Diarrhoeal disease: current concepts and future challenges

Water, sanitation and diarrhoea: the limits of understanding

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Abstract

This paper reviews the application of epidemiological understanding of diarrhoeal disease to interventions in water and sanitation. Over the past 20 years, great efforts have been made to elucidate the relationships between water supply, sanitation and diarrhoeal disease. At the outset, it was hoped that improved understanding of these relations could provide a rational framework for the planning of public health engineering interventions. This paper also reviews historical and recent perceptions of water, sanitation, and diarrhoeal disease, and summarizes progress to date. On the one hand, some fundamental ideas about the relative importance of water quality and quantity in the transmission of diarrhoeal disease have changed, and there is increased recognition of the complex interrelationships between interventions, hygiene behaviour and health. On the other hand, our understanding of the impact of interventions is painfully incomplete, and is unlikely to improve dramatically in the near future. While further research can usefully illustrate a variety of interactions in specific contexts, globally applicable planning guidelines and design criteria appear a dangerous will-o'-the-wisp. While we know more than ever before about water, sanitation and diarrhoea, much remains unknown, and is perhaps unknowable.

Water quality and quantity: common beliefs and their origins

Since the nineteenth century, most public health engineers have believed that water quality is the most significant indicator of a water supply's effect on health. This picture has changed for many as a result of the analysis by Bradley (in WHITE *et al.*, 1972), and the writings of Feachem and Cairncross (e.g., FEACHEM, 1977; CAIRNCROSS & FEACHEM, 1983), but most engineers still believe that clean water is the *sine qua non* for diarrhoeal disease control.

There are historical reasons for this belief, which were well described by CAIRNCROSS (1992). The first (and often only) lesson in epidemiology for engineers is how John Snow used reason and numbers to condemn a contaminated water supply in London to prevent the spread of cholera in 1854, before the promulgation of the germ theory of Pasteur. CHANLETT (1973) and others retell the story of how William Budd analysed the role of sewage in the spread of typhoid in communities in Wales and England in the 1850s and 1860s. Engineers also learn how sand filters in Altona kept the incidence of cholera to a small fraction of that in neighbouring Hamburg (without filters) in 1892. (The return of cholera the next year to filtered Altona, but not to unfiltered Hamburg, is less often told! [HAMLIN, 1990].)

These are real incidents of water-borne disease, in which improvements in drinking water quality could have saved many lives. Water-borne outbreaks of diarrhoeal disease are by no means restricted to the nineteenth century, as shown by the Croydon typhoid epidemic (HOLDEN, 1939) and the periodic reviews by the US Centers for Disease Control (e.g., HUGHES *et al.*, 1975; HARRIS *et al.*, 1983). The dramatic nature of such epidemics impresses the importance of water quality upon the minds of engineer and layman alike, and strengthens the impression of both that diarrhoeal disease is generally water-borne. Where the overall levels of faecal contamination and endemic diarrhoea are low, and the resources available for water and sanitation are relatively high, such beliefs serve to remind water supply professionals of their responsibilities, and are therefore benign.

Much of the developing world, however, is plagued with a relatively high level of faecal contamination in water and endemic diarrhoeal disease, and an acute shortage of resources for public health. It is therefore not surprising that health planners and economists have started to ask about the relative roles of water supply and sanitation in comparison with other means of controlling diarrhoeal disease (FEACHEM *et al.*, 1983).

Ways of thinking and about water and health

WHITE *et al.* (1972) and BRADLEY (1977) divided water-related infectious diseases into categories which reflected their means of transmission. The four categories were (i) infections spread through water supplies (water-borne); (ii) infections spread through lack of water for personal hygiene (water-washed); (iii) infections transmitted through an aquatic invertebrate host (water-based); and (iv) infections spread by insects that depend on water (water-related insect vectors). Bradley placed water-related diseases into each of these categories, and outlined the implications for disease control. If the disease were water-borne, improvement of drinking water quality would be the appropriate intervention. If the disease were water-washed, then the quantity of water used by people must increase. If the infection were water-based, or associated with water-related insect vectors, then interventions should be aimed at the intermediate hosts.

Engineers responded to this approach with enthusiasm; while they may have little taste for biological taxonomy or clinical diagnosis, engineers can think usefully about breaking routes of transmission. This was clearly a system developed for planning interventions and thus served as a bridge between engineers and more medically-oriented public health workers. This system has by and large set the agenda for thought about water interventions and diarrhoea for the last 20 years, precisely because it focused on the objects of such interventions. Health planners now found themselves able to ask questions about the relative return from investments in water quantity and quality, and how these compared with other interventions in diarrhoeal disease.

There was one difficulty in applying the scheme, which Bradley pointed out from its inception: the categories were not mutually exclusive. While engineers would like to know that diarrhoea is either water-borne or water-washed, in fact they can't know a priori; indeed, transmission may be by both routes. 'All the [faecal] infections that can be spread from one person to another by way of water supplies may also be more directly transmitted from faeces to mouth, or by way of dirty food. When this is the case, the infections may be reduced by the provision of more abundant or more accessible water of unimproved quality.' (BRADLEY, 1977).

FEACHEM (1977) observed that, as the overlap between water-borne and water-washed diseases lay only in the faecal–oral diseases, they should constitute a separate group. The Bradley–Feachem classification thus became: (i) faecal–oral diseases (water-borne and water-washed); (ii) strictly water-washed diseases (skin and eye infections);

(iii) water-based; and (iv) water-related insect vector. This system is more consistent, and renders explicit the co-existence of water-borne and water-washed disease transmission routes for faecal–oral diseases, including diarrhoeal disease. This system, however, ended the engineers' dream of a clear-cut guide to interventions; it was not going to be possible to say 'if diarrhoea is caused by agent X you increase the quantity of water; if caused by agent Y, then focus on treatment.'

What the epidemiological literature says

Major efforts were mounted during the 1980s, particularly by the World Health Organization, to determine the cost-effectiveness of various interventions in the control of diarrhoeal disease. Before these assessments, BLUM & FEACHEM (1983) had already undertaken a review of 44 published studies on water supply, sanitation, and diarrhoea. The paper did not try to identify the general trend of cause and effect between sanitary intervention and diarrhoea. Rather, it focused on 8 serious methodological problems, at least one of which affected each of the studies reviewed. In addition to encouraging a more critical approach to water and sanitation epidemiology, the paper made clear how difficult it is to perform a sound study of such interventions.

Notwithstanding these grim methodological conclusions, ESREY *et al.* (1985) reviewed 67 studies from 28 countries to assess the impact of water and sanitation interventions on diarrhoeal disease among young children. Their principal results are shown in Tables 1 and 2. Separate analyses of the 3 best studies on total mortality and the 4 best studies on morbidity were also performed. These revealed a median reduction of 30% in mortality (range 8%–64%) and a median reduction in diarrhoeal morbidity rates of 27% (range 0–68%).

Table 1. Percentage reductions in diarrhoeal morbidity rates attributed to water supply or excreta disposal improvements[a]

Type of intervention	No. of results	Percentage reduction Median	Range
All interventions	53	22	0–100
Improved water quality	9	16	0–90
Improved water availability	17	25	0–100
Improved water quality and availability	8	37	0–82
Improved excreta disposal	10	22	0–48

[a]From ESREY *et al.* (1985).

Table 2. Percentage reductions in morbidity/infection rates of cholera, *Shigella*, *Entamoeba histolytica*, and *Giardia* attributed to water supply or excreta disposal improvements[a]

Disease or infection	No. of results	Percentage reduction Median	Range
Cholera	11	41	0–91
Shigella	27	48	0–81
Entamoeba histolytica	17	2	0–80
Giardia	10	0	0–20

[a]From ESREY *et al.* (1985).

A more recent survey of 144 studies by ESREY *et al.* (1991), using more or less the same approach as the earlier one, presented the results shown in Tables 3 and 4.

Table 3. Expected reduction in diarrhoeal morbidity and mortality from improved water and sanitation[a]

	All studies	Reduction (%)		More rigorous studies	Reduction (%)	
	Number	Median	Range	Number	Median	Range
Morbidity	49	22	0–100	19	26	0–68
Mortality	3	65	43–79	–	–	–

[a]From ESREY *et al.* (1991).

Table 4 is particularly interesting because it recognizes a separate type of intervention which is not focused on the provision of hardware, but rather on changes in the behaviour of individuals in such areas of hygiene as handwashing.

Table 4. Median reductions in diarrhoeal disease morbidity from improvements in one or more components of water and sanitation[a]

	All studies No.	Median reduction (%)	Rigorous studies No.	Median reduction (%)
Water and sanitation	7	20	2	30
Sanitation	11	22	5	36
Water quality and quantity	22	16	2	17
Water quality	7	17	4	15
Water quantity	7	27	5	20
Hygiene	6	33	6	33

[a]From ESREY *et al.* (1985).

Some conceptual difficulties

Although median statistics provide tempting 'rules of thumb' for planners and decision-makers, the wide ranges shown in these reviews bring into question the validity of using a single number to describe a complex relationship. While some of the scatter is certainly due to the methodological problems outlined by BLUM & FEACHEM (1983), surely much of it is due to the very site-specific nature of disease transmission patterns. The complexity of such interactions is evident within the F-diagram (KAWATA, 1978) (Figure).

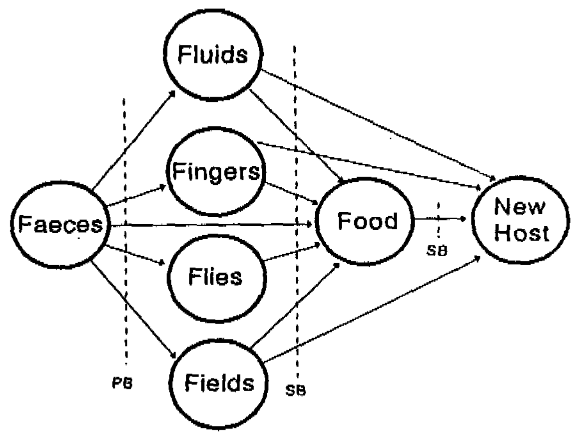

Figure. Routes of possible transmission of disease from faeces. PB, primary barrier; SB, secondary barrier (see text). (Redrawn from KAWATA, 1978.)

In addition, there are basic conceptual difficulties with studies involving multiple transmission routes. These were clearly described by BRISCOE (1984), who postulated a hypothetical diarrhoea-causing pathogen '*Bacterium experimentus*' with a probability of infection= $0{\cdot}5\times\log_{10}$ (dose). He also postulated 3 transmission routes for this pathogen, named Red, White, and Blue. Unknown to epidemiologists, individuals exposed to the Red route get a dose of 70 organisms, those exposed to the Blue route get a dose of 30 organisms, and those exposed to the White route receive no dose at all. Two hypothetical experimental intervention groups and a control were established, each with 100 members. The control group A was exposed to all 3 routes; the experimental group B was protected against the Blue route only, while the experimental group C was protected against the Red route only. The results, given the assumed dose-response curve and transmission route characteristics, are shown in Table 5. Briscoe asked: 'What conclusions would a naive epidemiologist draw?' Controlling the Blue route reduced diarrhoea by only 8%, while controlling the Red route reduced diarrhoea by

Table 5. Development of disease in Briscoe's experimental groups*

Group	Exposure	No. of organisms ingested	Probability of infection	No. of cases
A	Red+Blue+White	70+30+0	1·00	100
B	Red+White	70+0	0·92	92
C	Blue+White	30+0	0·74	74

*From BRISCOE (1984).

26%. It seems 'clear' that White is the most important route of transmission; the results suggest that eliminating both Red and Blue routes would reduce diarrhoea by only 26%+8%=34%. In fact, the White route transmits no diarrhoea, and eliminating both Red and Blue routes would eliminate disease transmission; the false analysis stems from the non-linear nature of the dose–response curve.

One of the most practical points made by Briscoe's analysis (BRISCOE, 1984) is that eliminating most of the contamination may not eliminate most of the disease. If non-linear dose–response curves hold, the overall level of environmental contamination may need to be brought down quite dramatically before single interventions like 'water supply' or 'sanitation' can show a major effect on disease, even if these are still major pathogen transmission routes. As noted by BRISCOE (1984), similar conclusions had been suggested by previous work, notably that of SHUVAL *et al.* (1981) who argued that the population 'response' to a 'dose' of water and sanitation intervention depended greatly upon the overall levels of faecal contamination, hygiene and socio-economic development.

Hygiene behaviour

One of the benefits of Bradley's classification of diseases (WHITE *et al.*, 1972; BRADLEY, 1977) is its focus on how interventions in water supply may affect health. Increasing the quantity of water available to a household can reduce water-washed disease transmission only if more water is used for washing, and used in an appropriate way. These are questions of hygiene behaviour, that is, those aspects of human behaviour which may affect hygiene. HUTTLY (1990) noted increasing recognition of behaviour as a risk factor in the epidemiology of water and sanitation. Examples of hygiene behaviour cited by CAIRNCROSS (1990) include the washing of hands, food and utensils, and the disposal of children's stools.

As noted by CAIRNCROSS (1992), the impact of hand-washing upon diarrhoeal disease control has been particularly well documented. For example, KHAN (1982) reported a 69% reduction in secondary infection of *Shigella* as a result of increased hand-washing with soap and water, and that washing without soap produced far less impact. AUNG MYO HAN & THEIN HLAING (1989) reported a 30% reduction in diarrhoeal disease among children under 5 years old as a result of a similar intervention to increase hand-washing.

CAIRNCROSS (1990) conceded that such behaviour was not as easy to measure as the presence of water supply or sanitation facilities. Nevertheless, he argued that 'The objective study of human behaviour is not impossible, as a wealth of anthropological literature can testify. The problem is that the necessary techniques are not well known in the water and sanitation sector.' To remedy this situation, a workshop on the measurement of hygiene behaviour related to water and sanitation was held in Oxford in 1991, and 2 publications (BOOTE & CAIRNCROSS, 1993; KOCHAR & CAIRNCROSS, in press) will help practitioners and scholars alike understand more clearly how water and sanitation facilities and hygiene education affect hygiene behaviour, and how such behaviour affects health.

Conclusions

From a practitioner's point of view, what are the lessons that have been learned over the past 20 years of epidemiological debate?

(i) *The quantity of water used by people is at least as important, and often more important, for diarrhoeal disease control than the quality of that water.* The general results in the epidemiological literature bear out the significance of water-washed diarrhoeal disease transmission. The importance of water quality is greatest in urban environments where concern about common-source outbreaks is legitimate; where diarrhoea is endemic and overall faecal contamination is high, it is reasonable to focus on quantity rather than quality.

(ii) *The impact of water and sanitation interventions upon diarrhoeal disease will vary greatly from place to place, for a variety of reasons.* Median or average statistics, widely used by health planners and economists understandably keen for comparisons with other interventions, hide the enormous diversity of impact. Papers by BRISCOE (1984) and SHUVAL *et al.* (1981) present reasons why impacts are likely to be influenced by the overall level of faecal contamination. Their arguments suggest that, in environments which are very heavily contaminated, the presence of multiple transmission routes (particularly among children who suffer most from diarrhoea) limit the effectiveness of controlling only one or two routes.

(iii) *The study of hygiene behaviour offers much promise in the development and implementation of water and sanitation interventions.* The need to integrate water supply, sanitation, and health education was part of the dogma of the International Drinking Water Supply and Sanitation Decade. In practice, however, there has been no practical way to monitor the effectiveness of hygiene education, or to explore the relationships between the provision of facilities and hygiene. Tools are now being developed to improve our understanding of such questions, and these can be of value in monitoring the impact of interventions. Engineers have long been frustrated by the sight of 'their' facilities not being used 'properly'. A better understanding of hygiene behaviour may help practitioners to restate this problem in a more constructive form; engineers may learn how to work with other disciplines, and with the communities themselves, to develop facilities which can be used to promote health.

Acknowledgements

Conversations and papers shared by Sharon Huttly (Maternal and Child Epidemiology Unit, London School of Hygiene and Tropical Medicine) were invaluable in reviewing the literature of water and sanitation epidemiology. I gratefully acknowledge the financial support of the British Overseas Development Administration.

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