoglobin levels, nor that the children had high or above normal methaemoglobin levels. Shuval's work also failed to identify higher methaemoglobin levels among children in areas with nitrate concentrations varying between 50 and 90 mg/l. Shuval urged caution in the interpretation of this result, as he pointed out that only 6% of the infants consumed appreciable amounts of tap water (combined with powdered milk formula) while the other children consumed either breast-milk or whole cow's milk. While accepting Shuval's point that this practice may underestimate the threat of methaemoglobinaemia in other areas, the point that breast-feeding can minimise the risk in children under 3 months of age should be borne in mind in assessing the epidemiological risk of high-nitrate waters.

In summary, the risks of high nitrate groundwater, either from cancer or from methaemoglobinaemia appear to be orders of magnitude less on a global basis than those from diarrhoeal disease, which is estimated to kill three million children a year. Nevertheless, high nitrate concentrations in groundwater may be a significant local phenomenon of which those working in water resources need to be aware. Cairncross & Feachem (1993) offer a useful "order of magnitude" computation to show how pit latrines in Botswana for an arid area with a population density of 63 people/hectare can lead to nitrate concentrations far in excess of the WHO guidelines. The authors point out that the problem arises largely because of the limited infiltration available to dilute the human nitrogen loading. (In many areas, agricultural fertilizer represents the greatest source of nitrogen and nitrate loading, and this too must be considered.) Cairncross & Feachem also point out that where high nitrate concentrations are likely to result from on-site sanitation, they do not, by themselves, always justify the exclusion of pit latrines as a sanitation option, as the choice of technology will vary with many factors. Some of these factors are considered in Chapter 5 of this document.

4.1.2 Diarrhoeal diseases

Diarrhoeal diseases represent a far more serious and widespread health problem than methaemoglobinaemia. Esrey (1991) reviewed a number of published studies, compiling figures from a range of studies in different settings which used different interventions and methods.

Box 15 summarises the expected reductions in diarrhoeal disease morbidity from improvements in one or more components of water and sanitation. As Box 14 indicates, separation of the effects of interventions one from another may produce artefacts of analysis rather than insight, so the figures in Box 15 are presented to give a broad indication of the potential effectiveness of different interventions. Effectiveness in the field may, of course, differ from that outlined. Diarrhoeal disease is used as an example as it is the largest contributor to the disease burden of the faecal-oral diseases (Lewin, Stephens et al., 1999).

Box 15 Median reductions in diarrhoeal disease morbidity from improvements in one of more components of water and sanitation

Intervention	All studies		Rigorous studies	
	no	**reduction (%)**	**no**	**reduction (%)**
Water quality and quantity	22	16	2	17
Water quality	7	17	4	15
Water quantity	7	27	5	20
Sanitation	11	22	5	36
Water and sanitation	7	20	2	30
Hygiene	6	33	6	33
All studies	49	22	19	26

Source: Esrey (1991)

Box 15 suggests that improving water quality on its own has a substantially lower impact on diarrhoeal disease than improving sanitation. There are two possible reasons for this (Lewin, Stephens et al., 1999):

- Improving water quality at source may not ensure a reduction in the transmission of water-related diseases. A number of studies (Lindskog and Lindskog 1988; Mertens, Fernando et al., 1990; Verweij, van Egmond et al., 1991; Genthe, Strauss et al., 1997) show significant deterioration in water quality between the source and the point of use. Contamination of drinking water *during collection and storage* appears to be more severe where the water source is outside the home (i.e. private outdoor and communal taps). Contamination of drinking water after collection may thus pose a greater risk for diarrhoea than any contamination of the water at source, and that improvements in water quality alone would therefore be expected to have little impact on diarrhoea in highly contaminated neighbourhoods.

- Water quality is less important than water quantity and receives too much attention relative to the role of water in 'washing away' pathogens. The availability of larger volumes of water is associated with child health benefits and can lead to increased domestic water consumption for hygiene purposes (Cairncross 1987; Aziz, B.A. et al., 1990). Household water consumption remains largely the same until the source is within the compound or home, when it rises exponentially, often to more than four times previous volumes (Cairncross and Cliff, 1987).

In a later paper Esrey (1996) analysed data from eight countries in Africa, Asia and South America to see whether incremental health effects regarding diarrhoea and nutritional status result from incremental improvements in water and sanitation conditions.

Unimproved water supplies were defined as rivers, ponds, lakes and unprotected springs. Unimproved sanitaton referred to open defecation. Communities with improved facilities did not all have the same facilities so services were classified broadly as intermediate or optimal. Intermediate water facilities were centrally located hand pumps, taps or wells. Optimal supplies were those located on the premises or inside the household. Pit latrines or similar facilities were classed as intermediate sanitation while optimal sanitation referred to water-based systems e.g. flush toilets.

Esrey (1996) found a reduction in diarrhoea from optimal sanitation to unimproved sanitation of 44% in the absence of improved water, 13% in the presence of intermediate water supplies and 19% with optimal water supplies.

General conclusions were that:

- improvements in sanitation had health impacts for diarrhoea and anthropometric factors at all levels of water supply, even when the water was not improved;
- improvements in water had no health impact if the sanitation remained unimproved and
- improvements in water and sanitation together were synergistic in producing larger impacts than either alone.

Cairncross and Kolsky (1997) criticise aspects of this paper based on grossly aggregated data, which do not permit control for a number of confounding variables. In addition, they question the conclusion that "optimal" sanitation (a flush toilet) brings health benefits over and above those of pit latrines, without considering what route of disease transmission a flush toilet will interrupt.

4.2 Health risks from other forms of sanitation

Alternatives to latrines, such as sewers and septic tanks also involve health risks. Septic tanks pose an obvious risk, and can create localised saturated flow conditions that imply greater risks of groundwater contamination than pit latrines with limited flows. Leaking sewers can also contaminate groundwater; a UK outbreak of gastro-enteritis in 1980 which affected over 100 people northeast of Leeds was traced to borehole contamination from a surcharged sewer. The sewage spread through 100 m of highly fissured magnesium limestone to contaminate a borehole used for the Bramham water supply. (Short, 1988).

Smith (1993) looked at the effect of piped sewerage on Ascaris (roundworm) infection in a Gaza Strip refugee camp. In this setting, *Ascaris* ova may be transmitted through a number of persistent alternative pathways involving environmental contamination and subsequent ingestion. Accordingly, Smith sampled sand from both houseyards and the street, as children played in both. While there was no statistically significant association between yard contamination and sewerage, a significant ($p < 0.04$) *positive* association was found between sewerage and street sand contamination; in other words, the sewered streets had *more* street sand contamination than the unsewered streets. The crude "relative risk" of contamination of sand in sewered streets was 1.53 relative to unsewered streets.

Smith studied the effects of this street sand contamination, and found that children aged 0-5 years were four times as likely to be reinfected with *Ascaris* after treatment if the street sand outside their yard door was contaminated, compared with children where the street sand was not contaminated.

> "The argument for cause and effect is strengthened by the magnitude of the relationship, the statistical significance both before and after controlling for confounding, and the biological plausibility of the result in that children living near contaminated street sand are more likely to ingest ova and hence develop reinfection. The use of reinfection, rather than infection, also strengthens the case for the effect because all young children in each alley were treated at the start of the reinfection period and were thus not likely to be a cause of sand infection during the reinfection period."

This study thus established that the sewerage intervention under investigation did *not* reduce environmental contamination or human infection with *Ascaris*, and indeed, appeared to have exacerbated the problem for those living nearby. Smith put forward the hypothesis that the Ascaris contamination of street sand could be associated with winter flooding, and that adequate storm drainage could thus reduce the problem.

Schulz and Kroeger (1992) reported on soil contamination as an indication of environmental hygiene in urban areas of northeast Brazil. The paper described the collection and analysis of samples for *Ascaris* from the domestic environment and street of two communities. The highest counts reported, both in terms of % samples positive, and in terms of median egg count/gram were in the vicinity of a sewage rivulet, formed by sewage flowing over the streets, "especially during the rainy season" due to the absence of adequate sewage conduits. Shade and rainfall were both significantly associated with contamination by *Ascaris* eggs. The authors noted that "the deficient sewerage system ...exposed the population in some cases to a higher infection hazard than if the houses had simple but clean latrines" and that "water toilets cannot always be recommended in a region with strong rainfall."

4.3 Drinking water quality and health

Water-borne transmission of faecal-oral disease is the main concern about groundwater pollution from on-site sanitation. Having discussed the various mechanisms for transport and removal of pathogens in groundwater, it is appropriate to review the evidence on water quality and health. What is known about the dose-response relation between faecal contamination and health outcomes?

Moe et al. (1991) examined the relationship between concentrations of bacteria in drinking-water and the prevalence of diarrhoea in a population that consumed this water. They evaluated four bacterial indicators of water quality:

- faecal coliforms
- *Escherichia coli*
- enterocci
- faecal streptococci

They found similar pattern of disease rates for each indicator and point to higher rates for the highest category (>1,000 indicators per 100 ml). They suggest that this density of indicator organisms represents an exposure threshold.

Box 16 Risk ratios of disease-exposure for four indicator organisms

Indicator	p value	risk ratio	95% CI
Escherichia coli	0.02	1.52	1.06-2.18
enterocci	0.03	1.56	1.04-2.33
faecal streptococci	0.08	1.47	0.95-2.28
faecal coliforms	0.29	1.22	0.85-1.74

from Moe et al. (1991)

Moe et al. then defined two exposure categories: low (≤1,000 indicators per 100 ml) and high (>1,000 indicators per 100 ml). They repeated the Mantel-Haenszel χ^2 test for association to find an overall association and estimate of an overall effect, or risk ratio. Each indicator had a positive relationship between exposure and disease (see Box 16).

Faecal coliforms had the smallest overall risk ratio and were not significant predictors of diarrhoeal disease at the 0.05 level. The p value for faecal streptococci was not significant at the 0.05 level and the 95% CI of the risk ratio includes unity.

Moe et al. did a stratified analysis of the relationship between water quality and the risk of 'highly credible' diarrhoea i.e. those cases from which a diarrhoea pathogen was isolated from a rectal swab (34% of all diarrhoea cases). Faecal coliforms and faecal streptococci were not significant predictors of risk. *Escherichia coli* were marginally significant when the data were combined over time (p= 0.06) but not when time was included as a stratification variable (p = 0.12). Enterococci were highly significant predictors of illness in both the combined analysis and when time was controlled (p values were 0.005 and 0.01 respectively).

Kirchoff et al. (1982)

There was little difference between the illness rates of children drinking good quality water (<1 E. coli per 100 ml) and those drinking moderately contaminated water (2-100 E. coli per 100 ml). This suggests other transmission routes are more important when the water quality is good

Box 17 Water contamination as a single factor determining the rates of gastrointestinal illness

The importance of water contamination as a single factor determining the rates of gastrointestinal illness within a community remains unresolved. Kirchoff et al. conducted a blind crossover trial to investigate water treatment with inexpensive hypochlorite.

A community health worker visited households in a rural village in NE Brazil. The householders in this village collected used pond-water for consumption and washing. Villagers filtered the water into clay pots and allowed it to settle, and 'cool', overnight. The pond was several acres in size and it was also used for washing and was open to animals.

20 households were divided geographically into two colour-coded groups:

- group 1 hypochlorite → placebo
- group 2 placebo → hypochlorite

Newly obtained water from each household was treated with 10% hypochlorite solution or distilled water. The health worker who treated the water was not aware of what the two liquids were but assigned the treatment according to the colour code. At the end of nine weeks the treatments were switched , thus crossing over the study ... The treatment was then continued for another nine weeks. Twenty-five families consented to join the study, twenty actually took part although four of these twenty households had dropped out by the end of the study.

The mean number of faecal coliforms per dl in the water samples was significantly less ($p<0.001$) in the hypochlorite treated water 70 vs 16,000 (range: 2 - 160,000). The mean number of faecal coliforms per dl in the water taken from the pond was 9,700 (range: 1,600 - 160,000) which suggests that a significant amount of contamination happened in the home.

The authors found no significant difference between the incidence rates in days of diarrhoea per year for children in the treatment or placebo groups (26.9 and 27.7 respectively).

Kirchoff et al. acknowledge the drop out rate causes methodological difficulties with their analysis. They suggest additional reasons why the households using treated water experienced no fall in diarrhoeal illnesses

- participants may have been drinking water from other sources outside the home (e.g. children at school or fathers at work) which were as highly contaminated as water from the pond
- while the reduction of contamination levels may have been statistically significant it may not have been sufficient to reduce disease rates

It is also likely that:

- multiple factors, in addition to water quality, may be primary determinants of diarrhoea incidence rates -

to moderate.

Children drinking water with >1,000 E. coli per 100 ml had significantly higher rates of diarrhoeal disease than those drinking less contaminated water (Moe, Sobsey et al., 1991). The authors suggested that where the quality of drinking water is good or moderate other transmission routes of diarrhoeal disease may be more important; they stress that grossly contaminated water is a major source of exposure to faecal contamination and diarrhoeal pathogens.

What conclusions can be drawn from these discussions?

- Much of the literature, and many of the policy arguments about groundwater pollution from on-site sanitation focus upon "contamination" as if it were an strictly categorical phenomenon; either there is faecal contamination or there is not. The emergence of such a perspective is understandable when drinking water standards are commonly set at "0 E. coli/100 ml" on the grounds of minimising the risk of faecal-oral disease transmission. .
- If, however, one reviews the epidemiological evidence concerning the relationship between dose and response in drinking water, the evidence for the most commonly used indicator (E. coli), appears significant at doses greater than 10^3 E. coli/100 ml.
- Apart from drinking water contamination, there seems little reason to be concerned about groundwater pollution. Natural streams are reported to have faecal contamination on the order of 10^3 to 10^4 E. coli/100 ml, and this is not viewed in either the industrialised or developing world as an unacceptable level of pollution unless specific activities (e.g. bathing, swimming, fishing or irrigation) are planned. Water standards for bathing and irrigation are clustered around a standard of approximately 1000 E. coli/100 ml (Mara and Cairncross, 1989; Kolsky, 1999), although there is a heated and legitimate debate about the best indicator to use. If groundwater is contaminated from on-site sanitation to this level, then the arguments for treatment before drinking are the same as those for treating equivalently contaminated surface water. Where the contamination is one or two orders of magnitude less than this, however, there is *not* overwhelming epidemiological evidence that treatment is now required to prevent a significant hazard to health. It would thus appear unwise to forego the health benefits of affordable and sustainable sanitation to eliminate the risk of groundwater contamination of less than 1,000 E. coli/100 ml.
- Groundwater contamination is thus a matter of degree, and rather than basing all decisions on absolute water quality targets or guidelines, it may be more helpful to strive for the best practicable water quality which may be achieved within economic, financial, technical and social constraints. Such an approach will vary with the locally available alternatives of water supply. As we shall see in the next section, in many cases it can be cheaper to retain the benefits of affordable latrine sanitation and pipe in high quality drinking water than to consider alternative forms of sanitation with the intent of protecting the groundwater. In the majority of cases, however, there need not be a conflict between on-site sanitation and groundwater quality. In most cases, where appropriate separation between the latrine and the water used for drinking can be maintained, and especially if the pit of the latrine can be kept above the water table, groundwater contamination by latrines need not be a serious concern.

5. Options and choices

5.1 Protect groundwater or provide an alternative source?

In communities where shallow groundwater is already in use as a source of water supply, many consultants and authorities are tempted to declare that on-site sanitation is unacceptable in order to protect the groundwater. Some or all of the following assumptions (Box 18) are made in arriving at such a position.

Box 18 Some dubious assumptions about latrines, groundwater and health

- **Alternative forms of sanitation will be adopted if on-site sanitation is rejected.** This assumption is dubious where the proposed alternative requires a great deal more water or a substantially increased cost.
- **Maintaining drinking water quality is more significant for public health than sanitation.** Available evidence suggests the opposite.
- **Groundwater pollution is a categorical phenomenon;** much literature fails to quantify the *degree* of pollution, and indicates instead only whether or not indicator bacteria are found.
- **Changing the sanitation is the most effective way to improve water quality in wells.** In a recent issue of Waterlines devoted to on-site sanitation and water quality, both Macdonald et al. (1999) and Barrett et al. (1999) suggest that better well construction may be more significant than latrine location or construction in protecting the water being consumed.
- **Groundwater quality is the primary determinant of water quality consumed by the population.** In fact, as noted above, a number of studies have identified the transport, storage, and use of water in the home as the major source of drinking water contamination.
- **If alternative forms of sanitation are adopted (e.g. sewers) then pathogenic organisms will be managed appropriately.** In practice, there is often little or no treatment at the end of the sewer, and even fully functional conventional sewage treatment is grossly inadequate for pathogen removal. In practice intelligent decisions between on-site sanitation and off-site sanitation require a clear identification of "what happens to the pathogens?" and "who is at risk?" for all options.

Rather than a blanket "policy", one needs to investigate a range of realistic alternatives for the affected communities, and adopt a holistic approach that traces the consequences (and pathogens) throughout the system. Some preliminary work done on data from India (see Box 19, overleaf) provides evidence that treating water and piping it to communal taps may in many cases be more cost-effective than developing alternative sanitation strategies. This is because the financial and economic cost of water supply can be a major factor in determining the cost-effectiveness of sewerage, and because transport and treatment costs of water tend to be lower than those of sewage.

Box 19 On-site versus off-site sanitation and water

This short analysis investigates the cost implications of avoiding the use of local shallow groundwater for domestic purposes. This is achieved by calculating the costs of different technical options using data from low income urban settlements in India (Cotton & Franceys, 1991)

The Options

The baseline situation (and "no action option") is that households use on-plot pit latrines for sanitation and shallow groundwater for all domestic purposes. Each house has a toilet connected to a twin-pit pourflush latrine; there is one low cost communal handpump serving 20 households which draws water from a shallow aquifer. Two further options which avoid the consumption of groundwater potentially contaminated by pollution from on-plot pit latrines are:

Retain on-plot sanitation, but to provide an off-site piped water supply to one double tap standpost serving 40 households; the handpumps are closed down and no longer provide a source of water.

Dispense with the latrine pits and connect the household toilets to a sewerage system with subsequent sewage treatment. The water supply is piped to individual house connections in order to provide sufficient water for the sewerage system to function adequately. Two sub-options have been included: firstly, sewerage with local low cost treatment using ponds; and secondly, centralised sewerage and treatment at the city level. These latter costs are calculated from the average unit costs across the city of Hyderabad.

Cost Analysis

We use the Total Annual Cost per Household (TACH) as a cost indicator; this is calculated by amortizing the present value of the capital, operation and maintenance costs of the infrastructure over a period of 20 years. TACH can be thought of as an annual cost attributable to each plot in order to recover the life cycle costs of the infrastructure. Calculations are made using financial costs without shadow pricing; the cost comparisons are developed from earlier work by Cotton & Franceys (1991, 1993) and use 1988 prices.

Infrastructure costs expressed as TACH in Rupees 1988 prices:

Option	**Water**	**Toilet**	**Excreta Disposal**	**Total**	**% increase over baseline cost**
Baseline costs	60	80	170	310	
Standpost, pit latrine	130	80	170	380	23%
Local sewerage & treatment	287	80	211	578	66%
Centralised sewerage & treatment	287	80	480	847	173%

Notes:

1. Water costs include the delivery cost of water at the prevailing tariff rate.
2. Sanitation costs are split into two: firstly, the cost of the toilet, which is incurred regardless of the disposal option; and secondly, the cost of excreta removal and disposal. For the on-plot sanitation option this includes pit construction and emptying costs; for the sewered option it includes sewerage and sewage treatment costs.

5.2 What really determines sanitation technology?

In the final analysis, planners and decision-makers also need to be clear about the variety of factors and preferences that ultimately decide the choice of sanitation technology by users. These factors include the following:

- Pit latrines are unsatisfactory as a means of disposing of large amounts of water. Separate soakaways may or may not be appropriate depending upon soil conditions, but where large amounts of water need to be removed from the household, pit latrines without some separate drainage or sullage removal will not be viable.
- Conversely, sewers are unlikely to be viable unless a regular supply of substantial quantities of water is available.
- Consumer preferences (including those related to costs) and the anticipated water supply situation are thus the over-riding determinants of the choice of technology, and are more significant than health criteria in determining the sanitation technology that will in fact be used by households and communities.

Finally, to the extent that planners and public health workers can influence the choices made by households and communities, they should remember that a decision to protect groundwater which leads, in practice, to a reduction in sanitation is a step backwards for public health.

6. References

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