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SURVIVAL AND TRANSPORT OF ENTERIC VIRUSES AND BACTERIA IN GROUNDWATER

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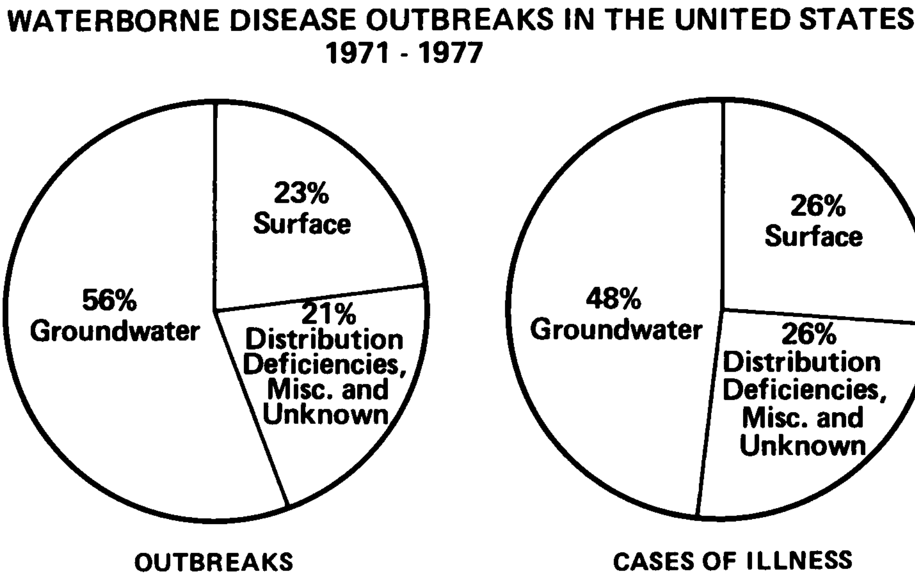
ABSTRACT

Microbial contamination of groundwater is responsible for large outbreaks of waterborne disease. The most important pathogens that may enter groundwater are viruses and bacteria. Environmental factors affecting their survival and migration in groundwater have only recently come under study and have proven to be highly complex. Only by understanding these factors will it be possible to control or prevent microbial contamination of groundwater.

INTRODUCTION

The microbial contamination of groundwater is a serious problem that can result in large outbreaks of waterborne disease. For example, Craun (ref. 1) reported that of all waterborne illness from 1946 to 1977 in the United States, 56% of the outbreaks and 48% of the cases of illness were due to contaminated (untreated or inadequately treated) groundwater (Fig. 1). Overflow from septic tanks and cesspools was responsible for 42% of outbreaks, and 71% of illness was caused by using untreated groundwater in nonmunicipal systems.

The large variety of pathogens that may be present in domestic wastewater includes pathogenic bacteria, viruses, protozoa and parasitic worms. The most common bacterial pathogens associated with sewage are *Salmonella* sp. (the cause of typhoid), *Shigella* sp., ETEC (enterotoxigenic *Escherichia coli*), and *Vibrio* sp. (associated with severe gastroenteritis). Over 100 different types of pathogenic viruses have been isolated from fecal material, including poliovirus, coxsackievirus, adenovirus, rotavirus, Norwalk-like virus, and infectious hepatitis virus. These viruses have been associated with a wide variety of diseases in man, including paralysis, gastroenteritis, diarrhea, hepatitis, meningitis, respiratory illness, eye infections, etc. While secondary sewage treatment as commonly practiced, including normal disinfection by chlorine, is ineffective in destroying parasitic protozoa and helminths, their large size results in highly efficient removal by filtration. Therefore, it is unlikely that they could gain entrance into the groundwater during groundwater operations by land treatment. Bacterial removal by soil also largely occurs by filtration at the soil surface, although adsorption is involved. Viruses are much smaller



than bacteria and removal is dependent entirely on adsorption. Thus, of all the pathogens present in sewage, viruses are the most likely to find their way into groundwater during land application. Another concern with viruses is the low number that needs to be ingested (perhaps only one) to cause an infection, in contrast to thousands required for bacteria.

Because of the previous lack of sensitive detection methods, there are only a few reports in the literature on virus isolation from groundwater used as potable water (Table 1). The presence of viruses in water is difficult to demonstrate unless extra efforts are made because the contamination requires special detection techniques.

In contrast, although there have been no reports of disease outbreaks associated with land treatment of sewage wastes, there are a growing number of studies reporting the detection of viruses in groundwater after wastewater application to land or direct groundwater recharge. Furthermore, two recent rural water supply surveys (ref. 3, 4) in the U.S.A. have clearly demonstrated widespread bacteriological contamination of groundwater, suggesting a widespread viral contamination also. For example, 35% of the samples in one study and more than 92% in the other were found to contain bacteria, whereas only 7.5% of 460 samples taken in a third study were uncontaminated. Much of this pollution is due to faulty wells and poorly constructed septic tanks. In such a manner, contamination of a groundwater source by a single household can lead to widespread dissemination of microorganisms and disease.

TABLE 1[a]

Isolation of viruses from drinking water wells

Location	Virus types
Florida	echo 22/23
Germany	echo 3,6,30; coxsackie B1,4,5; U[b]
India	U
Michigan	polio 2
Israel	echo 6,7; coxsackie B6; polio 1; U
England	polio 2
Israel	polio 1; U
Ghana	polio 1; coxsackie B3
Mexico	rota; coxsackie B4,6
Texas	hepatitis A;[c] coxsackie B2,3

[a]Modified from Keswick and Gerba (ref. 8)

[b]U = Unidentified.

[c]Sanchez et al. (ref. 2).

VIRUS SURVIVAL IN GROUNDWATER

It is difficult to make firm assessments on virus survival in natural waters because virus resistance to factors that influence their survival varies. In addition, these factors have shown great variation temporally, which makes predictions even more difficult. For instance, little is known concerning survival rates of human enteric viruses in soil and groundwater. Field studies (ref. 5) suggest that viruses can survive for at least 28 days in groundwater. Survival of viruses in surface waters for as long as 188 days has been reported (ref. 6), while in other laboratory experiments viruses survived more than 200 days in drinking water. Our experimental data indicate a reduction of 99.9% in 20 days.

BACTERIAL SURVIVAL IN GROUNDWATER

Although bacteria are well known as waterborne-disease-causing organisms, only a limited amount of information is available on the survival of bacteria in groundwater. *E. coli* (ref. 7) bacteria have been found to survive and even multiply on organic matter filtered out from lake water during underground recharge projects in Israel.

Coliforms in sewage pumped underground have been isolated from observation wells up to 5 m away for 3 months after they were introduced into the original well. It was also observed that a pathogenic strain of *E. coli* survived for a period of 4 months in natural subsurface water held in the dark in the laboratory. Under the same conditions, a saprophytic strain of *E. coli* survived 5.5 months. Our experimental data demonstrate a reduction of 99.9998% of *E. coli* and 99.9995% of fecal streptococci in 20 days.

Table 2 lists the important factors in the survival of microorganisms in groundwater.

TABLE 2

Factors affecting survival and migration of viruses and bacteria in groundwater

Hydrogeological
Soil
Texture (sand, silt, clay)
Organics
Humic acids
Cations
Adsorption
pH
Ionic strength
Permeability
Biological
Nature of microorganism
Microbial antagonism
Meteorological
Rainfall
Temperature
Desiccation

NATURE OF THE MICROORGANISM

The nature of the microorganism also plays a role in survival. Resistance of microorganisms to environmental factors varies among different species as well as the particular strain. Most enteric bacterial pathogens die-off very rapidly outside the human gut, whereas indicator bacteria such as *E. coli* persist for longer periods of time. Survival times among different types of viruses vary greatly and are difficult to assess without studying each type individually.

SOILS

Soils vary considerably both in their composition and in their overall texture. Laboratory studies have shown the importance of the composition of soils, including the organic content, percent sand, silt and clay, pH, cation-exchange capacity, permeability, texture, moisture, and iron oxide levels in virus survival and adsorption. Understanding the physicochemical properties of soil as related to virus adsorption has been seen as an aid in understanding the potential for groundwater contamination during recharge operations. Virus adsorption to soil surfaces is believed to be largely governed by electrostatic double-layer interactions and van der Waal's forces. Thus, the surface charge on both the virus and the soil and factors controlling the net charge are important in determining the efficiency of virus adsorption. The variability of adsorption by different soils has been repeatedly demonstrated (ref. 7-9). In general, sandy and organic soils are poor adsorbers and clay soils are good adsorbers.

MIGRATION OF VIRUSES AND BACTERIA IN GROUNDWATER

In early studies, it could be concluded only on epidemiologic evidence that viruses (mainly hepatitis A) move from sources of contamination into well water some distance away. Now, it is generally accepted that once in groundwater, viruses can migrate great distances under the right conditions (ref. 8).

However, the specific factors affecting virus and bacteria movement in groundwater have not been studied directly. As mentioned above, there are many factors, such as the degree of saturation, subsurface flow, hydrogeologic structure, and the like, involved in this movement which are site-specific and which need to be evaluated for any site where wastes are to be applied.

It is apparent that, although filtration generally effectively removes bacteria, under certain conditions bacteria also can migrate over long distances in groundwater. Subsurface structure has been demonstrated to be an important promoter of groundwater contamination. For example, movement of bacteria through fracture zones has been shown (ref. 10) to be rapid and to follow the fracture lines, leading to rapid and wide dispersal.

It is evident that viruses and bacteria in groundwater pose a proven hazard to health as evidenced by the large number of outbreaks of waterborne disease caused by contaminated groundwater. Our ability to predict and prevent this contamination is dependent on our understanding of the underlying factors. This understanding in turn requires further research.

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