The role of water supply in improving health in poor countries (with special reference to Bangla Desh)[1]

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The literature on water supply and health is strikingly heterogeneous in design, in method, and in conclusions (1) and "offers little in explaining water's health impact beyond confirming the existence of a general association between improved quality and increased quantity of domestic water and a reduced incidence of enteric disease" (2).

Several excellent recent reviews examine the relevant literature (1–5). This review addresses itself to the role of improved water supplies in easing the burden of infection in poor countries. Since the relationship between health and water is so markedly affected by the cultural, socioeconomic, and ecological characteristics of an area, it is recognized that universal conclusions are impossible and general ones are of limited practical value. The approach taken in this paper, therefore, is to examine in detail a limited set of studies that have been conducted in the same environment, a rural area of Bangla Desh. The analysis is illustrative rather than comprehensive. Through examination of these studies, general methodological problems will become apparent, the difficulties in drawing a consensus from a set of studies of essentially the same population will become clear, and the ways in which imperfect information may yet be useful in formulating policy will be illustrated.

Research on water supply and health

Some methodological issues in studies of the effect of water supply on health

Both inferential and deductive reasoning have been used in analyzing the relationships between water supply and health. A large number of diseases are believed to be contracted through the ingestion of pathogenic organisms that are present in the water. It is assumed that the provision of a "pure" water supply will drastically reduce their incidence. Diarrheas, accounting for about 30% of the mortality in the Indian subcontinent, are usually assumed to be the most important of these diseases, yet understanding of this most important syndrome is rudimentary (2).

Although interesting epidemiological models of typhoid and cholera have been developed by Cvjetanovic and his colleagues at the World Health Organization (6, 7), it is questionable whether adequate primary epidemiological data exist for the construction of realistic models for even these much-studied diseases. In general, the epidemiological understanding of enteric diseases is so poor that realistic *a priori* models cannot be constructed. Investigators therefore usually use statistical inferential methods to analyze the relationships between water supply and disease.

The large amount of literature on the empirical relationships between water supply and health consists of both cross-sectional and longitudinal studies. The former, such as those of the World Health Organization Diarrheal Diseases Advisory Team (8), have been plagued by the existence of high multicollinearity of "independent" variables. For example, income and nutritional status are usually highly correlated with quality of water supply. That one may show a correlation between water supply quality and health may imply either that the communities or individuals with better health status are more healthy because of the quality of their water supply, or that a more healthy community has taken

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steps to improve the quality of its water supply. It is somewhat surprising and unfortunate, given the frequency with which the multicollinearity question has arisen, that no analysis of cross-sectional data using multivariate techniques has been attempted.

The longitudinal studies are generally prospective; water supply improvements are made in an "experimental" community, while the health of this and a "similar" control community are monitored. The assumption that the two communities are similar in all important respects has proved to be a major problem. Frequently, adequate preintervention monitoring has not taken place and differential changes in the "experiment" and "control" communities occur during the study which have unmeasurable effects on health in the two communities. Particularly serious is the fact that the communities are often exposed to quite different probabilities of infection due to the occurrence of an epidemic in only one of the communities. Conversely, the carefully conducted INCAP three village longitudinal study (9) failed to yield definitive conclusions, perhaps because the interventions failed, for a variety of reasons, to substantially alter either water use or defecation patterns.

Studies of water supply and diarrheal diseases in rural Bangla Desh

Under the auspices of the Cholera Research Laboratory, four studies have been conducted on the effect of the provision of hand-pump tubewells on the incidence of cholera and other diarrheal diseases in Matlab Thana, a rural area in the deep water flooding plain of the Meghna River (10).

One study upheld the traditional belief that "large-scale installation of adequate tubewells would be of cardinal importance for the prevention of cholera in rural areas in which it is not possible to provide for piped water supplies" (11) in the case of classical cholera, but not for the El Tor biotype. The other three studies (12–14) found no difference in attack rates between tubewell users and nonusers for both *Vibrio cholerae* biotypes. All four of the investigators suggested that the hand-pump tubewell program was not meeting its stated objective, namely, reducing the incidence of cholera. The studies raise another important policy issue by examining the hypothesis that those who use tanks to meet their needs for water have lower cholera attack rates than those who draw their water from other surface sources. The findings of the two studies which address this issue are apparently contradictory.

Beyond the field of water per se, the studies have implications for the understanding of transmission of disease in general. These counterintuitive results have suggested to some that the widely accepted model of cholera as primarily a waterborne disease may be incorrect, at least in the tropical countries. Moreover, counterintuitive and apparently contradictory results undoubtedly confuse those who are attempting to devise appropriate water improvement programs in rural Bangla Desh.

Surface water sources (ditches, tanks, canals, and rivers) are easily accessible to most Matlab families and all use them for all purposes other than drinking. Despite the fact that these sources are frequently contaminated with fecal organisms, the water "quality" (color, turbidity, temperature, smell, and taste) is generally perceived as satisfactory. The only protected water sources available are hand-pumped shallow tubewells, about 20% of which are privately owned. Although about 30% of the families report tubewell water as their source of drinking water, tubewells are virtually never used for any other purposes. Tubewell water is not attractive for a variety of reasons, including being less accessible than surface water sources, requiring considerable effort to pump, and in this area being generally poor in quality. Although it often looks clear when fresh, it turns turbid and forms brown scum and precipitates on overnight storage. "It causes discoloration of teeth, rice, curry, clothes and tea and tastes of iron" (13).

Sommer and Woodward (10) examined the effect of use of protected drinking water sources (i.e., hand-pump tubewell) on cholera attack rates. They considered the answers given by villagers to questionnaires on water use to be unreliable, and therefore compared cholera attack rates between families living within 50 feet of a functioning tubewell and those who lived further away during 2 successive years in Meheran, a Hindu fishing village of about 1,800 inhabitants. The first epidemic (1968–1969) was caused by the classical/Inaba strain. In the immediate vicinity of tubewells, there was a lower rate of infection (1 of 27 or 3.7%) than farther away (19 of 75 or 25.3%). During an epidemic the following year (1969–1970), now caused by the El Tor/Ogawa strain, there was no difference in the rates of infection of these two groups (16 of 53 or 26.9%, and 37 of 149 or 26.4%, respectively). The authors suggested that the difference in the 2-year results "might reflect the inherently different patterns of transmission of the classical and El Tor biotypes. Infection with the El Tor strain results in both a longer period of vibrio shedding and a lower incidence of clinically apparent disease than infection with the classical variety. In addition, the El Tor vibrio is hardier than the classical and remains viable in water much longer" (8).

Khan et al. (13) examined the relationship of reported water use patterns to cholera attack rates for a random sample of over 2,000 families in Matlab Thana during the period from 1966 to 1970. During this period, cholera was of the classical/Inaba type. Connected tank users were excluded. Table 1, which shows these data, suggests that those who used tank water for drinking, washing, or bathing had attack rates from cholera that were lower than those for families using other sources. In particular there was no significant difference between attack rates of families drinking canal, river, or tubewell water, whereas the attack rate for tank water drinkers was significantly lower than that for users of any other source. Extending the period of analysis to 10 years and thus including both classical and El Tor cholera, Khan found similar differential attack rates.

Levine et al. (14) observed the water collection practices of 88 families in two cholera-prone villages in 1975. Hospitalization rates for cholera and diarrheal diseases from 1963 to 1969 were computed for all families. The attack rates for those families who collected tubewell water at least five times more often than water from any other source for the stated purpose of drinking were compared with the attack rates for other families (Table 2). They concluded that "tubewell users had as much or more cholera and other diarrheal diseases than nonusers," and "in affected baris, annual rates for canal and tank users were almost equal (cholera = 11.9 versus 10.4, and hospitalized noncholera diarrhea = 4.0 versus 3.8 per 1,000 annual, respectively" (14). Tubewell water was found to be free of coliforms whereas canal water had coliform counts of over 1,800/ml. Since "connections exist between tanks and canal, particularly during the monsoon" (14), tank water was also, presumably, highly contaminated.

Curlin et al. (12) have recently reported the preliminary results of the 1st year of a 2-year project to study the impact of the hand-pump

TABLE 1
The effect of water source on cholera attack rates in Matlab Thana, Bangladesh[a]

	% of families with cholera 1965–1970	Significant difference at 5% level?			
		Canal	River	Tank	Tubewell
Drinking					
Canal	6.9 (27/389)		No	Yes	No
River	5.6 (19/342)	No		Yes	No
Tank	1.9 (18/962)	Yes	Yes		Yes
Tubewell	5.2 (27/515)	No	No	Yes	
Washing					
Canal	8.9 (35/395)		No	Yes	
River	4.1 (6/145)	No		No	
Tank	3.0 (50/1663)	Yes	No		
Bathing					
Canal	7.0 (32/459)		No	Yes	
River	5.4 (17/317)	No		Yes	
Tank	2.9 (42/1430)	Yes	Yes		

[a] From Reference 13.

TABLE 2
Tubewell use and diarrheal disease[a]

	Cases	Person-years	Annual rate/ 1000	Rate ratio	Rate ratio (90% CL)[b]	P (2-tailed exact)
Cholera						
Tubewell users	53	3725	14.2			
Tubewell nonusers	13	1545	8.4	1.7	1.0;2.8	0.08
Noncholera diarrhea						
Tubewell users	28	3725	7.5			
Tubewell nonusers	5	1545	3.2	2.3	1.0;5.2	0.07

[a] From References 14. CL, confidence limits.

TABLE 3
One-year disease rates (per 1000 per year)[a]

Drinking water source	Reported diarrhea rates (in field)	Confirmed cholera rates (at hospital)	Confirmed shigellosis rates (at hospital)
Tubewell	789	4.32	0.93
Other sources	757[b]	1.04[b]	1.50[c]

[a] From Reference 12. [b] Rates are significantly different at 1% probability level. [c] Rates are not significantly different at 1% probability level.

tubewell on diarrheal illness rates in 12 villages of Matlab Thana. Families were visited weekly and diarrheal episodes recorded, and each month families were questioned on the sources of water for drinking, bathing, cooking, washing utensils, and use after defecation (Table 3). The authors "failed to detect a consistent pattern relating drinking tubewell water and diarrhea rates" (12).

These studies were executed in the belief that the findings would provide policy makers with guidelines for future water improvement programs, but serve to confuse rather than to illuminate. Several hypotheses can be offered to explain the surprising and contradictory findings. The epidemiological and practical implications of the studies are critically dependent on which set of hypotheses appears to be most plausible. Some of these hypotheses have been suggested by the investigators themselves, others have appeared in the literature as possible explanations of the findings. A few have not been presented previously, but appear to me to resolve some of the confusions arising from this set of studies.

Hypothesis 1: the use of tubewell water for drinking does not protect individuals against cholera

Hypotheses concerning the effect of protected drinking water supplies on attack rates from cholera arise from the knowledge that the vibrios must be ingested and that the bulk of this ingestion comes through the swallowing of polluted water. To test the hypothesis that those who drink bacteriologically pure water will have lower cholera attack rates than those who drink polluted water, the variable which needs to be measured is actual water ingestion by the individual in terms of its source, quality, and quantity. Since these data are extremely difficult to collect, a variety of surrogates has been used in these studies. Thus, despite the fact that each of the Matlab studies has been interpreted as rejecting the hypothesis that the use of tubewell water for drinking protects individuals against cholera, it cannot be tested on the basis of the available data, since none of these studies have collected data on actual water consumption by individuals.

Sommer and Woodward (10) stated that villagers' responses were unreliable and assumed that distance to a protected source was a proxy for the use of drinking water from that source; Khan et al. (13) used questionnaire response data directly; Levine et al. (14) observed water collection patterns at the village tubewells; and Curlin et al. (12) checked questionnaire responses by testing drinking water containers in the home for iron (since the iron content of Matlab tubewell water is high). As will become evident, this failure to measure actual consumption of water by individuals may be a serious deficiency in these studies. This limitation is clearest in the study of Sommer and Woodward (10). They assumed that villagers who lived within 50 feet of a tubewell would be much higher users of tubewell water than those who lived further away. However, Levine et al. (14) observed that families close to tubewells did not take water from this source any more frequently than those further from the tubewell. Although the data of Curlin et al. (12) show that there is a relationship between proximity and use by the family, this relationship is much less pronounced than that assumed by Sommer and Woodward (10). This assumption is compared with actual questionnaire data from the study village in Table 4. There is virtually no misreporting of tubewell water use, since every family which claimed to drink tubewell water had a container of tubewell water in their house (12). Thus, the Sommer and Woodward analysis appears to be completely invalidated by their choice of an inappropriate water consumption surrogate. The other three studies do not obviously suffer from the same deficiency in the surrogate measure. They provide convincing evidence that those families who say that they use tubewell water for drinking, who carry tubewell water to their homes, and who have tubewell water in a container in their homes, do not have significantly lower attack rates than those families who do not use tubewell water. These studies do not, however, refute the hypothesis that those individuals who drink primarily tubewell water have lower cholera attack rates than those who drink primarily from surface sources. The difference is subtle but, as will become apparent, possibly extremely important.

Hypothesis 2: cholera in rural Bangla Desh is not primarily a waterborne disease

The Matlab studies have stimulated a provocative response from Feachem, who has stated that "cholera is more likely to be spread by indirect fecal-oral contacts, for example with contaminated food, than by water" (15) and who considers the paper by Levine et al. to be "another piece of evidence to support the concept that much fecal-oral disease transmission in the rural tropics is nonwaterborne" (16).

TABLE 4
Relationship between tubewell use and distance from the well

Distance from tubewell	Usage of tubewell water for drinking	
	Sommer and Woodwards assumption	1974 Census data
feet		%
<50	Very high use	100
>50	Very low use	89.7

For cholera in Bangla Desh, however, a large body of epidemiological evidence corroborates the classical findings of John Snow, leaving little doubt that water is the primary vehicle of transmission while person-to-person contact is of secondary importance. Martin et al. (17) found that classical cholera clustered in geographically compact communities, each of which was affected for a relatively short time. "Family outbreaks were seen in only 6.9% of families where adult males were the first cases . . . multiple cases occurred in 21.3% of families in which women and children were the first cases." The postulate that this discrepancy in secondary case development was due to the closer contact of women and children with food and water supplies is not supported by the timing of these secondary cases. The authors suggest that this differential was due to the fact that the more mobile male was exposed to sources of infection which were not shared by other family members. The relative unimportance of person-to-person spread in Bangla Desh is suggested by other data as well. Mosley (18) noted that repeated bacteriological examinations of hospital attendants of cholera patients and of neighborhood contacts not sharing common water supply have rarely revealed infection, "suggesting that person-to-person contact is very rare." Extensive monitoring for the presence of *V. cholerae* in the environment of index cases in the 1976 to 1977 cholera season in Matlab Thana by Spira et al. (personal communication) supported previous findings that *V. cholerae* are seldom detected in food (19) and fomites (20) under natural conditions. Spira et al. were seldom able to isolate *V. cholerae* from the hands of those who lived in the community of the index case, but consistently detected vibrios in the majority of tanks and canals in the vicinity. Moreover, exceptionally high attack rates in groups whose occupations bring them into close association with surface water sources, indicate the primary role of water in cholera transmission in Bengal. Boatmen and people who reside on boats have been especially afflicted (11) while boatmen and fishermen have frequently been the source of infection for others using surface waters (21, 22).

Thus, while contaminated foods, in addition to contaminated water, have been implicated in explosive cholera epidemics in the typical protracted cholera epidemics of Bangla Desh, "this pattern has been related primarily to transmission by water. Usually a large body of water, such as a river, tank or canal, exposes a community to a relatively low dose, which only occasionally reaches a susceptible person to produce a frank case" (20).

Hypothesis 3: the small amount of protection afforded by drinking bacteriologically safe water is overwhelmed by the exposure to polluted surface water through bathing, food preparation, and utensil washing

In rural Bengal, in general, during bathing and washing a handful of water is repeatedly taken into the mouth and "the nose and mouth are irrigated and rinsed, a procedure accompanied by vigorous hawking and spitting" (23). In addition, in Matlab the high-iron content in the tubewell water ensures that it is virtually never used for cooking or utensil washing. The investigators of each of the tubewell studies in Matlab have suggested that use of nontubewell water for purposes other than drinking may explain why families who used tubewell water did not have lower cholera attack rates than those families who did not use tubewells. This explanation does not appear to be entirely satisfactory. The water use habits of rural Bengalis are such that all members of a community would be exposed to cholera if the surface sources contained cholera vibrios. The issue, however, is not whether it is possible for those who drink tubewell water to contract cholera from surface water sources, but whether cholera attack rates among tubewell drinkers are substantially lower than attack rates among populations who do not drink tubewell water.

To examine this issue further, consider the following simple model:

$$\text{Probability of acquiring cholera} = \sum (\text{Probability of ingesting i vibrio} \times \text{Probability of contracting cholera given the ingestion of i vibrio})$$

Although we know little about the behavior of vibrios in water, it seems unlikely that there would be systematically different vibrio counts, per unit of volume, in the water used for bathing and in the water that is drawn from the same surface source for drinking. Whereas, again, there are no data on this factor, it seems reasonable to assume that the quantities of water that people consciously drink are likely to be substantially larger than those that are ingested during other uses of water. We would thus expect people who drink tubewell water to ingest a given number of vibrios (e.g., "i" vibrios) far less frequently than people who drink surface water. Although something is known of the second factor in the above equation for a small group of U.S. prison volunteers (24), nothing is known about the susceptibility of any population, including rural Bangladeshis, to various doses of cholera vibrios under field conditions. What is important, however, is not the absolute level of this dose, but the relative levels of this dose in the tubewell-using and surface water-drinking populations. There is unlikely to be any systematic difference. This simple model would suggest that the finding that people who drink primarily tubewell water do not have substantially lower cholera attack rates than those who drink surface water is not plausible. That this model is not radically different from the implicit models of cholera epidemiologists is evident from the results of informal interviews with a small sample of foreign cholera experts living in Dacca. These people all drank boiled water but generally brushed their teeth, bathed, and washed their dishes in unboiled water. Although they agreed that if there were cholera vibrios in the water supply it might be possible for them to contract cholera, they believed that the probability of contracting cholera would be substantially reduced as a result of their drinking exclusively boiled water.

Hypothesis 4: in families who are tubewell users there may be individuals who do not drink tubewell water and these individuals may be those who are most susceptible to cholera

The hypothesis that the tubewell program in Matlab would affect cholera rates in the population was founded on the two assumptions that cholera is primarily a waterborne disease in this environment, and that individuals who drink bacteriologically pure water are much less likely to contract cholera than those who drink contaminated water. These assumptions have been examined above and seem to hold in the Matlab environment. Why, then, do tubewell-using families not have lower attack rates from cholera? McCormack et al. (22) have published data on the age-specific attack rates from classical cholera in Matlab in 1963 to 1964, 1964 to 1965, and 1965 to 1966. The age structure for Bangla Desh as a whole in 1961, as presented by Mosley and Hossain (25), is assumed to hold for Matlab in these years. Yen (26) has documented an outbreak of cholera in Taiwan which occurred 16 years after the previous outbreak, and found that the carrier to case ratio in children was such much higher than in adults. In Bangla Desh, an endemic cholera area, the opposite is found—the carrier to case ratio is higher for adults than it is for children in both urban (27) and rural settings (22, 28). By pooling the available Bangla Desh data, we find the carrier to case rate to be 1.22 for children under 10 and 2.07 for individuals over 10. From these data Table 5 is derived. Cholera in Matlab, then, is strikingly a pediatric disease and, overwhelmingly, an infection of young children. These age-distributed characteristics of cholera make the drinking habits of those over the age of 10 essentially irrelevant in the Matlab investigations. If the drinking habits of children under the age of 10 are such that they consume most of their water from nontubewell sources, even when there is tubewell water in the house and this water is used for drinking by other family members, then we would not expect the presence of this tubewell water to have a discernible effect on the incidence of cholera disease and infection in this community.

In fact, experienced field workers suggest that children in tubewell-using families may drink primarily surface water. Since no families use tubewell water for cooking, there is always at least one container of surface water in the house. In middle-class Matlab families,

TABLE 5
Age-specific patterns of cholera in Matlab Thana

Age group	Average attack rate (3 seasons' data) Cases/1000/year	% of total population	% of total cholera cases	% of total cholera carriers
0–4	10.0	19	48	63.0
5–9	6.2	17	26	35.0
10–14	2.9	10	7	0.7
15–29	2.9	21	15	1.5
30–49	0.6	20	3	0.3
Over 50	0.0	12	0	0.0

"children below the age of about one year are said never to be given plain cold water to drink as its temperature is considered too chilling for them . . . (and) . . . some people say that (tubewell water) temperature is too cold and causes them to catch cold and lose their voices" (29). Indeed, children are unlikely to be instructed or supervised concerning the choice of a container from which to extract drinking water. Children may prefer the nontubewell water for drinking, since "the surface water is warm . . . (and) of much better quality in both a chemical and aesthetic sense" (12). Moreover, and finally, children may drink water from outside of the home.

Two ways of investigating the issue further remain. First, if it is true that children under the age of 10 do not drink tubewell water even when it is in the house but that people over the age of 10 do drink this water, then we would expect no differential attack rates for those under the age of 10 but would expect to find differential attack rates for those over 10 years old. It is clear that a large sample, even greater than the population observed by Khan et al. (13) is needed before meaningful conclusions can be drawn from such an analysis. This would certainly be a useful exercise, but the work involved would be considerable. Second, to study, at the household level, the water consumption practices of different age groups in both tubewell using and nontubewell using families would be helpful. This would appear to be a highly worthwhile study which would give a good indication of whether the hypothesis advanced in this section provides an explanation for the counterintuitive results of the Matlab studies.

Hypothesis 5: those who use water from "disconnected" tanks for their surface water requirements are likely to have lower cholera attack rates than those who use canal or river water for drinking, cooking, bathing, and utensil washing

There is an apparent contradiction in the findings of Khan et al. (13) and Levine et al. (14) on the difference in attack rates between tank water users and canal water users. The former results, based on data for the whole of Matlab Thana, indicate that those who use tanks which are disconnected from canals and rivers during the cholera season have much lower cholera attack rates than those who use canal water. However, Levine et al. found no such differential. They compared cholera rates among users of all tanks which appear to be mostly "connected" tanks and canal water users in two villages which, in addition, had unusually high attack rates. Since these findings have potentially important policy implications, I will examine this apparent "contradiction" further. Extensive monitoring of water sources in villages that had cases of cholera during the 1976 to 1977 season by Spira and his colleagues (personal communication) showed that there is little, if any, difference in the mean vibrio counts among tank, river, and canal water in these villages. These data and those of Levine et al. suggest that once cholera is introduced into a community it would be unlikely for any difference in attack rates between tank users and canal users to be found.

The spread of cholera has historically been widely associated with communication and transportation routes (11). In Bangla Desh, the association between rivers and canals has been documented many times and unusually high cholera attack rates in boatmen and fishermen have been recorded (20). We thus expect communities that are located on busy canals to have higher attack rates than those that are more isolated.

Two factors may account for the finding that disconnected tank users have lower cholera attack rates (13). On the one hand, communities that are not located on canals and rivers may be expected to have a higher proportion of disconnected tanks. Since these communities are likely to have lower cholera rates for the same reason, namely their distance from canals, the apparent relationship between the use of disconnected tanks and low attack rates may be, in part, a spurious relationship. On the other hand, the probability of introduction of cholera into a community that is located on a canal may be proportional to the percentage of the population who use the canal and/or connected tanks to meet their water requirements. The findings of Khan et al. (17) and Levine et al. (18), then, are not necessarily contradictory. They can be reconciled, in part, by making two assumptions:

1) Given its location relative to a canal, if the proportion of the community using disconnected tanks increases, the likelihood of that community having cases of cholera will decrease.

2) Once cholera has entered a community, those who use disconnected tanks are likely to have the same attack rates as those who use canal, river and "connected" tank water.

Issues in domestic water supply policy

The policy implications of studies on water supply and cholera in rural Bangla Desh

The Cholera Research Laboratory investigators have suggested that the present 40 million dollar program for increasing the number of tubewells in rural Bangla Desh may not be justified for the stated purpose of controlling cholera and other waterborne diseases. On the basis of the cholera data alone, however, the implications of the analysis presented above are quite different.

The unusually high population density (2,322 persons per square mile in Matlab Thana compared with 1,286 persons per square mile in Bangla Desh as a whole) (30) implies an unusually high density of housing. The deep flooding to which the Matlab area is subjected (World Bank data show that only 15% of the population of Bangla Desh live in comparably flooded areas) necessitates abnormally large flood-protection mounds for these houses. Since tanks are excavated to obtain earth for both the mounds and the houses themselves, the areal density of tanks in Matlab is almost certainly extraordinarily high. These demographic and hydrologic factors further lead to an exceptionally dense network of rivers and canals. The average Matlab villager, then, in terms of access to surface water sources, is atypical for the rest of the country. While the government has experienced difficulties in its tubewell program in other thanas (approximately 14% require deep tubewells, 2% have chloride problems, and 1% are unsuitable for either deep or shallow tubewells in at least some areas), in only 6% have problems similar to those of Matlab been experienced with high-iron content of the groundwater (31). The combination of these factors means that in Matlab tubewell water is less attractive than it is in most other parts of Bangla Desh, while there is an uncharacteristically high availability of water from tanks, canals, and rivers.

If the hypothesis that young Matlab children are drinking a large amount of surface water which is in the house for cooking purposes is correct, then we would expect quite different results from a similar study of water use and cholera in an area where the groundwater quality is good and where this water is used for drinking and cooking. Although data on water use habits in other parts of Bangla Desh are few, informal interviews with Bangladeshis from different parts of the country suggest that in most areas groundwater sources are used for both cooking and drinking water. Data from the Teknaf Dysentery Project in the extreme southeastern tip of the country show that, despite the availability of surface water in a few tanks, drinking water is obtained exclusively from groundwater sources (85% from ringwells), and that in virtually all families cooking water and drinking water are drawn from the same source (M. Rahaman, personal communication). In this area we would expect groundwater users to have substantially lower attack rates than those who use surface water sources for drinking and cooking. If the hypothesis behind these speculations is correct, in areas where tubewell or other groundwater is used for drinking, but not for cooking, health education programs should be initiated to stress the importance of encouraging young children to drink from the drinking water source and not the cooking water pot.

The interpretation of the data on differential attack rates among disconnected tank users and other surface water users has interesting policy implications. It would appear that the probability of introducing cholera into a village would be substantially reduced if a higher proportion of villagers used disconnected tanks for most of their water requirements. This could be achieved by a construction program that would convert connected tanks into disconnected tanks. It could also be achieved by educating people to use disconnected tanks and by enhancing the attractiveness of these tanks through further excavation and by improving the quality of the ghats. Although land is scarce, the possibility of constructing new disconnected tanks should also be considered. Tank development programs should explicitly take into account the integral relationship between health and poverty and, particularly, health and nutrition. The use of ponds for other important purposes, such as irrigation, fish, fertilizer, and fuel production (32, 33) may be competitive with their use for domestic water supply. Pond fertilization, for instance, may increase fish productivity but adversely affect water quality, while the maximum demands on the ponds for both irrigation and domestic water supply are likely to occur during the dry season. Problems arising from unequal distribution and divided and disputed ownership of tanks must also be explicitly addressed if these resources are to be efficiently and equitably utilized.

The use of classical waterborne diseases, such as cholera, as models for water-related diseases

The approach taken by John Snow in his investigations of the Broad Street pump cholera epidemic of 1854, an approach that has been modified and elaborated in many subsequent studies of common-source epidemic outbreaks, has enormous appeal. The scientific method, in which a model of disease communication is postulated and the validity of the model tested by the acquisition of field data, is elegant, and the results have clear and immediate policy implications. For most endemic diarrheal diseases, however, understanding of transmission is relatively poor. Microbiologists are unable to isolate causative organisms for most diarrheas and epidemiologists have yet to satisfactorily describe the relationships of most diarrheal diseases to environmental conditions. The clarity of the cholera-type model has made this the dominant form for conceptualization of the relationships between the environment and water-related diseases. "Waterborne" is widely considered to be synonymous with "water-related" and the provision of a pure water supply is generally accepted as the foremost priority in domestic water planning.

The traditional classification of water-related diseases as bacterial, protozoal, helminthic, and viral provides few insights into the modes of transmission of these diseases and few clear policy guidelines. The most important recent advance in understanding the relationships between water and health has been the development of a scheme by Bradley (5), in which diseases are classified according to the specific nature of their relationships to water. Waterborne diseases, such as cholera and infectious hepatitis, are contracted through the drinking of contaminated water which acts as the passive carrier for the pathogenic organism. These diseases are combated through water quality improvements and by the prevention of the casual ingestion of water from contaminated sources. Water-washed diseases, such as shigellosis and scabies, are prevalent where hygienic practices are poor. The incidence of these diseases declines when water becomes more available and increased quantities of water, irrespective of quality, are used for hygienic purposes. The pathogens transmitting water-based diseases, such as schistosomiasis and guinea worm, are dependent on aquatic organisms for completion of their life cycles. Water improvement strategies for combating these diseases include improving the quality of the water, controlling the vector, and reducing the contact of the population with infected water sources. Diseases such as sleeping sickness and malaria are transmitted by water-related insect vectors which either breed or bite near water. Control strategies include improved surface and waste water management and reduction in time spent in the vicinity of breeding sites.

When the important water-related diseases of an area are classified according to this scheme, a series of policy directions are immediately evident. In Bangla Desh, the ancestral home of cholera, water improvement programs have been exclusively focused on the provision of a pure source of drinking water. The most important diseases in young infants and children, the diarrheas in general, are, however, usually transmitted by person-to-person contact (10) and their prevalence is likely to be affected more by water quantity than by water quality (2). The diarrheas are, therefore, properly classed as water-washed diseases (5). In rural Bangla Desh the highest seasonal prevalence of diarrheas is not coincidental with the cholera season in the post-monsoon months, but occurs, as in other areas of the world (35), during the season of low water availability. Superficial water-washed diseases are also important. In Noakhali district "scabies is a major cause of death from overwhelming infection and from nephritis subsequent to less serious infection with streptococcal organisms" (34). Water-based and water-bred diseases are relatively unimportant at present, although indications are that malaria may soon be a major health problem once again. The strategies for reducing the threat of cholera and other primarily waterborne diseases discussed earlier should not be ignored, but should be considered in conjunction with the logical primary water improvement objective, which is the provision of adequate quantities of water within the home, particularly during the season of lower water availability.

The use of "intermediate variables" in research and planning

Water improvement programs are expected to improve health by facilitating different patterns of water use and by altering the quality and quantity of water used by individuals. In the cholera studies we have seen how serious problems of interpretation arise from the use of intermediate variables such as distance from tubewells rather than the actual water use patterns of individuals. In designing water improvement programs, a primary aim is to improve health by altering water use patterns. Since the planning and execution of these programs are the responsibility of bureaucrats and engineers, the success of such programs tends to be measured in terms of the proportion of allocated resources that have been spent and the achievement of physical targets such as the installation of tubewells. Little attention is paid to the behavioral changes induced by the program.

The result of such centralized, technocratic planning is that the association between the provision and use of water supply and sanitation facilities is often weak. This is particularly marked for rural areas. Changes are required in both research and planning methodologies. Microlevel behavioral research must be undertaken to expand the present rudimentary understanding of factors which affect the choices of water sources for different purposes and the quantity of water used. As Navarro (36) has shown, the health planning process reflects the distribution of political power within a country. In Bangla Desh, as in many other poor countries, rural preventive health programs have been accorded low priority by the Western-trained urban elite. Where rural water improvement programs are undertaken, villagers are seen as "ignorant beneficiaries" of the benevolence of the central government. They, therefore, simply need to be educated to change their habits and therefore are seldom consulted on what they perceive to be their water supply problems. Until the power structure is altered and the masses become involved in the health planning process, it is unlikely that the current poor correlation between investment and health (1) will change.

The specification of water supply standards

As has been the case with the importation of technology, poor countries have frequently adopted the quality standards of Western countries. This has been particularly marked in engineering and medical practice. Water supply quality standards, and health standards in general, however, reflect the society's implicit valuation of human life, the opportunity cost of capital and the cost of water treatment (37). Given the existing distribution of resources, poor countries should, *ceteris paribus*, set lower quality standards than rich countries, since the opportunity cost of capital in poor countries is higher. Although economies of scale may imply lower per capita treatment costs in urban areas and thus justify somewhat higher water supply standards in these areas, the high public expenditures on the water supply of certain groups and the much smaller per capita expenditures for the majority suggests that the lives of the elite are being valued much more highly than the lives of other members of society. This is not surprising but it is not generally understood that this is implicit in the frequent maintenance of "international" standards for the few, while the many receive little or no attention. Bradley (1) arguing for similar changes has stated: "(The engineer) must design less orthodox low cost systems. These increase the risk of water-borne disease and he must choose between some people catching typhoid from one of his systems, or leaving a lot of others to go on catching typhoid from unimproved wells .... The problem is strictly analogous to the struggle over community medicine in the education of doctors. The physician's view was limited to his patients, he felt no responsibility for the sick (or healthy) who did not come to see him."

Summary and conclusions

Awareness of a relationship between water use and health is not new. Frontinus, the Water Commissioner of Rome, understood that health was affected by the quality and quantity of water consumed and that different water sources were appropriate for different purposes (38). Our knowledge has advanced, in some ways, so little, and we are still able to make only general statements such as "other things being equal, a safe and adequate water supply is generally associated with a healthier population" (39). The state of the art should make us cautious of undertaking multimillion dollar research projects in the hope that these will provide definitive answers to all of the important questions. The literature on the subject of water and health is both extensive and confusing. What appears to be necessary is some serious thinking, perhaps along the lines of the analysis of the cholera studies above, on the reasons for the many apparent contradictions in the findings of already published studies. These differences are frequently brushed aside too lightly with the assertion that we should not expect similar results in different study areas. We must explain why the effect of improved water supplies on cholera is different in the Philippines and Bangla Desh, and why the effects of water supply are different for shigellosis and cholera in Bangla Desh.

In water supply policy the fundamental need appears to be a reorienting and restructuring of the decision-making process. The continuation of traditional water use habits when the people of poor countries are presented with alternative sources of pure water is generally ascribed to the "ignorance of the uneducated masses." The prescription then becomes education of the ignorant and the identification of communication barriers. In this paper it has been suggested that the fault lies not so much with the recipients of these programs as with the process of decision-making on water improvement programs.

Addendum

This addendum reports new actual observations of the water consumption practices of young children in Matlab families who reported using tubewell water for drinking, which are relevant to the explanation of the "failure" of tubewell water to reduce the incidence of cholera.

Ten families were chosen on the basis of the following criteria: *1*) The villages chosen were to be easily accessible to the Matlab Hospital but were not to be part of the Matlab Bazaar area; *2*) The families were to have at least two young children; *3*) The families were to have reported using tubewell water in the 1974 census; *4*) The families were to be chosen such that the socioeconomic and educational status ranged from well-off and educated to poor and uneducated; and *5*) Both Hindu and Muslim families were to be represented.

During the month of April 1977, two trained female field workers were employed for this brief study. Each family was observed for a full day, with one observer stationed in the house from 6 AM until 2 PM and the other observing from 1 PM until the children went to bed (at about 8 PM). One child of age 4 or 5 was chosen in each family and every interaction of that child with water was observed and the time and nature of the interaction was recorded. All interactions of other young children with water was recorded where these could be observed. Particular attention was paid to the source of the water in the various containers, the place in which the water was stored, whether the water was taken from a container inside or outside of the dwelling, whether the water was given to the child by an adult, and whether water appeared to be ingested during the interaction. Although the families were informed that the activities of the children were to be observed, the mothers were not aware that the specific purpose was to observe water use patterns.

In nine families the tubewell water for drinking was stored in containers inside the house, while the surface water for cooking and washing of hands and feet was stored outside of the house. In the 10th family three containers of canal water and two of tubewell water were inside the house, while one container of canal water was placed outside of the house. Thirty-six children between the ages of 6 months and 10 years were observed to ingest water a total of 105 times. Despite the fact that in nearly 50% of the cases the water was drawn by the children themselves, on every single occasion the water was drawn either directly from a tubewell or from a container of tubewell water.

In collecting these data a 4- or 5-year-old child was followed throughout the day; the activities of the other children were recorded when possible. The mobility of children under the age of 5 proved to be limited and it is believed that most of the activities of all children in this age group were recorded. The older children were less accessible for observation since they played further from the home and, in some cases, went to school. It seems certain that a significant proportion of water that was ingested by these children was not observed. Despite the fact that the sample is very small, it is striking that young children *do* drink tubewell water when this is stored in the drinking water vessels within their homes. This is true when the children withdraw the water from the containers themselves and when the water is drawn for the child by an adult. Although this preliminary study was conducted in April and not in the "cholera season" (November to January), it seems unlikely that these patterns would vary greatly.

We are thus left with no satisfactory explanation of the results of the tubewell studies in Matlab. A large body of epidemiological data points to water as the primary vehicle of transmission in rural Bangla Desh and it appears that in those families who use tubewell water, the vast majority of the water ingested by the most susceptible group—young children—comes from this safe source. Tubewell water in Matlab does not become polluted between the pump and the mouth (Spira, personal communication). Thus, children who ingest, almost exclusively, water of good bacteriological quality apparently have the same cholera attack rates as those children who drink highly polluted water. The question, why, remains.

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Glossary of Terms

Ghat: A structure providing access to a surface water source in Bangla Desh, varying in quality from a muddy embankment to a concrete structure.

Ring well: An uncovered shallow dug well, lined with concrete or sun-dried or fire-burned clay rings. Wells are typically 2 to 3 feet in diameter and water is drawn by bucket and rope.

Tank: An artificial reservoir, usually excavated to obtain earth to build flood protection mounds and houses. Tanks are also frequently used for fish production and domestic water supply.

Thana: The smallest administrative unit in Bangla Desh.

Tubewell: A small diameter cased well fitted with a cast-iron suction hand pump. The lift of these pumps is limited to about 25 feet, although the water is typically drawn from aquifers 50 to 250 feet away.

References

1. Bradley, D. J. Measuring the Health Benefits of Investments in Water Supply. Washington D.C.: Water Supply Projects Division, International Bank for Reconstruction and Development, 1974, p. 125.
2. Wall, J. W., and J. P. Keeve. Water Supply, Diarrheal Disease and Nutrition: A Survey of the Literature and Recommendations for Research. Washington D.C.: Water Supply Projects Division, International Bank for Reconstruction and Development, 1974, p. 101.
3. Saunders, R. J., and J. J. Warford. Village Water Supply: Economics and Policy in the Developing World. Baltimore: Johns Hopkins University Press, 1976, p. 279.
4. White, A. N., and C. Seviour. Rural Water Supply and Sanitation in Less-developed Countries: A Selected Annotated Bibliography. Ottawa: International Development Research Centre, 1974, p. 81.
5. White, G. F., D. J. Bradley and A. U. White. Drawers of Water: Domestic Water Use in East Africa. Chicago: University of Chicago Press, 1972, p. 306.
6. Cvjetanovic, B., B. Grab and K. Uemera. Epidemiological model of typhoid fever and its use in planning and evaluation of anti-typhoid immunization and sanitation programs. Bull. World Health Organ. 45: 53, 1971.
7. Uemera, K., B. Cvjetanovic, T. K. Sundaresan, D. Barua, B. Grab and Y. Wanatabe. Modele Epidemiologique du Cholera: Ses Applications a la Planification des Programmes de Lutte et l'analyse de Couts et Advantages. Geneva: Bacterial Diseases Division, World Health Organization, 1971, p. 55.
8. Van Zijl, W. J. Studies on diarrheal diseases in seven countries by the W.H.O. diarrheal diseases advisory team. Bull. World Health Organ. 43: 249, 1966.
9. Scrimshaw, N. S. Synergism of malnutrition and infection: evidence from field studies in Guatemala. J. Am. Med. Assoc. 212: 1685, 1970.
10. Sommer, A., and W. E. Woodward. The influence of protected water supplies on the spread of Classical/Inaba and El Tor/Ogawa cholera in rural East Bengal. Lancet 2: 985, 1972.
11. Pollitzer, R. Cholera. Geneva: World Health Organization, 1959, p. 1019.
12. Curlin, G. T., K. M. A. Aziz and M. R. Khan. The Influence of Drinking Tubewell Water on Diarrhea Rates in Matlab Thana, Bangladesh. Dacca: Cholera Research Laboratory, 1977, p. 18.
13. Khan, M. U., J. Chakraborty, A. M. Sardar and M. R. Khan. Water Sources and the Incidence of Cholera in Rural Bangladesh. Dacca: Cholera Research Laboratory, 1975, p. 31.
14. Levine, R. J., M. R. Khan, S. D'Souza and D. R. Nalin. Failure of sanitary wells to protect against cholera and other diarrheas in Bangladesh. Lancet 2: 86, 1976.
15. Feachem, R. G. Water supplies for low-income communities in developing countries. J. Environ. Eng. Div. A.S.C.E. 101: 687, 1975.
16. Feachem, R. C. Is cholera primarily water-borne? Lancet 2: 957, 1976.
17. Martin, A. R., W. H. Mosley, B. B. Sau, S. Ahmad and I. Huq. Epidemiological analysis of endemic cholera in urban East Pakistan, 1964–1966. Am. J. Epidemiol. 89: 572, 1969.
18. Mosley, W. H. Epidemiology of cholera. In: Principles and Practice of Cholera Control. Geneva: World Health Organization, 1970., p. 23.
19. Barua, D. Survival of cholera vibrios in food, water and fomites. In: Principles and Practice of Cholera Control. Geneva: World Health Organization, 1970, p. 29.
20. Gangaroza, E. J., and W. H. Mosley. Epidemiology and surveillance of cholera. In: Cholera, edited by D. Barua and W. Burrows. Philadelphia: W. B. Saunders Co., 1974, p. 381.
21. Khan, M., and W. H. Mosley. The role of boatmen in the transmission of cholera. E. Pak. Med. J. 11: 61, 1967.
22. McCormack, W. M., W. H. Mosley, M. Fahimuddin and A. S. Benenson. Endemic cholera in rural East Pakistan. Am. J. Epidemiol. 89: 393, 1969.
23. Bang, F. B., M. G. Bang and B. G. Bang. Ecology of respiratory virus transmission: a comparison of three communities in West Bengal. Am. J. Trop. Med. Hyg. 24: 326, 1975.
24. Hornick, R. B., S. I. Music, R. Wenzel, R. Cash, J. P. Libonati, M. J. Snyder and W. E. Woodward. The Broad Street pump revisited: responses of volunteers to ingested cholera vibrios. Bull. N. Y. Acad. Med. 47: 1181, 1971.
25. Mosley, W. H., and M. Hossain. Population: Background and prospects. In: Health Crises in a Developing Country, edited by L. C. Chen. New York: Oxford University Press, 1973, p. 8.
26. Yen, C. H. A recent study of cholera with reference to an outbreak in Taiwan in 1962. Bull. World Health Organ. 30: 811, 1964.
27. Mosley, W. H., S. Ahmad, A. S. Benenson and A. Ahmed. The relationship of vibriocidal titre to susceptibility to cholera in family contacts of cholera patients. Bull. World Health Organ. 38: 777, 1968.
28. Benenson, A. S., W. H. Mosley, J. Fahimuddin and R. O. Oseasohn. Cholera vaccine field trials in East Pakistan, 2: effectiveness in the field. Bull. World Health Organ. 38: 359, 1968.

29. LINDENBAUM, S. Notes on the use of water in a rural Muslim community. Dacca: Cholera Research Laboratory, 1965, p. 3.
30. Government of Bangladesh. Population Census 1974, Dacca: Ministry of Home Affairs, 1975, p. 218.
31. Government of Bangladesh. Plan of Operations for the Second Rural Water Supply Construction Project in Bangladesh. Dacca: Department of Public Health Engineering, 1975, p. 62.
32. National Academy of Sciences. Making Aquatic Weeds Useful: Some Perspectives for Developing Countries. Washington D.C.: National Academy of Sciences, 1976, p. 175.
33. SMITH, D. V. Opportunity for village development: the tanks of Bangladesh. Bangladesh Econ. Rev. 1: 297, 1973.
34. MCCORD, C. What's the Use of a Demonstration Project? Dacca: Ford Foundation, 1976, p. 36.
35. GORDON, J. E., M. A. GUZMAN, W. ASCOLI AND N. S. SCRIMSHAW. Acute diarrheal disease in less-developed countries: II Patterns of epidemiological behaviour in rural Guatemalan villages. Bull. World Health Organ. 31: 9, 1967.
36. NAVARRO, V. The underdevelopment of health or the health of underdevelopment: an analysis of the distribution of human health resources in Latin America. Intern. J. Health Serv. 4: 5, 1974.
37. THOMAS, JR., H. A. The animal farm: a mathematical model for the discussion of social standards for the control of the environment. In: Economics of the Environment, edited by R. Dorfman and N. S. Dorfman. New York: W. W. Norton and Co., 1972, p. 250.
38. BABCOCK, R. H., AND J. J. MATERA. The Two Books on the Water Supply of the City of Rome of Sextus Julius Frontinus. Boston: New England Water Works Association, 1973, p. 252.
39. International Bank for Reconstruction and Development. Measurement of the health benefits of investments in water supply. Washington D.C.: International Bank for Reconstruction and Development, 1976, p. 12.