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# Pollution of village wells in developing countries - a review

by

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## ACKNOWLEDGEMENT

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## 1. INTRODUCTION

Many of the countries within the African and Asian continents may be classed as "developing" countries. In order to achieve a higher standard of living, an adequate supply of suitable water is one of their basic requirements, hand-in-hand with improvements in sanitation, hygiene and health education. In 1973 the World Health Organisation estimated that 86% of the world's rural population were without "reasonable access to safe water". The exploitation of groundwater is an essential factor in the attempt to reduce this figure drastically by 1990.

In arid regions, groundwater is often the only source of fresh water. But even in humid tropical areas with adequate supplies of surface water, groundwater may be a useful alternative as the demand for water increases. As a rule, groundwater is free of pathogens, less susceptible to contamination and requires less treatment than surface water, which is a distinct advantage in poorer countries. Groundwater storage is usually much greater than that of surface water, not seriously affected by short droughts and is available in many areas where surface water supplies are not dependable. In addition, surface storage in hot climates has the attendant problems of evaporation losses and health hazards.

However, once an aquifer is polluted, from a practical point of view the process can be regarded as irreversible, as the remedies are very difficult and extremely costly (Deutsch, 1965). The principles involved in groundwater contamination are not widely understood. For the long-term success of any water resources project, it is essential that the hydrogeologists involved, the administrators of overseas aid and the recipiants of the aid all comprehend the reasons for, and the practicalities of, groundwater pollution and its prevention.

This review attempts to bring together the relevant information on groundwater pollution from various disciplines, presented from a hydrogeological standpoint. An extensive manual and computer-based literature search formed the basis of the report and copies of all the referenced documents are held in the Unit by the author.

## 2. SOURCES OF GROUNDWATER POLLUTION ON A VILLAGE SCALE

In industrialised areas, possible causes of groundwater pollution include wastes from food processing, metal refining, oil and chemical industries and mining. However, in rural areas and villages in many developing countries, the most serious threat to groundwater quality is contamination by human and animal wastes. Especially in regions where shallow groundwater is tapped as a source for domestic supply, this water may be reached, often without great difficulty, by pollution from privies, cesspools and seepage pits, septic tanks and farmyard manure (Wagner and Lanoir, 1959). Pollution from these sources results in increased levels of inorganic chemical constituents and micro-organisms, including pathogens. High concentrations of nitrate in groundwater may arise from domestic pollution as well as from fertilizers and can cause infantile cyanosis, but this type of non-infectious water-related disease is only of concern in industrialised countries, where infectious diseases have been greatly reduced (Feachem, 1977).

In developing countries it is the infectious water-related diseases which are of primary importance. Most action taken to eliminate pathogens from a water source will automatically reduce the concentration of associated harmful inorganic ions. The spread of pathogens via polluted groundwater sources is related to sanitation practices, the hydrogeology of the region, well location and construction and education of the villagers. An appreciation of all these topics is vital to the development and conservation of groundwater supplies in rural areas of developing countries.

## 3. HEALTH ASPECTS OF WATER SUPPLIES

The relationship between water and disease needs to be understood when considering any water supply programme for developing countries. In tropical countries, in particular, there are two main causes of death: infectious disease and malnutrition. A large proportion of deaths, probably 5-10% in many places, results from water-related diseases. Any benefit which may be derived from improved water supplies depends on the mode of spread of the causative organism. Bradley (1977) divides 20 to 30 infective diseases into four categories, depending on the mechanism by which the disease is water-related.

(i) Infections spread through water supplies - water-borne diseases.

(ii) Diseases due to the lack of water for personal hygiene - water-washed diseases.

(iii) Infections transmitted through an aquatic invertebrate - water-based diseases.

(iv) Infections spread by insects that depend on water - water-related insect vector diseases.

### (i) Water-borne diseases

Outbreaks of water-borne diseases such as cholera and typhoid are likely to occur when a communal water supply is contaminated by faeces from a person suffering from, or carrying, one of these infections. Man is the sole reservoir of both these pathogens and, since they are highly infective, only a few organisms are needed to infect someone. Other diseases in this category, like infectious hepatitis and bacillary dysentery, require larger initial doses of the pathogen.

Although a disease such as cholera is classed as water-borne, it should be noted that all water-borne diseases can also be transmitted by any route which permits faecal material to be ingested. Thus, sanitation and hygiene have a strong influence on the spread of diseases in this category.

### (ii) Water-washed diseases

There are many infections of the intestinal tract and skin which, especially in the tropics, may be significantly reduced following improvements in domestic and personal hygiene (Feachem, 1977). These improvements often depend upon an increased availability of water and they depend on the quantity rather than the quality of the water. The prevalence of a water-washed disease will fall if more water is used for hygienic purposes, such as washing, irrespective of the quality of the water.

Water-washed diseases are of three main types: infections of the intestinal tract, such as the diarrhoeal diseases; infections of the skin and eyes; infections carried by fleas, ticks, lice and mites. Any disease which is transmitted by the pathogen passing out in the excreta of an infected person and subsequently being injested (a faecal-oral disease) can either be transmitted in a truly water-borne route or by an almost infinite number of other faecal-oral routes, in which case it is probably susceptible to hygiene and therefore water-washed. In communities that have been studied, diarrhoeal diseases, although potentially water-borne, were primarily water-washed and mainly transmitted by faecal-oral routes which did not involve water as a vector.

In contrast, infections of the skin and eyes and those carried by fleas, lice, mites and ticks can never be water-borne but they can be reduced by improvements in personal hygiene. However, it is difficult to ascertain what is an adequate volume of water for hygienic purposes. In practice, it appears that, unless water is piped into the house, it is not used at the optimum rate desirable for health (Bradley, 1977).

### (iii) Water-based diseases

All these diseases are due to infection by parasitic worms which depend on aquatic intermediate hosts to complete their life cycles. An important example is schistosomiasis. Eggs from the worms escape in the faeces and, if this excreta pollutes water containing aquatic snails, the schistosome larvae continue to develop in the snails until mature, when the infective schistosome worms are shed into the water. These schistosome worms are able to bore their way directly through human skin and are therefore a hazard to all in contact with the infected water. The eggs in the excreta perish unless they reach water quickly, so that improved sanitary arrangements could be beneficial. However, because of the large numbers of mature worms produced asexually in the snail host, reducing the amount of excreta reaching the water by itself would not significantly decrease the prevalence of the disease in a community. By comparison, the provision of a piped water supply, by greatly reducing the frequency of contact between human skin and contaminated water, would make a much greater contribution to control.

The guinea-worm infection (dracunculiasis) is transmitted through the secondary host cyclops, a minute crustacean. The worm matures in a blister under the skin of humans and when the blister bursts the larvae are released and easily washed into water courses and wells containing the secondary host. In Nigeria, the disease has been controlled by building an outward sloping concrete collar around the top of the dug wells to prevent polluted water draining back into the wells.

### (iv) Water-related insect vector diseases

Malaria, yellow fever, dengue and onchocerciasis are transmitted by insects which breed in water;trypanosomiasis (Gambian sleeping sickness) is transmitted by the riverine tsetse fly which bites near water. Water storage jars can act as breeding sites for many of these insects.

Table 1 summarises the main points of this section. Many diseases in the water-borne, water-washed and water-based categories depend on human wastes having access to water or people's mouths; accordingly their incidence may be reduced by improved waste disposal. However, excreta disposal practices are a profoundly cultural aspect of a community and cannot be considered independently of community ethnography. One of the main reasons why the supply of an increased volume of water is likely to be more effective than improved sanitation against some water-related diseases is that the use of new water supplies presents fewer difficulties than persuading people to use new sanitary facilities.

| CATEGORY | EXAMPLES | RELEVANT WATER IMPROVEMENTS | PREVENTIVE STRATEGY |
|---|---|---|---|
| i) Water-borne diseases | | | Improve water quality<br>Prevent casual use of other unimproved sources |
| a) Classical | Typhoid, cholera | Microbiological sterility | |
| b) Non-classical | Infective hepatitis | Microbiological improvement | |
| ii) Water-washed diseases | | | Improve water quantity<br>Improve water accessibiltiy<br>Improve hygiene |
| a) Skin and eyes | Scabies, trachoma | Greater volume available | |
| b) Diarrhoeal diseases | Bacillary dysentery | Greater volume available | |
| iii) Water-based diseases | | | Decrease meed for water contact<br>Control snail populations<br>Improve water quality |
| a) Penetrating skin | Schistosomiasis | Protection of user | |
| b) Ingested | Guinea worm | Protection of source | |
| iv) Water-related insect vector diseases | | | Improve surface management<br>Destroy breeding sites of insects<br>Decrease need to visit breeding sites |
| a) Biting near water | Sleeping sickness | Water piped from source | |
| b) Breeding in water | Yellow fever | Water piped to site of use | |

Table 1. Classification of infective diseases in relation to water supplies and the appropriate preventive strategies. After Bradley (1977).

## 4. MOVEMENT OF BACTERIA AND VIRUSES THROUGH AN AQUIFER

### 4.1 Introduction

General hydrological considerations apply to the movement of any contaminant in an aquifer. Deutsch (1965) gives a good summary of the pertinent factors:

(1) *The nature of the contaminant;* its chemical, physical, and biological characteristics - especially its stability under varying conditions. The number and variety of potential contaminants that can enter underground sources of supply are, for all practical purposes, limitless.

(2) *The hydraulics of the flow system* through which the contaminated liquid moves enroute to, and in, the aquifer. The contaminant may enter the aquifer directly by injection through wells, flow through open channels, by percolation through the zone of aeration, by infiltration or migration in the zone of saturation, by vertical interaquifer leakage through aquicludes, or free flow through open holes.

(3) *The natural processes* that may remove or degrade the contaminants from water while it is moving through the underground flow system until it is discharged to a well or stream. These include filtration, sorption, ion exchange, and, of course, dilution and dispersion. In the zone of aeration, oxidation and various biochemical processes are important degradation phenomena.

(4) *The physical and chemical characteristics of the geologic media* through which the liquid wastes flow. The best aquifers, in quantitative terms, are those composed of, and recharged through, the most permeable materials. Such aquifers, however, are the most susceptible to contamination. This paradox is illustrated by the relationship between the aquifer and a septic tank and drain field discharging common household effluents. If the intervening materials are very

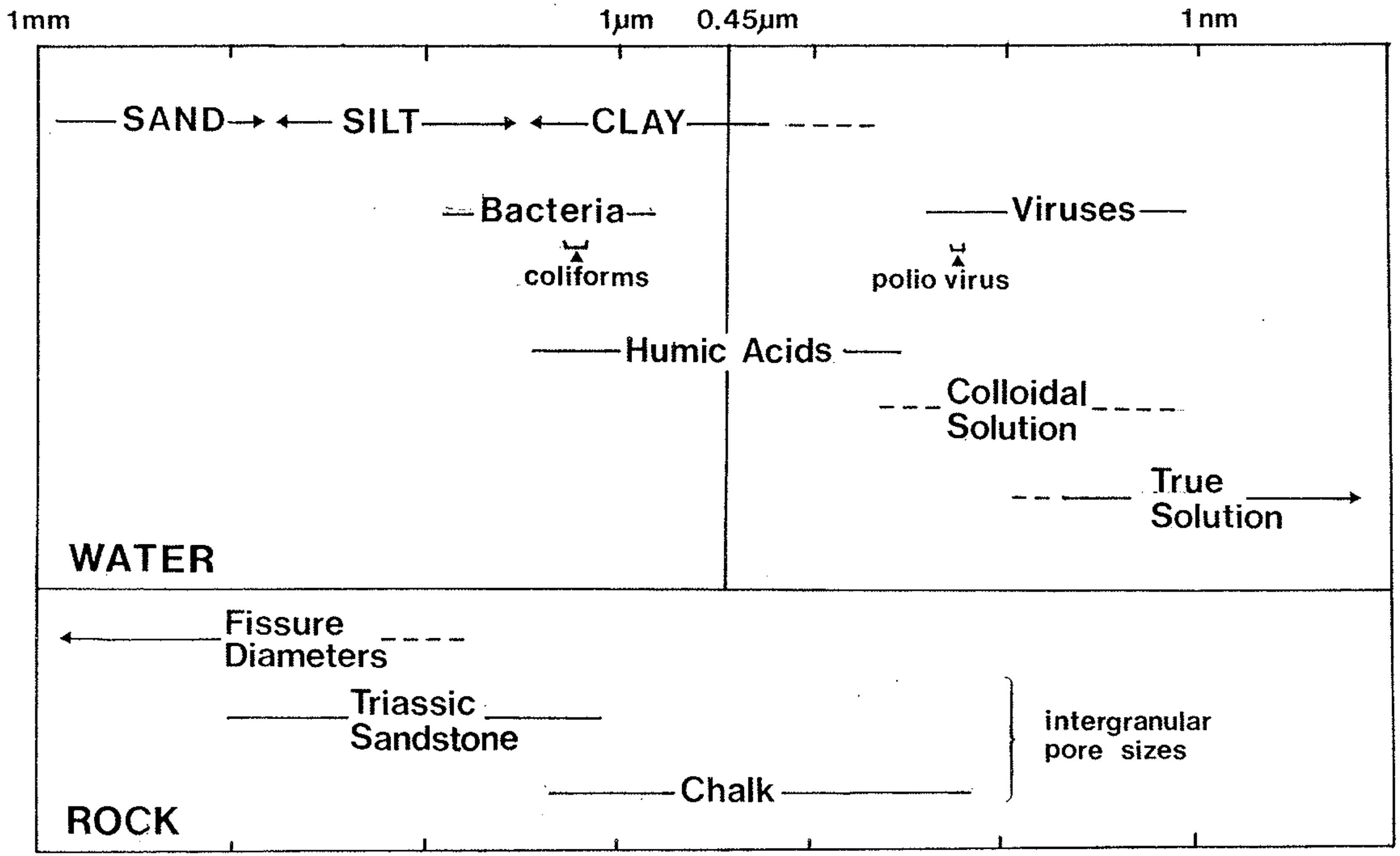


Figure 1. Sizes of solute, suspended particles and micro-organisms in groundwaters in the range $10^{-3}$ to $10^{-10}$ mm, compared with typical mean intergranular pore and fissure diameters.

permeable as in sandy terrains, the septic tank "works" very well, but the aquifer may be readily contaminated by substances in the effluent such as detergents or other stable chemicals. If the intervening materials are not permeable, the aquifer is protected, but the septic tank will not operate efficiently. The structure of the aquifer is equally important because - for example - fluids percolating through primary interstices are subjected to more intensive degradation or removal conditions than liquids flowing relatively freely through secondary openings in dense rocks. The mineral content is a factor also to be considered inasmuch as some minerals, such as the various clays, take up some contaminants - especially metallic ions - by exchange, whereas other minerals have no effect on the contaminants with which they come into contact.

If groundwater is susceptible to the discharge of human and animal wastes, it is important to know how far any pathogens will move vertically and horizontally from the point of discharge and for how long they are able to survive. The movement of protozoal cysts and helminth ova, for example, can be expected to be very limited because their size will restrict their passage. Figure 1 indicates the relative sizes of bacteria and viruses compared with some typical pore and fissure diameters.

## 4.2 Movement through the unsaturated zone in porous media

In homogeneous porous media, under <u>ideal</u> conditions, the unsaturated zone or zone of aeration is highly effective in attenuating most contaminants (LeGrand, 1965). Under these conditions great numbers of bacteria are effectively removed by percolation through a few feet of fine sand; a fact that is used in most water purification works throughout the world. The removal process involves mechanical and biological straining (a result of soil clogging) and/or death induced by environmental changes (Romero, 1970). Generally, soil clogging occurs within the first six inches of soil. Harmful bacteria are destroyed by:

(1) their inability to adjust to abrupt temperature changes;

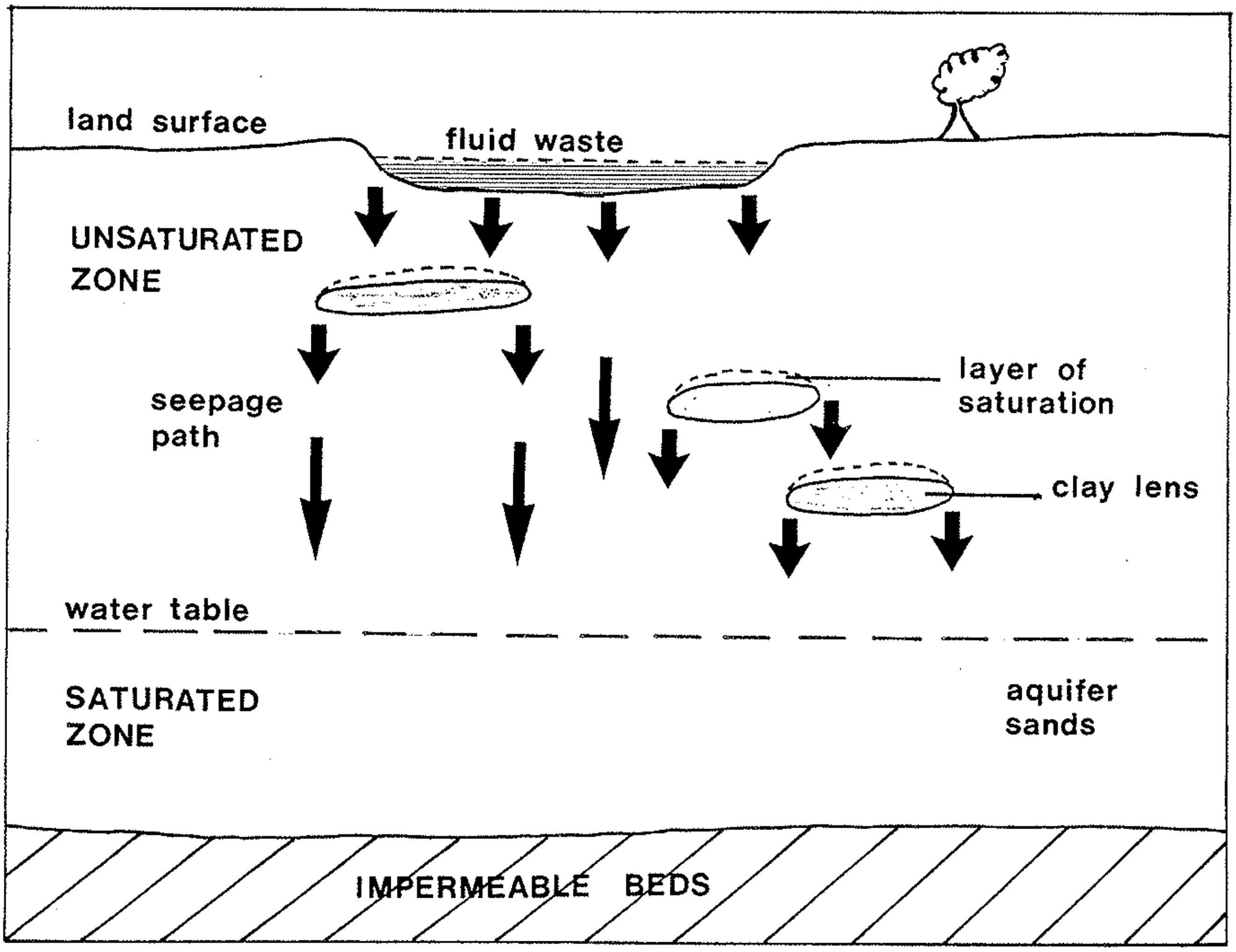


Figure 2. Movement of fluids through an unsaturated zone occupied by clay lenses.

(2) "oxygenation" and "nitrification" and

(3) pre-existing soil bacteria.

When Baar (1957) made a study of the movement of bacteria in sandy soils he came to the following conclusions:

(1) Self purification requires time and occurs best in dry soils containing a sufficient supply of free oxygen.

(2) A sand size of 0.15 mm or less is preferable for self-purification.

(3) Harmful bacteria might travel 25 ft or more in very coarse material where the rate of groundwater flow is 25 feet or more per day.

(4) In groundwater systems containing much pre-existing nutrient material, self-purification might require a much greater length of time.

(5) Harmful bacteria are generally absorbed in the first ten feet of travel as a result of oxygenation and nitrification.

However, it must be emphasized that most studies have been made under rather artificial conditions. When natural conditions are considered the picture is much more complicated. Along with geological heterogeneities, factors such as the decay, sorption and dilution of the bacteria, make it difficult to predict the degree to which the pollution will be attenuated (LeGrand, 1965). For example, Figure 2 indicates the lateral spreading which may result if the unsaturated zone is occupied by clay lenses.

In general, a considerable depth to the water table is desirable, as this increases the likelihood of self-purification before the contamination reaches the water table.

## 4.3 Movement in the saturated zone in porous media

Prediction of the direction of flow in the saturated zone is necessary, so that wells may be located up-gradient of any waste disposal site. LeGrand (1973) observes that it is more difficult to predict the direction of flow in arid regions than in wetter regions where the frequency of precipitation is sufficent to keep the water table relatively close to the ground surface; in arid regions, areas of natural groundwater discharge are more widely scattered and the general movement of water frequently less discernable.

Romero (1970) records a study by Stiles and Crohurst (in 1923) of the pollution of groundwater by privy wastes. Their findings include:

(1) The pollution travelled only in the direction of groundwater flow and only in a thin sheet at the surface of the zone of saturation.

(2) As the water table fell, in dry weather, the pollution tended to remain in the new capillary fringe, where it remained stranded until the water table rose again.

(3) The ultimate distance to which pollution travels depends on many factors, such as the frequency of wet and dry weather and the resulting rise and fall in the water table level; the rate of groundwater flow and the viability of the micro-organisms under the prevailing conditions.

## 4.4 Summary of the characteristics of movement in porous media

Although further study is needed, it would appear that viruses are influenced by the same factors as bacteria (Romero, 1970). However, because viruses are much smaller than bacteria, the mechanical filtering action of the porous medium is not so effective. Several investigations have indicated that virus removal is primarily a result of adsorption onto soil particles, but the viruses are not inactivated and may remain viable for many months in the soil matrix (Melnick *et al*., 1978).

For all organisms, survival is highly dependent on temperature, with greatly increased persistence at lower temperatures (Feachem et al.,1978). Bacterial survival is also very dependent upon the presence of other micro-organisms in the water which might provide competition or predation. For example, 20 days is the likely maximum survival time for E. coli at 20-30$^{o}$C in water, but under optimal conditions faecal coliforms can survive for several years. For viruses in water and sewage, 2 months is a likely maximum survival time at 20-30$^{o}$C, whereas around 10$^{o}$C nine months is a more realistic figure. A comprehensive compilation of the survival of pathogens in water is given in Appendix IV of Feachem et al., (1978).

Romero (1970) presents a list of the characteristics of the movement of biological pollutants through porous media:

(1) Bacteria and viruses travel with the flow of water; they do not travel or move against the groundwater gradient.

(2) In general, most bacteria and viruses are removed by the aquifer medium in the same manner as the coliform group of bacteria..

(3) The rate of bacterial and viral removal with distance is a function of an aquifer characteristic termed 'filterability'.

(4) For any degree of 'filterability', the rate of bacterial and viral removal depends upon distance only and not upon the rate of pollutant recharge.

(5) Pollution travel in non-saturated systems is considerably less than that in saturated systems.

(6) Aquifer materials best suited for the removal of biological contaminants are those uniformly composed of very fine to fine grained sand with a high clay content. In such an aquifer, the maximum length of travel of biological pollutants in the saturated zone varies between 50 and 100 feet, whereas in the unsaturated zone the maximum lengths of travel appear to be in the vicinity of 10 feet.

(7) The nature of the soil in contact with the source of contamination plays a dominant role in the subsequent travel of bacteria.

(8) Bacteria and viruses might travel much further than predicted if nutrient-laden waters are intercepted.

## 4.5 Bacterial movement through fractured bedrock

Clearly, the movement of fluids and the behaviour of bacteria in dense fissured rock are rather different to those in porous granular media. Generally, the rate of flow is faster, and the surface area of rock in contact with the fluid smaller, resulting in greatly reduced opportunity for the filtration and destruction of the bacteria.

Allen and Harrison (1973) give a good account of the problems associated with bacterial movement through fractured bedrock from a study in Colorado:

> The movement of bacteria-laden waters percolating through fractured crystalline bedrock in mountainous terrain was examined to determine whether effluent originating from domestic waste disposal systems could contaminate shallow ground-water supplies. Inoculated waters were injected into holes and/or wells at two geologically different test sites (granitic, metamorphic) to evaluate the extent of microbial filtration in or along bedrock fractures. Microbiological examination of tracer waters, sampled both above and below the zone of saturation, was made.
>
> Field studies showed that the direction and rate of movement of contaminated ground waters were controlled largely by the anisotropic nature of the geologic stratum, particularly by the orientation of major bedrock fracture sets. Inoclulated waters were found to be readily transported by the ground-water gradient into a downslope well. At one test site, a tracer bacterium traversed a horizontal distance of 94 feet in 24-30 hours. Continued bacteriological analysis of the contaminated well found the organism to be present for at least five days after inoculation of the upslope well.

> In the zone of aeration, bacteria-laden effluent was found to percolate in or along fractures with inadequate filtration prior to entering the ground water. Studies conducted in metamorphic rock demonstrated that while faecal-type bacteria decreased slightly during percolation through bedrock fractures, total bacterial densities were generally unchanged.
>
> From the hydrogeological and microbiological data obtained at both test sites, it was concluded that moderate percolation rates and minimum distances between water wells and leachfield type waste disposal units were inadequate to protect potable ground-water supplies from contamination in mountainous terrain.

The study by Jones and Murray (1977) also highlights the difficulties in preventing bacteria from contaminating the groundwater in severely folded and fractured limestone:

> The construction of wellsyielding safe, sanitary water in areas of severely folded, fractured and crevised limestone depends on the retention of enough sediment in the transmission paths.to restrict the movement of contaminants. Intermittant spring-sinks along streams or in low-lying areas indicate a reversal of groundwater flow in the area. When the water level rises above a critical·level, sediments that have accumulated in the formation over many years may be discharged in a few days, resulting in a loss of filtering ability.
>
> Groundwater levels and bacteriological contamination have been monitored on four wells in Washington County, Maryland, since 1973. Groundwater quality deteriorated after tropical storm Agnes washed sediments from the formation. Techniques for preventing entry of surface contaminants, improving filtering ability of the formation and providing controlled relief of hydrostatic pressure have been studied as ways of protecting groundwater in the formation.

## 4.6 Conclusion

The foregoing serves to illustrate the complexities of any prediction of the movement of bacteria or any other contaminant through an aquifer. To determine the extent of the movement of a contaminant and the degree of pollution at certain points from the source of pollution involves a knowledge of aspects such as the distribution of permeability and sorptive materials and the rate and paths of water movement in and above the aquifer (LeGrand, 1973).. In effect, every case has to be assessed individually when planning the location of a sewage disposal site or a well for domestic use. There will always be a dilema between safeguarding health on the one hand and excessive costs on the other hand. Every decision will be a compromise.

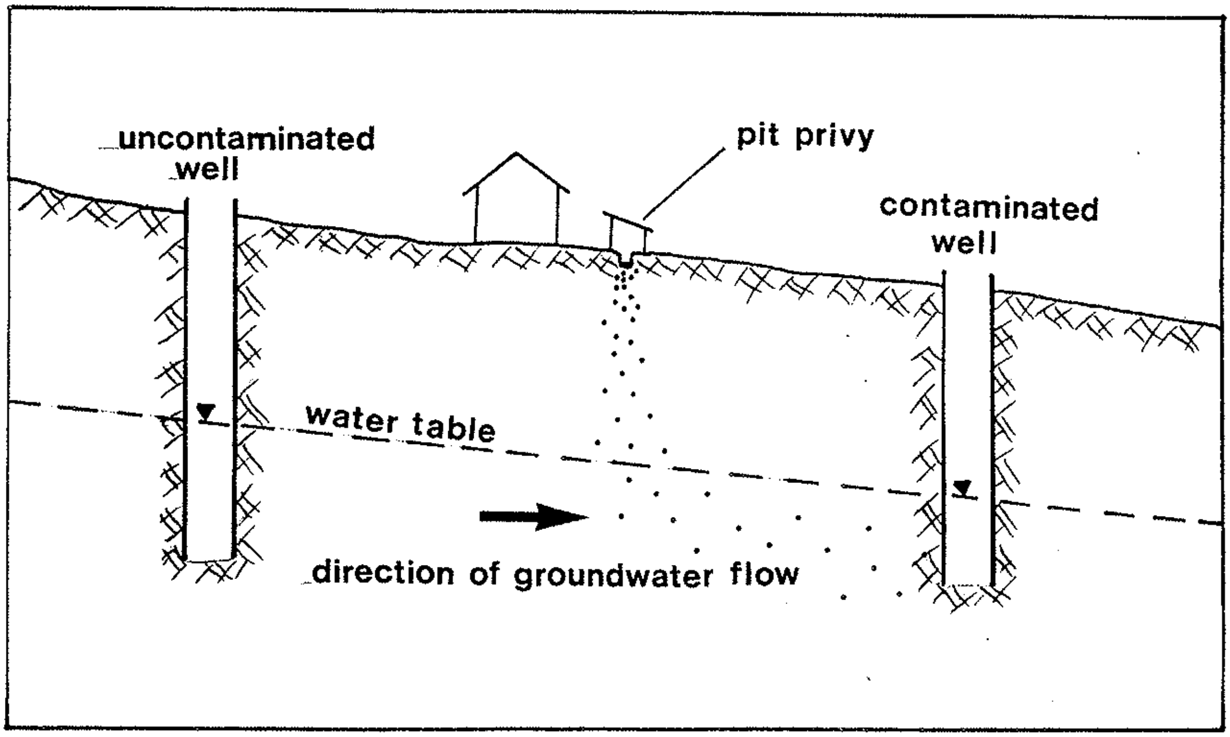


Figure 3. Movement of wastes from a pit privy down to an aquifer and into a well.

# 5. PREVENTION OF POLLUTION

## 5.1 Introduction

It is essential that any well should be located, designed and constructed in such a way that it protects the groundwater source from contamination by being used and maintained in a hygienic manner. Failure to ensure adequate protection will turn the well into a potential source of the very disease it was designed to prevent.

The reader is referred to authorities such as Campbell and Lehr (1973), Johnson Division (1966), Wagner and Lanoix (1969) and Gibson and Singer (1971) for details of well construction. The type of well is dictated by individual circumstances but the possible routes for contamination are similar.

## 5.2 Well Location

Although the location of a well will depend on hydrogeological considerations, it is equally important that a well should be sited as far from potential sources of pollution as is compatible with other restrictions, such as its distance from the houses of the users. The well should also be positioned so that it is higher, with respect to the water table, than the source of pollution (Figure 3).

Because factors such as the slope and height of the water table and soil permeability affect the rate of removal of bacteria, any rule governing the 'safe' distance between a latrine and a source of potable water can only be arbitrary (Wagner and Lanoix, 1958). Various authors quote different 'safe' distances: Watt and Wood (1977) insist that the minimum distance should be 50 metres, whereas Romero (1970) recommends distances varying from 25 to 100 feet and more, depending on the geological formation and the height of the source of pollution above the water table.

In areas containing fissured rocks or limestone formations it is recognised that the pollution may be carried rapidly through fractures or solution channels, without natural filtration, to distant sources of potable water. It is recommended (Wagner and Lanoix, 1958) that a careful investigation should be made before building pit privies, bored-hole latrines, cesspools and seepage pits in such areas, and Romero (1970) states that the minimum distances in such circumstances should be 100 feet.

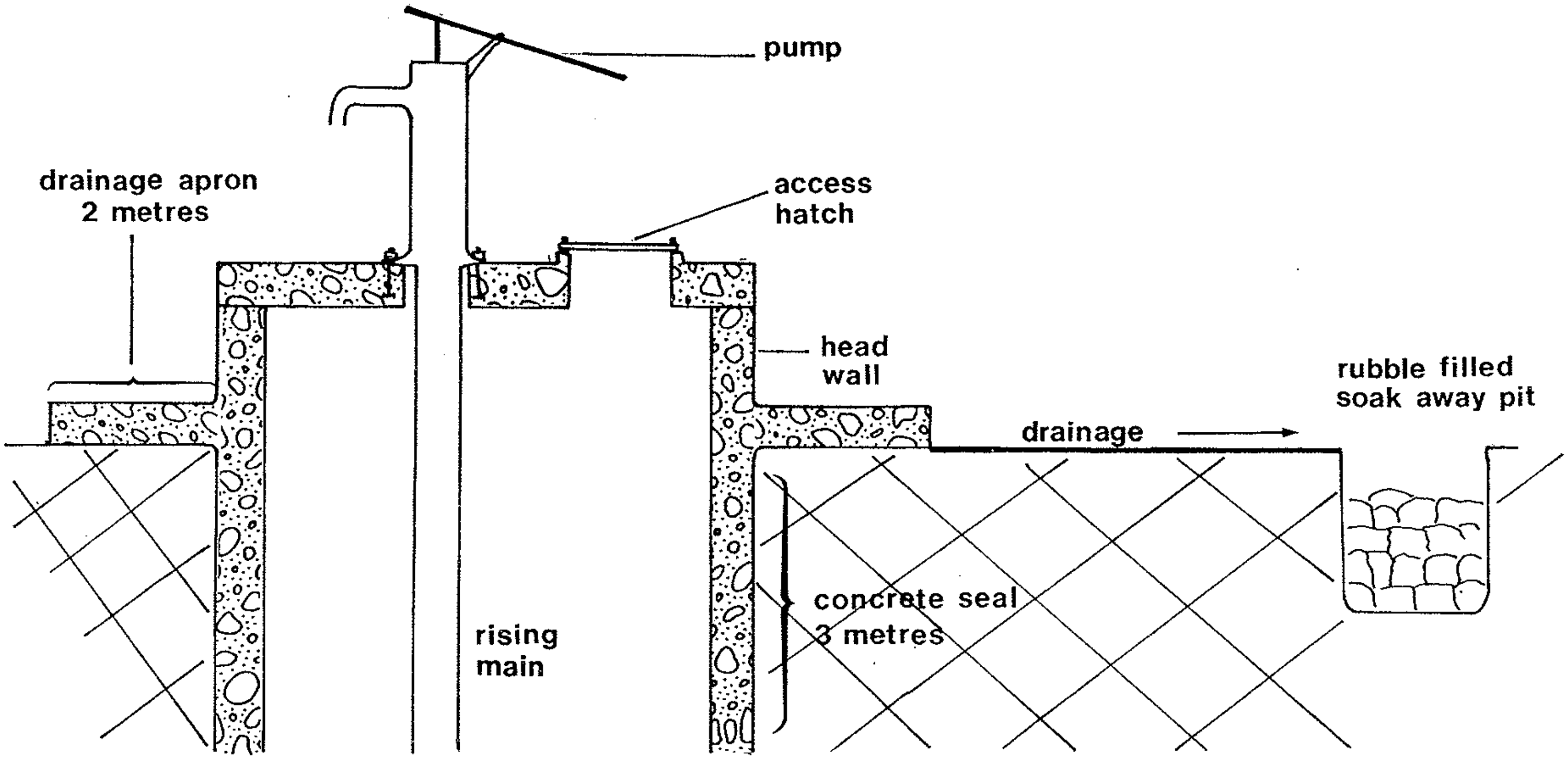


Figure 4. The important features of a protected wellhead.

## 5.3 Wellheads

An open well without a wellhead is always a potential point of entry for pollution (Watt and Wood, 1976). A properly designed wellhead should prevent rain and spillage washing into the well, discourage the use of insanitary buckets to draw water and not allow people to defecate or wash themselves or their clothes in the vicinity.

Two main features of any wellhead should be:

(a) a curb or headwall sufficiently high to prevent anything from washing or blowing into the well mouth, and narrow enough to discourage users from standing on it;

(b) an impervious apron 2 metres wide, sloping away from the shaft in all directions. The apron itself should be drained to a soakaway a safe distance away.

For complete safety, a sealed cover is desirable, but such a cover is only feasible where a pump is fitted. Where it is necessary for the well to be left open to draw water, a moveable cover should be provided to prevent wind-blown dust, insects and such like from entering the well when it is not in use (Figure 4).

It should also be ensured that animals are watered some distance from the well and the wellhead is fenced off to keep animals clear of the apron. In addition, washing facilities (for people and their clothes) should be provided far enough away to avoid wastewater seeping back into the ground around the wellhead.

## 5.4 Linings

Hand-dug wells, by their very nature, are usually constructed in unconsolidated formations and require some casing to prevent caving of the well shaft. If the well is lined with anything other than concrete, then particular care must be taken to ensure that the top three metres of lining and its junction with the wellhead are watertight (Figure 4). In fact, the first three metres of any well, however constructed, should be cased to ensure sanitary protection from surface seepage.

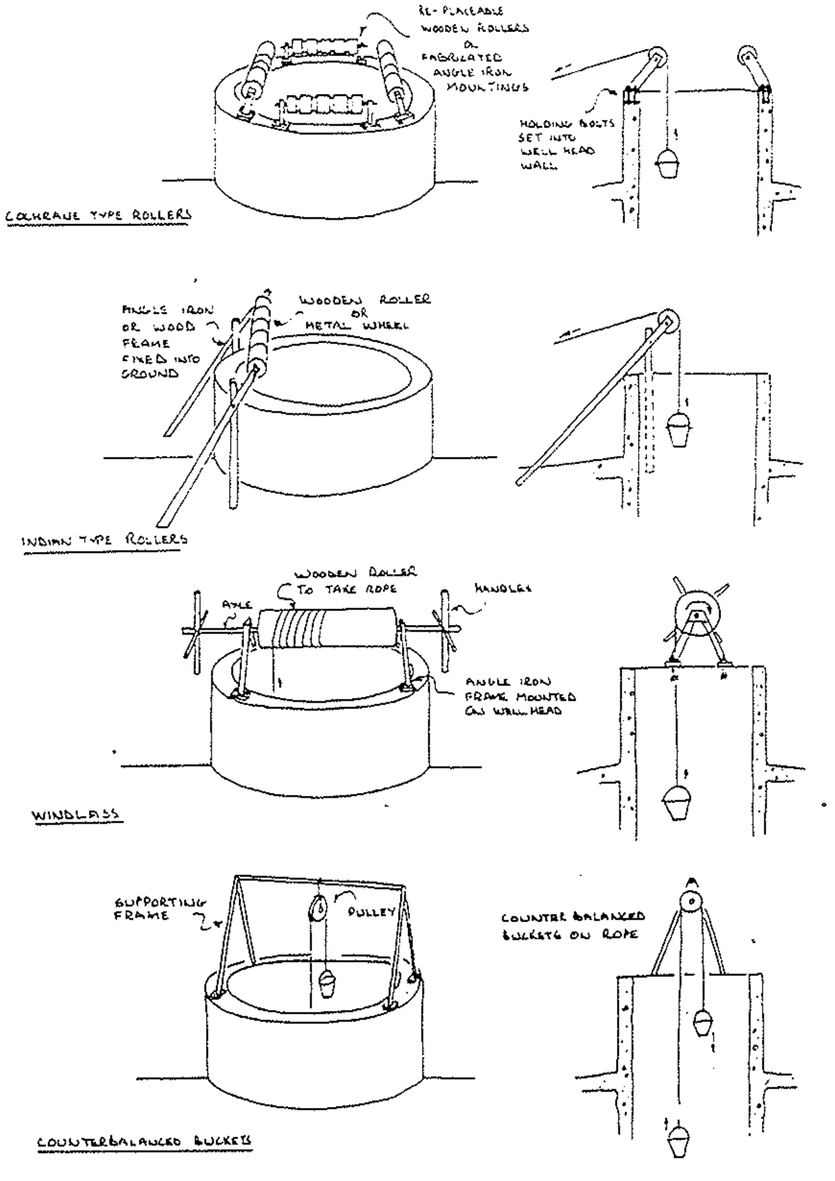


Figure 5. Simple water lifting equipment for hand dug wells. After Watt and Wood (1976).

Where a well is cased, the shaft must, of necessity, be larger than the well casing. It is important to fill and seal the space behind the casing to prevent seepage of surface water into the well. This space should be grouted with cement or a clay slurry to a minimum depth of three metres below ground surface (Gibson and Singer, 1971).

### 5.5 Equipment for drawing water

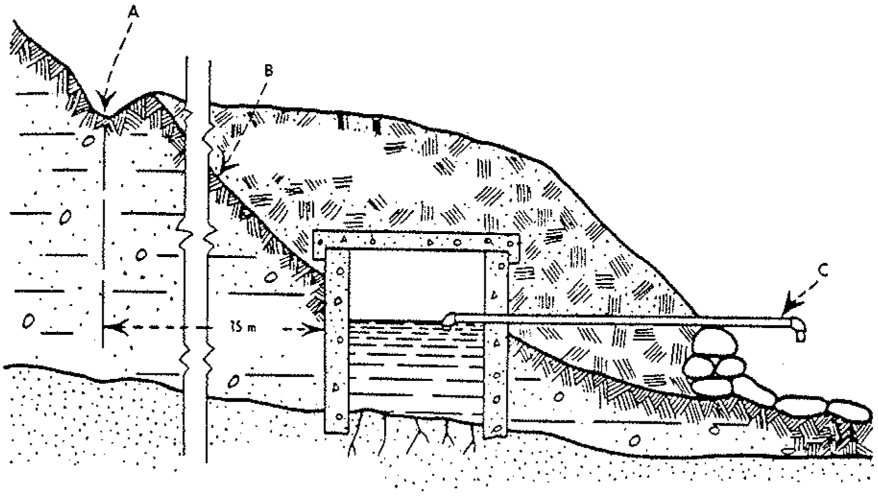
Where a pump is not available, the use of ropes and buckets is a potential source of pollution. This can be minimised if communal buckets are provided and so fixed to the wellhead that they cannot be removed, thrown onto the ground or stored in an insanitary manner (Figure 5). Devices such as windlasses or counterpoised buckets are a good compromise, although there is always some risk of contamination from handling. In places where it is customary (and unavoidable) for villagers to use their own ropes and buckets, they should be persuaded to hang them up clear of rats and domestic animals when not in use, and to refrain from depositing them on bare ground near the wellhead before and after use.

If a pump is available, it should be constructed and installed so as to prevent contaminated water and other materials from entering the well or coming in contact with the pumped water (Wagner and Lanoix, 1959). The pump should be designed to give a watertight seal with the well cover or casing. Another important feature is that the pump should always be self-priming, since contamination can originate from dirty water used to prime a handpump.

### 5.6 Well Completion

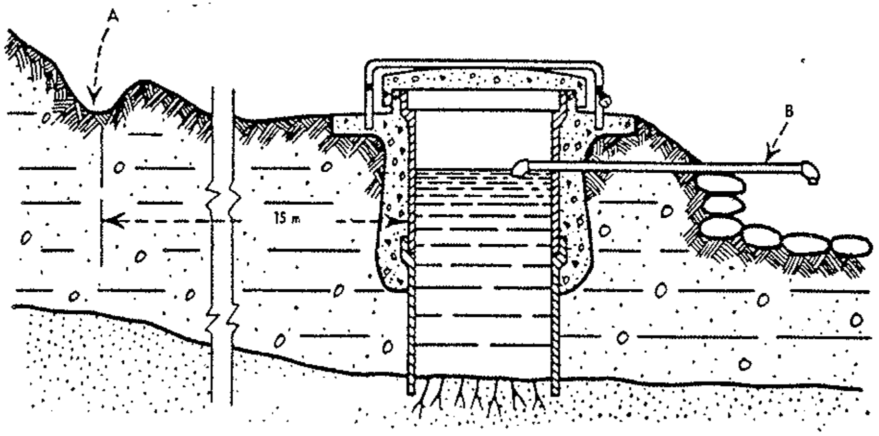
Before being put into operation, or immediately after repair, a well should always be disinfected to counteract any bacterial contamination introduced by workmen, equipment or surface water. Wagner and Lanoix (1959) recommend the following procedure:-

> "Prepare a strong solution containing 100 ppm of available chlorine by dissolving 50 g of calcium hypochlorite in 100 litres of water. Wash and scrub the casing lining with this solution. Then calculate the volume of water in the well and add a chlorine solution such that the effective chlorine dose is between 50 and 100 ppm. The


PROPERLY PROTECTED SPRING (I)

A = Protective drainage ditch to keep drainage water a safe distance from spring
B = Original slope and ground line
C = Screened outlet pipe : can discharge freely or be piped to village or residence

Springs can offer an economical and safe source of water. A thorough search should be made for signs of ground-water outcropping. Springs that can be piped to the user by gravity offer an excellent solution. Rainfall variation may influence the yield, so dry-weather flow should be checked.


PROPERLY PROTECTED SPRING (II)

A = Protective drainage ditch to keep drainage water a safe distance from spring
B = Screened outlet pipe : to discharge freely or be piped to village or residence

Figure 6. Two designs for spring protection. After Wagner and Lanoix (1969).

solution should be applied at different levels in the well water, which should be agitated to ensure even distribution. The chlorinated water should be allowed to stand for at least 12 hours, after which it may be pumped out."

### 5.7 Abandoned Wells

Whenever a well is abandoned, for whatever reason, it should be sealed by filling it with clay, concrete or earth. This prevents contamination from the surface, avoids possible movement of inferior water from one aquifer to another and conserves water in flowing wells.

### 5.8 Springs

Similar considerations apply to the prevention of pollution of springs. As always, the principle is to avoid contamination by polluted surface water and by people during water collection. Protection can be provided by digging a ditch at least 15 metres from the spring to divert surface water and constructing a covered cistern to collect the spring water (Figure 6). The supply may be drawn from a tap near the spring or piped to buildings. An overflow and drain should always be provided, all outlets should be screened and waste water from the overflow and drainage pipe led away from the spring by adequate drains. A further precaution is to exclude animals from the area around the spring by erecting a fence.

### 5.9 Chlorination

Whenever water is supplied to rural communities in developing countries, the best source is one which requires no treatment at all. If a treatment process is installed and subsequently receives inadequate attention, it can become a positive danger to health.

One of the simplest and cheapest forms of treatment often used in small water-supply schemes, where the physical and chemical quality of the water is satisfactory, is chlorination. Chlorine is an oxidising agent

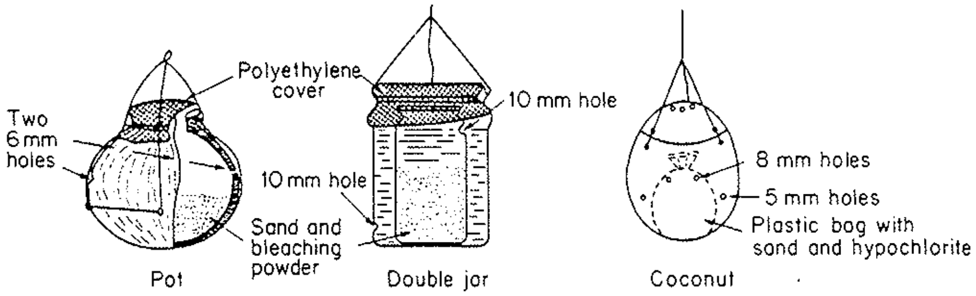


Figure 7. Simple chlorination pots. After Feachem _et al_., (1977).

and therefore enough chlorine must be added to react with the organic material present, as well as the micro-organisms, and leave a surplus of 'residual chlorine' to deal with any further infection by pathogens. Chlorine requires a period of time, called the 'contact time', to be effective. In general, for rural supplies, a residual chlorine of 0.5 mg/l after 30 minutes is recommended. Chlorine is a good bacteriocide but only of doubtful value as a viral disinfectant.

Figure 7 illustrates some simple chlorination pots which contain a 1:1 mixture of bleaching powder and sand and are suspended in the well. The containers have to be made of wood, plastic, ceramic or cement to prevent corrosion and they have small holes to allow the water to pass through slowly. When considering the installation of even such a comparatively simple system, it has to be remembered that reliable supplies of bleaching powder are necessary and that the powder is fairly unstable and loses strength during storage and when exposed to sunlight. In addition, successful operation of this system requires frequent attention.

### 5.10 Education and Maintenance

These topics are perhaps the most important. All the work and effort expended to provide a good supply of safe water is wasted if the villagers do not understand the precautions necessary to keep their water wholesome, and if they are unable to maintain the equipment in working order and in a sanitary condition.

A report on the construction of shallow wells in Tanzania (Divars Heederik en Verhey, 1976) highlights the defects often encountered: broken handles, hinge points worn out, bolts and nuts taken away, manhole covers removed, unscrewed rising main and pump rod, worn out pump parts and broken slabs. These defects can be avoided if inspections and repairs are carried out. In this particular project each village appointed 2 men per well to receive basic training in maintenance. The pump attendants were asked to report regularly on the state of the well and take care of the day-to-day jobs such as check the operation of the pump, clean the slab and spoil gutter, tighten any loose nuts and bolts and prevent the well from being used as a working area or a playground. Also on this project, there were several maintenance groups, whose task was to inspect the wells regularly, take chemical and bacteriological samples and carry out any major repairs.

It is very necessary to organise any well construction project so that the villagers are closely involved. At the same time it is vital that some degree of health education is given, so that those drawing water appreciate the basic rules of hygiene and the implications for the health of themselves and their neighbours.

Public support must be won; experience has shown that persuasion can achieve results that regulations cannot.

## 6. INDICATORS OF POLLUTION

In this review of village wells, the main sources of pollution are identified as the disposal sites of human and animal wastes. The potential pollutants from these sources are mainly bacteriological and inorganic. But, if potable water supplies are endangered, the pollutants of most concern will be the pathogenic micro-organisms. Associated with this microbiological pollution are high levels of nitrate, chloride and other ions. These inorganic ions can often give advance warning of more serious bacteriological pollution, because they may not be attenuated to the same degree as the micro-organisms and tend to move more rapidly through the aquifer.

Although the water-related diseases prevalent in the tropics are caused by a wide variety of viruses, bacteria, protozoa and parasitic worms, only bacterial examination of water is carried out routinely. The general philosophy is that, if it is shown that faecal contamination of the water has occurred, it is assumed that pathogens may be present. The characteristics of an ideal faecal indicator bacterium are that it should be:

(1) a normal member of the intestinal flora of healthy people;

(2) exclusively faecal in origin;

(3) exclusively present in humans and/or animals;

(4) present whenever pathogens are present, and present only when pathogens might be reasonably expected to be present;

(5) present in higher numbers than pathogens;

(6) unable to grow outside the intestine and have a die-off rate slightly less than that of pathogens;

(7) easy to detect and count;

(8) non pathogenic.

In temperate countries, bacteria such as faecal coliforms, faecal streptococci and Clostridium perfringens come close to fulfilling these requirements. In hot climates, problems arise because of physiological changes in the organisms which alter the selectivity of the tests and enable at least some organisms to grow outside the intestine.

In the past, many studies have used the total number of coliforms as an indication of faecal pollution. However, coliform bacteria, other than those originating in the intestine of warm-blooded animals, are widely distributed in nature and may gain access to water via non-faecal sources. Escherichia coli is exclusively faecal and constitutes over 90% of the coliform flora of the human intestine. Thus the faecal coliform (E. coli) test is a more specific indicator and Evison and James (1977) believe it is the most sensitive and specific indicator of feacal pollution at present available. While this may be true for temperate countries, Feachem et al., (1978) point out that in hot climates some non-faecal coliforms can mimick E. coli, and their occurrence has resulted in a search for a more satisfactory indicator organism for use in hot climates.

Faecal streptococci are occasionally used as indicator organisms, especially when the faecal coliform test gives dubious results. However, some non-faecal streptococci are indistinguishable from truly faecal streptococci in routine detection procedures. Animals generally excrete much higher numbers of faecal streptococci than humans; hence the ratio of faecal coliforms to faecal streptococci (FC:FS) in a sample can indicate whether the pollution is derived from a human or animal source. Ratios of FC:FS greater than 4 are strongly indicative of predominately human contamination, with the associated danger of the transmission of human disease. Ratios less than 1 suggest mainly animal contamination. However, the FC:FS ratios in fresh faeces may vary widely between different species and different locations. Also, the rapid death of faecal streptococci at temperatures greater than 20°C diminishes the value of this test in tropical waters.

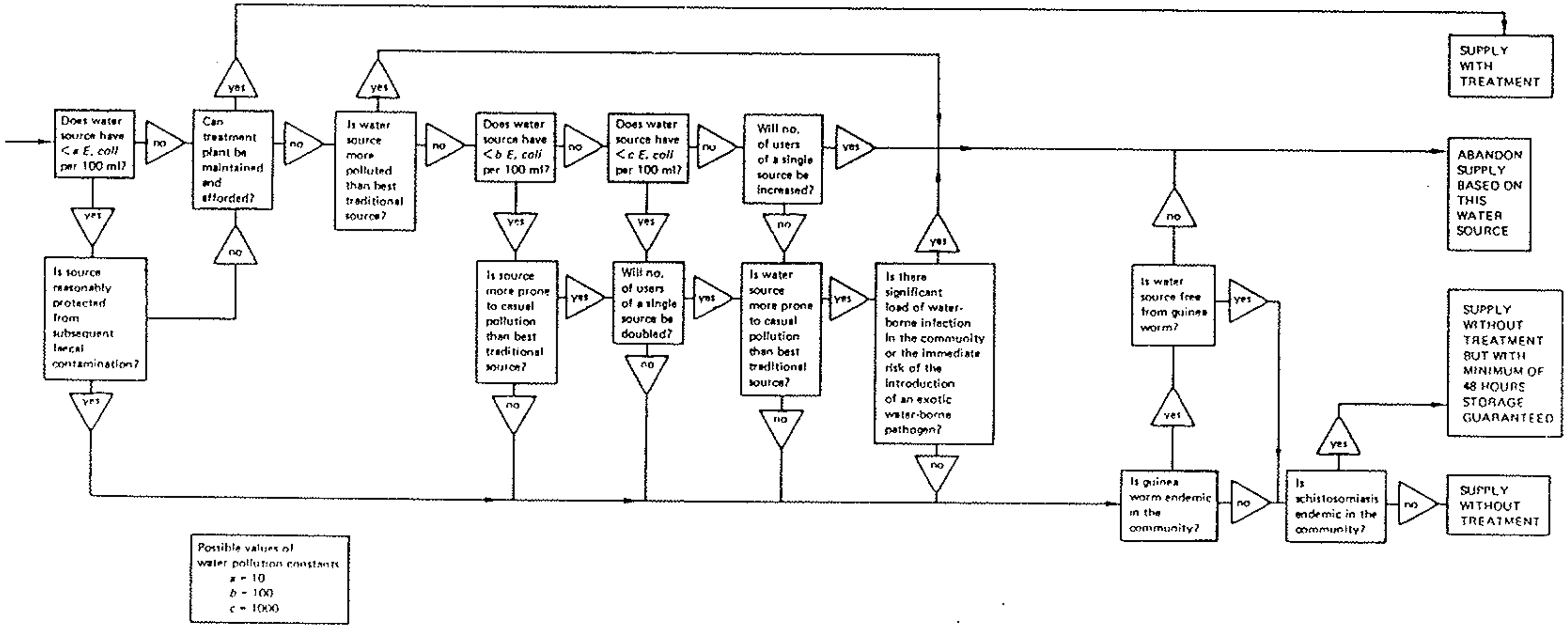


Figure 8. An algorithm of the decision to treat, not to treat or to abandon a particular water source. After Feachem et al., (1977).

The spore-forming anaerobe C. perfringens is sometimes used for the detection of intermittant pollution and can be used for this purpose both in temperate and tropical waters. Another anaerobe, Bifidobacterium, has also been proposed as an indicator of faecal pollution, as it is exclusively faecal in origin and does not grow outside the intestine.

Historically, the emphasis has been placed on the relationship between faecal indicators and bacterial pathogens. Much has been written about the persistence of indicator organisms and pathogenic bacteria, but little work has been done on the comparative survival of faecal indicators and non-bacterial pathogens such as viruses, protozoa and helminths, especially in warm climates (Feachem et al., 1978). In addition, caution has to be exercised in assessing the significance of data on faecal indicator survival in environments outside the original study area.

It is recommended by the World Health Organisation (WHO, 1971) that, for individuals or small communities, the drinking water source should be condemned if it is repeatedly found to contain more than 10 coliforms or 1 E. coli per 100 ml. However, Feachem (1977) argues that the standards set by WHO are far too stringent for hot climates in view of the capacity of coliforms for regrowth, and would result in the condemnation of the vast majority of existing water supplies in low-income communities. He suggests that water containing less than 10 E. coli per 100 ml of water should be supplied without treatment and advises the treatment of all other water sources. Figure 8 presents Feachem's algorithm of the decision to treat, not to treat or abandon a particular water source. The associated increased cost and maintenance problems may not justify treatment of the water supply, but the incidence of water-washed diseases may still be reduced by increasing the quality, availability and reliability of the water supply.

In areas where the background concentrations of inorganic ions, such as high fluoride or low iodide, present a serious health problem, appropriate modifications have to be made to Figure 8 , but, as they tend to be localised phenomena, no general statement can be incorporated.

For the shallow wells project in Tanzania (Divars Heederik en Verhey, 1976), the main criteria used to determine the suitability of a source of water were: pH, conductivity, fluoride concentration and bacteriological examination. The standards recommended were <2000 μs/cm conductivity and <8 mg/l fluoride, compared with the WHO maximum admissible limits of 2500 μs/cm and 0.1-1.5 mg/l respectively. In practice, most waters with harmful concentrations of total dissolved solids will not be drunk because they are so unpalatable. However, a high concentration of fluoride in the water can cause chronic fluorosis. Surface waters commonly contain less than 1 mg/l F, but, in some places, groundwaters may regularly contain 3-15 mg/l and even up to 40 mg/l F on occasions. Under these circumstances, where the water would be judged potable under WHO standards except for the level of fluoride, it would appear reasonable to raise the upper limit to 8 mg/l F, especially when there is good reason to believe that, in areas where high levels of fluoride have always been present, resistance to fluorosis may have been acquired.

WHO drinking water standards should not be applied rigorously, without due consideration of the particular situation. If the highest level of water quality is unattainable, it does not mean that it is not worth attempting anything. There are usually many improvements possible which, although falling short of the ideal, may have a considerable impact on health or on other problems of the local community.

# 7. CASE HISTORIES

## Introduction

Several case histories have been included to illustrate the complexities of any particular situation and how various aspects of pollution covered in this report differ in importance depending on the circumstances. The case histories serve to put the generalities into a specific framework.

However, during the extensive literature search which formed the basis of this report, it became apparent that only a handful of case histories had been well documented. Rybczynski et al., (1978) had similar problems while reviewing the available literature on unconventional waste disposal technologies suitable for developing countries. They found that the data bases searched by computer were not indexed for the needs of developing countries and that much of the relevant literature was published as studies or reports which tend to be hard to acquire. This would perhaps suggest that the pollution of groundwater in developing countries has not been, in the past, a high priority.

## 7.1 A detailed evaluation of the pollution hazard to village water supply boreholes in Eastern Botswana

Lewis, W J; Farr, J L and Foster, S S D (1978)

Report GS 10/4. Botswana Geological Survey

In many populated villages in eastern Botswana the nitrate levels in water-supply boreholes are extremely high, far in excess of WHO limits. A public water-supply borehole in the village of Mochudi, which was known to be severely contaminated, was selected for a study to identify the causes of pollution and the mechanisms of pollution movement. The groundwater flow regime and aquifer characteristics were investigated, and chemical and bacteriological analyses of groundwater samples were carried out, together with soil analysis and chemical tracer experiments.

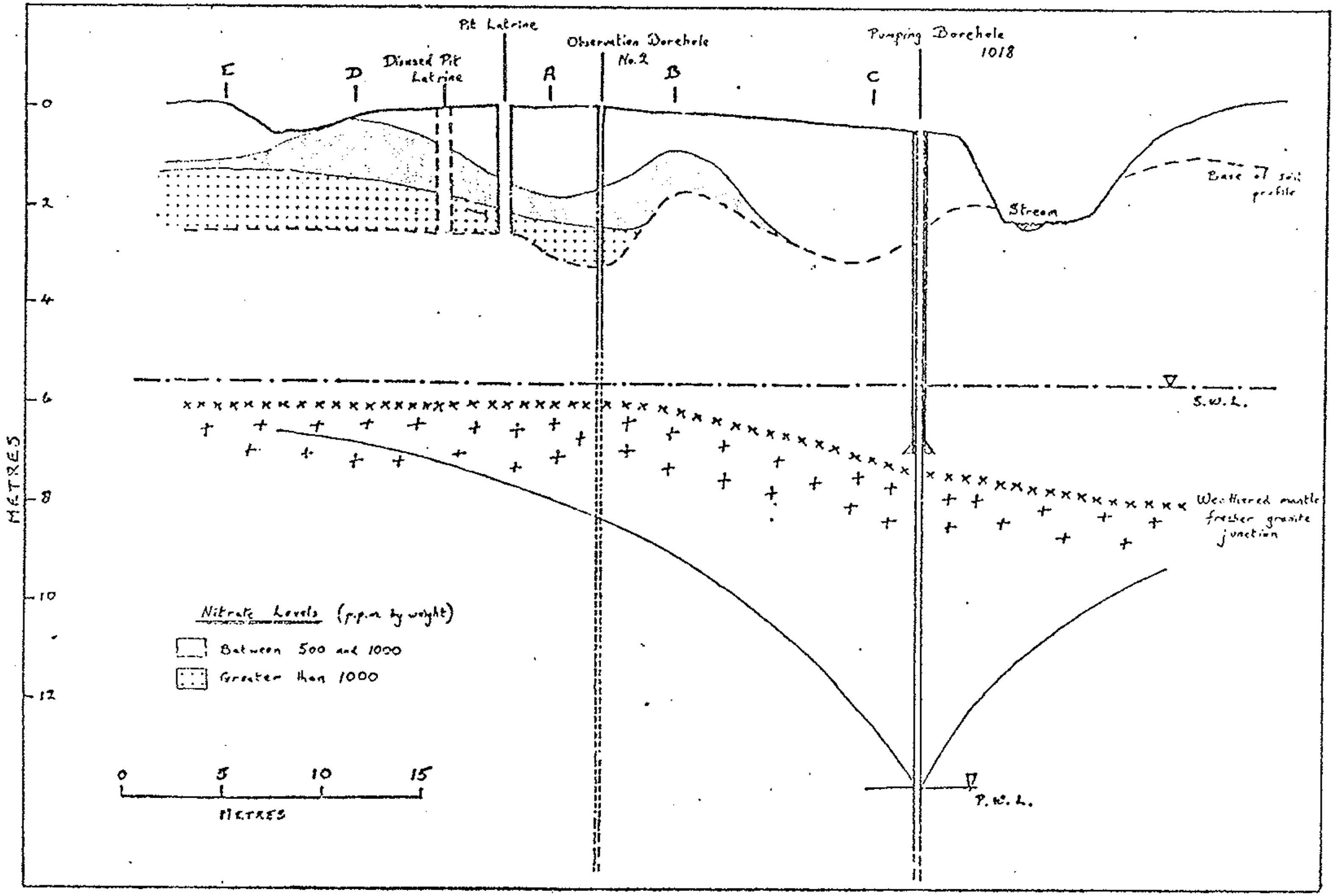


Figure 9. Schematic hydrogeological summary section with nitrate levels in the vicinity of Mochudi. After Lewis et al., (1978).

The weathered granitic material forming the aquifer was found to have a very low transmissivity, which probably indicated that there were few open fractures, the majority being filled by clayey weathering products. The electrical conductivity/temperature logs indicated the presence of two distinct layers of water, with a fresher lens of water above a more saline groundwater. The volume of fresh water was found to be relatively small and was due to influent seepage from a nearby stream.

The water from the Mochudi borehole contained very high levels of nitrate and suffered intermittant contamination by faecal bacteria. Until 1977 this water had been used to supply the nearby Dutch Reform Mission Hospital, in spite of the serious health hazard involved.

Pit latrines were situated 20-25 metres away from the boreholes, with the natural groundwater flow from the latrine to the borehole. Extremely high concentrations of chloride and nitrate were found in soil samples collected near the pit latrines. Generally, the nitrate levels were highest in the soil layer directly above the unweathered rock and at sites along the preferred drainage path from the borehole. The pit latrine was estimated to extend down to the bedrock, with the water table a further three metres below the base. A chemical tracer experiment, using lithium, showed that the transit time from the pit latrine to the water supply borehole was less than 235 minutes. From the quantity of tracer remaining 'at source', it was suggested that the flow of tracer had only occurred at isolated fissure horizons.

The report highlights the hazards associated with pit latrines in an area with rapid seasonal infiltration through a thin soil cover to bedrock formations with a relatively shallow water table. There was extremely rapid movement of faecal bacteria to the water table with inadequate natural degradation and filtration, and the huge build-up of nitrogenous effluent in the soil and weathered rock near the latrines was leached by infiltrating rainfall (Figure 9). All this emphasizes the public health risk of siting public water supply boreholes in the proximity of pit latrines and vise versa.

In this study, an additional pollution hazard was a small ephemeral stream near to the borehole, which supported influent seepage to some degree, and thus could be another source of faecal bacteria.

The recommendations in the report included:

(a) Relocation of public water supply boreholes in unpopulated areas, with reticulation to stand pipes within the villages themselves.

(b) Chlorination of the remaining doubtful sources, bearing in mind that chlorination can never be 100% effective in practice.

(c) Protection of sources from pollution must form an important part of the water supply policy. Protected zones need to be established around the boreholes and the size of these zones should be dictated by the prevailing hydrogeological conditions.

(d) Last, but not least, villagers should be made more aware of the hazards associated with the domestic use of certain boreholes, and of simple sanitary precautions.

## 7.2 A study of the water supply in rural health centre, Sarajini Nagar, Lucknow District

Bagchi, S C, Murty, Y S and Prasad, B G (1967)

The Indian Journal of Medical Sciences, 16, 1043-1063

In the region of Sarojini Nagar the main source of drinking water is open wells, usually 'pucka' wells with a parapet wall and a pulley. The study revealed that of the 145 'pucka' wells in the area, only 13 were plastered inside with cement mortar, leaving the remaining 132 open to sub-surface pollution. Even where parapets existed, only 33 of the wells had parapets higher than 25 cm, so that surface pollution from washing and bathing could enter these wells with ease. The chances of contamination were increased by each family using its own bucket and rope, proper drainage of waste water being absent and housedrains and sometimes village ponds being fairly close to the wells.

Not surprisingly, the survey indicated that all the open wells in use in the area were susceptible to heavy contamination. Of the 41 open wells sampled, only 13 contained water which was considered potable by chemical criteria. A preliminary bacteriological examination of 18 samples showed that, except for one, all the samples were grossly contaminated, even in the non-rainy season.

In view of these findings it was decided, firstly, to improve the design of one open well and, secondly, to sink some shallow tube wells in the area. The bacteriological quality of the water from both types of well was to be monitored. It was felt that these were the only two feasible solutions available to improve the potability of the water in an area where the average villager prefers to draw his drinking water from a well rather than an alternative source.

The improvements made to the open well were to reline the well with bricks and cement down to the water level, raise the parapet wall and place a heavy manhole cover over the well. A shallow handpump was fitted, ensuring that the pump extended below the water level at all times to avoid the necessity of priming. A circular concrete platform with a raised edge and a drain were constructed to prevent stagnant water collecting around the wellhead. Periodic maintenance visits were organised to check that the handpump was in working order.

Before reconstruction, the coliform most probable number (MPN) was 1800+, whereas in the subsequent six months this figure was reduced to 200 and eventually stabilized below 100. The persistance of this level of coliforms remains unexplained. Thus there was a considerable reduction in the MPN index, even though the Indian standard of 40 for rural water supplies could not be attained.

The few existing shallow tube wells did offer water of good bacteriological quality. In the few cases where the MPN index was above 10, inspection of the pump invariably revealed some defect in the working of the machine, such as a leaking foot valve, an incompletely closed tap, frequent priming and so on. Bacteriological samples only were taken from the 9 experimental tube wells because good results had been obtained from existing ones. It was observed that it took a month after installation for the new tube wells to stabilize bacteriologically and then the existing and experimental shallow tube wells yielded water of the same quality.

The reconstructed well proved to be popular among the villagers and the number of families using the well increased about 4-fold from the previous average of eight families. This reconstructed well attracted a large number of people from surrounding villages on market day; one of the main reasons for this popularity was the hand pump, which required less physical effort to operate compared to buckets and ropes.

The cost of reconstruction was less than the provision of a new 'pucka' well and provided vastly improved quality of water and enhanced the use of the well. The response to the shallow tube wells was also encouraging, especially as they provided a source of potable water. In this particular study the presence of latrines only 20 feet from one shallow tube well was not thought to be critical because the physical properties of the 'water bearing sand strata' overlain by silt and clay indicated that the strata would be an ideal natural filter for the bacteria. Although, in this particular case history, well construction and use were the important factors, well location should not be dismissed as lightly as the authors suggest.

## 7.3 A study on drinking water in village Rahimabad of Lucknow District

Dhar, G M, Prasad, B G, Mathur, Y D and Bhatnagar, J K (1971)

Indian J. Med. Res., 59, 1922-1931

A survey of all the wells in Rahimabad was carried out and details such as the construction of a well, its ownership, its distance from potential sources of pollution and the arrangement for drawing were sought.

Water samples from the wells were also sent for chemical and bacteriological analysis.

The main sources of drinking water in the village were "open shallow" wells. Bacteriologically, all 51 of these open shallow wells were unsatisfactory, as the presumptive coliform count was over 180 per 100 ml of water, compared to an Indian limit of 20. The insanitary condition of these wells was mainly due to the presence of sources of pollution such as cesspools, surface drains and refuse dumps which, in 47 out of 51 cases, were located within 15 metres of the wells. The state of the wells themselves can be assessed from the figures - 40 wells had no covers, 12 had no parapets, 24 had no lining and 50 had no sanitary arrangements for drawing water.

In the village there were also 7 wells fitted with handpumps. Bacteriological examination of these waters gave a presumptive coliform count that was generally below the permissible limit of 20, with occasional lapses, and showed that, although the bacteriological quality of the water from the handpumps was not entirely satisfactory, it was far superior to that of the open shallow wells.

The differences in the bacteriological quality of the water were not reflected in the chemical analyses. By chemical quality standards neither type of source was satisfactory. This would appear to demonstrate the difficulty of extrapolating from inorganic determinands to the bacteriological quality of a water supply.

## 7.4 Nitrates and bacterial distribution in rural domestic water supplies.

Brooks, D and Cech, J (1979)

Wat. Res., 13, 33-41

This study in Houston County, East Texas, U.S.A., focussed on nitrate levels in groundwater and sought to establish whether the origin of excessive nitrates was anthropogenic or natural.

At the time of the survey (1976) about 57% of the population were served by public water supply, 39% from private wells and the rest from other sources. Similarly, 39% of the population were served by sewerage systems, 38% used cesspools and septic tanks and 23% used other means of sewage disposal. The reliance upon individual methods of waste disposal by more than half the population, plus the use of shallow strata for water supply, suggested there might be a groundwater quality problem.

To take account of the differences in geology in Houston County, groundwater samples were taken from wells in all the sandy strata which were known to be aquifers. The background level in the area was low, from 0-14 ppm nitrate. In general, the concentration of nitrates was fairly uniform, with the exception of localised areas with levels in the range 100-200 ppm nitrate, which clearly contrasted with the background and were unrelated to geological deposits or other geographical factors. An evaluation of man-related factors which could cause elevated nitrates was made and the results indicated:

(a) No strongly defined relationship with agricultural activity, such as the use of nitrogenous fertilizers.

(b) More congruity existed between the nitrate levels and the location of wells in relation to animal feedlots or farmyards, but the relationship was not of statistical significance.

(c) The wells with the highest nitrate concentrations were those located in close proximity to septic tanks, some at a distance of less than 5 metres.

(d) Elevated concentrations of nitrate were found in dug wells, primarily those yielding water from depths of roughly 15 metres or less. There was a very strong correlation between the nitrate level and the type of well, such as dug compared with drilled, and the depth of the well was also an important factor.

(e) All the dug wells of 15 metres or less were found to give positive counts of faecal bacteria.

(f) While all wells with high nitrate levels gave positive faecal bacteria counts, it did not follow that the highest nitrate concentration coincided with the highest count of faecal bacteria. In some cases of gross faecal bacterial contamination the nitrate concentration was low.

(g) The wells with the highest nitrate levels had ratios of faecal coliforms to faecal streptococci of one or higher, suggesting that domestic sewage was the most likely primary source of the nitrate. Moderately elevated nitrates and bacterial ratios of 0.6 or less were found in samples from wells located near to farmyards and animal pens, which supported the preliminary conclusion in paragraph (b) that seepage from such sources can contribute nitrates to the aquifer.

The ratio of faecal coliforms to faecal streptococci, although confirming the other findings of the study, did not show a statistically significant association with the nitrate content of the waters. This suggests that the relationship is intricate and involves other factors which are not presently understood.

In many cases, even where the wells were constructed in accordance with existing guidelines, septic tanks, privies and the like built afterwards were placed without due regard for the water sources.

## 8. CONCLUSION

In the forthcoming United Nations Water Decade (1981-90), great emphasis will be placed on the provision of safe water supplies and sanitation facilities for the majority in developing countries, who do not enjoy access to these facilities at the moment. This will require a substantially increased use of groundwater as a source of potable water, which is in conflict with the provision of the on-site sanitation systems envisaged. Thus, it is of vital importance that the hazard of pollution of groundwater from on-site sanitation can be assessed and means of defining the potential pollution are evolved.

The fundamental questions that need to be answered are:

(a) how far do the pollutants move vertically and horizontally from the point of discharge, and

(b) in the case of pathogens, for how long are they able to survive?

Both these questions are extremely difficult to answer, as there are so many variables to consider and every set of parameters is unique. This report endeavours to indicate the factors that need to be evaluated when an assessment has to be made of a particular situation.

However, several points should be emphasized. Up to five months is generally reported for bacterial survival in groundwater (Feachem et al., 1978), although most reduction takes place in the first few days. Viruses may survive for 6 months or more. Thus, the passage of time is a most important factor and a knowledge of the rate of movement of micro-organisms, especially in the unsaturated zone, would be of great assistance in assessing the potential health hazard. Micro-organisms have a finite life so that any inorganic indicator of pollution would not necessarily imply the future presence of microbiological pollution.

A good hydrogeological appreciation is necessary to determine the rate and direction of groundwater flow. This information dictates the relative positions of a well and any on-site sanitation or other potential sources of pollution, such as livestock. Of equal importance is well construction, as many cases of contamination result from insufficient protection against polluted water gaining direct access to the aquifer via the well.

Although the pollution of village wells in developing countries is already acknowledged as a problem and remedies such as those suggested in this report are available, the whole subject needs to be placed on a more quantitative footing to be sure that much of the work envisaged in the next Decade will be of long term benefit. No-one will be thanked if better sanitation facilities result in irreversible degradation of the groundwater quality. To this end, the World Bank, under the auspices of the United Nations Development Programme, are setting up a programme in several countries, to monitor the change in groundwater quality with sanitation construction and usage. The work envisaged includes an initial assessment of the hydrogeology and existing groundwater and surface water quality in the project area. A sampling network round the area where the sanitation units are to be installed will enable regular sampling for microbiological and inorganic indicators in a three-dimensional framework. Such information, although only directly applicable to the project area, would be extremely valuable, as existing relevant data is minimal, and would place all future plans on a firm basis.

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## APPENDIX A - RELEVANT LITERATURE

Several bibliographies which have not been included in the main body of the report but contain some pertinent information are given.

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