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Irrigation water as a source of drinking water: is safe use possible?

Wim van der Hoek[1], Flemming Konradsen[1], Jeroen H. J. Ensink[1], Muhammad Mudasser[1] and Peter K. Jensen[2]

1 *International Water Management Institute, Colombo, Sri Lanka*
2 *Department of Veterinary Microbiology, The Royal Veterinary and Agricultural University, Frederiksberg, Denmark*

Summary

BACKGROUND In arid and semi-arid countries there are often large areas where groundwater is brackish and where people have to obtain water from irrigation canals for all uses, including domestic ones. An alternative to drawing drinking water directly from irrigation canals or village water reservoirs is to use the water that has seeped from the irrigation canals and irrigated fields and that has formed a small layer of fresh water on top of the brackish groundwater. The objective of this study was to assess whether use of irrigation seepage water for drinking results in less diarrhoea than direct use of irrigation water and how irrigation water management would impact on health.

METHODS The study was undertaken in an irrigated area in the southern Punjab, Pakistan. Over a one-year period, drinking water sources used and diarrhoea episodes were recorded each day for all individuals of 200 households in 10 villages. Separate surveys were undertaken to collect information on hygiene behaviour, sanitary facilities, and socio-economic status.

RESULTS Seepage water was of much better quality than surface water, but this did not translate into less diarrhoea. This could only be partially explained by the generally poor quality of water in the in-house storage vessels, reflecting considerable in-house contamination of drinking water. Risk factors for diarrhoea were absence of a water connection and water storage facility, lack of a toilet, low standard of hygiene, and low socio-economic status. The association between water quality and diarrhoea varied by the level of water availability and the presence or absence of a toilet. Among people having a high quantity of water available and a toilet, the incidence rate of diarrhoea was higher when surface water was used for drinking than when seepage water was used (relative risk 1.68; 95% CI 1.31–2.15). For people with less water available the direction of the association between water quality and diarrhoea was different (relative risk 0.80; 95% CI 0.69–0.93). This indicates that good quality drinking water provides additional health benefits only when sufficient quantities of water and a toilet are available. In a multivariate analysis no association was found between water quality and diarrhoea but there was a significant effect of water quantity on diarrhoea which was to a large extent mediated through sanitation and hygiene behaviour.

CONCLUSIONS Increasing the availability of water in the house by having a household connection and a storage facility is the most important factor associated with reduced diarrhoea in this area. Safe use of canal irrigation water seems possible if households can pump seepage water to a large storage tank in their house and have a continuous water supply for sanitation and hygiene. Irrigation water management clearly has an impact on health and bridging the gap between the irrigation and drinking water supply sectors could provide important health benefits by taking into account the domestic water availability when managing irrigation water.

keywords diarrhoea, risk factors, drinking water, water quality, irrigation, Pakistan

correspondence Wim van der Hoek, International Water Management Institute, PO Box 2075, Colombo, Sri Lanka. Telephone: 00 94 1 867 404; Fax: 00 94 1 866 854;
E-mail: w.van-der-hoek@cgiar.org

Introduction

Availability of safe drinking water combined with the use of facilities to dispose of faeces in a sanitary way and improved hygiene standards could prevent much of the diarrhoeal disease morbidity and mortality in developing countries (WHO 1992). Piped water supply systems providing treated water are prohibitively expensive for rural communities in many developing countries and technologies have therefore been developed that can provide at least basic facilities to low-income communities. One of the main strategies to provide safe drinking water in rural areas has been the installation of low-cost hand pumps that exploit bacteriologically safe shallow groundwater. There is a general belief that appropriate technologies are available and that it is now mainly institutional problems and inadequate investments in drinking water and sanitation infrastructure that hamper further progress (Black 1998).

While it is true that important successes have been achieved, it has not been sufficiently recognized that the present strategies are not appropriate for all areas of the world (van der Hoek *et al.* 1999). In particular in South Asia, the Middle East, and East Africa there are large areas where groundwater cannot be used for drinking because of high arsenic, fluoride, iron, or salt levels. In addition to these naturally occurring water quality problems, there are increasing problems with availability of shallow groundwater as a result of overexploitation for agricultural and industrial purposes. However, much of the discussion of the relationship between water supply and diarrhoea has assumed that there are clear options for the study population to graduate from using polluted surface water to safer groundwater sources. The options for improvement in areas where groundwater cannot be used have received little attention.

This paper reports on a one-year prospective study on risk factors for diarrhoea in an area in Pakistan where people depend completely upon irrigation water because of brackish groundwater conditions and very low rainfall. We studied how irrigation water management in this area may impact on the availability and quality of water for domestic use and hence on the incidence of diarrhoea. The objective of this study was to assess whether use of irrigation seepage water for drinking results in less diarrhoea than direct use of irrigation water. This could provide the necessary baseline information for the design of interventions aimed at improving domestic water supply and sanitation in this and similar areas where morbidity and mortality due to diarrhoeal diseases is very high but where conventional strategies for improvement are not applicable.

Methods

Study area

The study took place in the area irrigated by the Hakra 6R canal, located in the Bahawalnagar District of the Southern Punjab, Pakistan. Hakra 6R is part of the Indus Basin Irrigation System, the largest contiguous irrigation system in the world. The length of the Hakra 6R canal is 45 km and its water is used to irrigate about 50 000 hectares of agricultural land. There are 94 villages in the Hakra 6R area with a total estimated population of 160 000. Groundwater in the entire area is brackish and cannot be used for irrigation, drinking, or washing. The typical layout of a village in this area includes a watercourse (the smallest irrigation canal) that provides water to an open village water reservoir (*diggi*) on an irregular basis. During the annual canal closure period no water can be supplied for 4–8 weeks. To supplement the water supply from the village reservoirs, people have installed PVC pipes linked to hand and motor pumps in places where seepage water is available, for example next to canals, village water reservoirs, animal ponds, and in irrigated fields. The pumps capture the water that has seeped out from these fresh water bodies to form a fresh water layer on top of the saline groundwater. However, the availability of this fresh water is governed by irrigation water releases and the pumps quickly run dry or start producing saline water when irrigation canals are closed. Some villages in the Hakra 6R area have a piped water supply system with sedimentation tanks and slow sand filters; however, all the slow sand filters are dysfunctional and untreated canal water is provided to these villages.

Study population

Firstly, 10 villages were randomly selected from the 94 villages in the Hakra 6R area followed by a random sample of 200 households, proportionally distributed over the 10 villages. The households included in the sample were visited in March 1998 to explain the purpose of the study and to request their co-operation. Three households refused to participate and were replaced by three other households, randomly selected from the respective villages. A household was defined as all individuals permanently living within the same compound and eating from the same pot. If there were more than 10 individuals in a household, only one core family of husband, wife, their children, and parents was included. Basic demographic data were collected and unique identification numbers were assigned to all 1470 members of the 200 households. However, this was a dynamic study population and persons who were absent from the village for more than one month were censored. If there were new members of the 200 selected households, they were included.

Data collection

One or two trained research assistants visited each of the 200 sample households in the 10 villages once a week over a one-year period from May 1998 to April 1999. During each weekly visit the drinking water sources used and illness episodes since the previous visit of the interviewer were recorded for each day for all individuals in the household. Diarrhoea was defined as a 24-h period with three or more non-bloody loose stools or one or more bloody loose stool. Whenever possible the wife of the head of household was interviewed because most of the diarrhoea episodes were expected among children and in Pakistan the mothers are always the caregivers when the child is ill (Zaman *et al*. 1993). However, in 16 households it was not possible for the male enumerators to interview women directly because of strict adherence to the *purdah* system of female seclusion. In 10 of these 16 households the male head of household provided the information after consulting his wife during the weekly interview. In the remaining six households males provided the information. The simple calendar format data-recording sheet was field-tested during the training of the research assistants. The names and identification numbers of each household member were preprinted on the forms. In the course of the study period the research assistants became well established in the villages and gained easy access to most houses.

All the drinking water sources of the 200 households and a selection of 50 of their in-house water storage vessels (traditional clay pitchers) were analysed for *Escherichia coli* on a weekly basis to determine the level of faecal contamination. The 50 households where water quality was tested in the in-house water storage vessels were purposely selected to represent all sources and only households were included that agreed to provide access to their house once a week. Water samples were analysed by the membrane filtration method using the selective medium m-ColiBlue24® (Hach Company, Colorado, USA) for the enumeration of *E. coli* in a laboratory established in the study area. Approximately 5% of the water samples collected were not enumerated because heavy background growth made identification of the bacterial colonies impossible.

A previous study in the area had shown that the quantity of water available to each household was dependent upon the presence of a water connection to the house and the presence of a large storage facility (results will be reported separately). Households with a private water connection in the compound (either a piped connection or a tubewell) and with a water storage facility (mostly overhead tanks) were classified as having a good availability of water. Households without a private connection were unable to store large quantities of water and had to fetch water from a public water supply point or directly from canals. They were classified as having a poor availability of water. Those with a connection, but no storage, were classified in between the other two categories for the quantity of water available.

If a household in the area had a toilet facility it was generally a flush toilet with septic tank. Some houses lacking a flush toilet had a 'female' toilet, which is a designated place within the compound where mainly female family members take baths and which directly drains into the street. However, in the analysis a distinction was made between households having a flush toilet and those not having such a facility, which in most cases indicated no toilet facility at all.

To collect information on socio-economic status, hygiene behaviour and sanitary practices, short structured questionnaires were administered in a phased manner throughout the year to the 200 households. Questionnaires were administered to females if possible, except for the socio-economic survey where any reliable adult household member was questioned about ownership of land and other assets. During each survey on hygiene behaviour and sanitary practices a male enumerator interviewed one of the household members with a structured questionnaire while a female enumerator scored general hygiene standards of the compound according to a structured observation checklist. Pictures were used in the questionnaire surveys as a communication tool. Two female anthropologists supervised the surveys. To score each household according to hygiene standards a number of topics were selected based on the literature and the local situation. Each hygiene topic on which the household showed or reported a good knowledge or practice, was scored with one point. The topics in the questionnaires focused on means of disposal of children's faeces, hand washing at critical times, and food storage practices. Knowledge was tested by asking the opinion of the respondent on three stories illustrated with pictures. Direct observations in the compounds focused on presence of faecal material, availability of soap, food storage practices, and general cleanliness of the compound. At the end of the survey each household obtained a score for 41 items. Those with a score below the median were classified as poor and those above the median were classified as good with respect to hygiene status.

The socio-economic status of each household was determined with a similar composite scoring system and classification, whereby each of the following 13 situations qualified for one point: good overall physical appearance of house construction; five or more acres of land under cultivation in the *rabi* (winter) agricultural season; three or more acres of land under cultivation in the *kharif* (summer) season; ownership of at least one cow; buffalo; goat; camel; poultry; tractor; car; family members with off-farm employment; sale of home-based nonagricultural produce; and receipt of income from relatives overseas.

Data analysis

Incidence rates were used as the outcome measure to estimate the risk of diarrhoea in the population. The incidence rates were calculated by dividing the number of diarrhoea episodes by the person-time of observation resulting in the number of episodes per person-year of observation. A diarrhoea day was marked as a new episode if preceded by two days without diarrhoea (Morris *et al.* 1994). Multivariate analysis was done with logistic regression. For statistical analysis, SPSS version 8.0 and EpiInfo version 6 were used.

Results

As expected, the quality of the water obtained from seepage sources was much better than that obtained directly from surface sources (Table 1). Piped water in the two villages that had a water supply scheme was of poor quality although not as contaminated as the surface water from the village reservoirs and the canals. There were no significant differences in the distribution of *E. coli* counts between the different seepage sources ($\chi^2 = 14.32$; $P = 0.074$). In the further analyses the seepage sources were considered as a homogenous group with relatively low pollution levels to be compared with the moderately to heavily contaminated water of the water supply schemes and the surface water sources. The 1868 samples that were taken from the in-house drinking water vessels of 50 households showed a high level of contamination with only 18% containing zero *E. coli*, 48% containing between 1 and 99 *E. coli* per 100 ml, and 34% containing 100 or more *E. coli* per 100 ml. None of the 200 households reported boiling water before consumption.

By far the highest incidence of diarrhoea was in the first few years of life (Table 2). Surprisingly, the incidence rate of diarrhoea was not significantly different between people who obtained their drinking water from surface sources and those using seepage sources. The Mantel-Haenszel weighted relative risk of diarrhoea, adjusted for age, when using surface water was 0.92 (95% CI 0.81–1.05).

Other risk factors for diarrhoea which were significant in a bivariate analysis were absence of a water connection and water storage facility, lack of a toilet, poor standards of hygiene, and low socio-economic status (Table 3). Boys had a significantly higher risk for diarrhoea than girls. Contrary to what was expected, people from households in which the mother was literate had higher risk for diarrhoea. There was no clear difference in diarrhoeal risk between small and large households.

Table 4 shows that there were clear interactions between several of the determinants of diarrhoeal disease. Households that had a water connection and storage facility were more likely to have a toilet, good hygiene behaviour, and be of high socio-economic status than the households without storage or connection.

Table 1 Distribution of *E. coli* counts of drinking water sources used by 200 households in 10 villages of the Hakra 6R area, from May 1998 to April 1999

	E. coli colonies per 100 ml						
	0		1–99		>= 100		
	n	(%)	*n*	(%)	*n*	(%)	Total
Pumped from seepage sources:							
Next to canal	586	(52)	472	(42)	68	(6)	1126
Next to village water reservoir	157	(56)	111	(39)	14	(5)	282
Next to animal pond	237	(56)	167	(39)	22	(5)	426
In agricultural field	139	(49)	122	(43)	23	(8)	284
Within the village	232	(57)	164	(40)	11	(3)	407
Water supply scheme	24	(22)	42	(38)	45	(41)	111
Well connected to village water reservoir	21	(8)	97	(35)	156	(57)	274
Direct from village water reservoir	4	(1)	137	(41)	192	(58)	333
Direct from canal	0	(0)	3	(10)	27	(90)	30
Total	1400	(43)	1315	(40)	558	(17)	3273

In Table 5 the incidence rate of diarrhoea among people using seepage and surface water is stratified by level of water availability and sanitation. Clearly, the association between water quality and diarrhoea varies by the level of water availability and the presence or absence of a toilet. In the group of people with access to a high quantity of water and a toilet, the incidence rate of diarrhoea was lower among those using good quality seepage water for drinking those using poor quality surface water. For people with less available water the direction of the association between quality, water and diarrhoea was different. The magnitude of the effect estimates did not change after controlling for confounding by age: Mantel-Haenszel weighted relative risk for diarrhoea when using surface water with good availability of water and presence of a toilet was1.64 (95% CI 1.26–2.14) and relative risk when using surface water with poor availability of water 0.78 (95% CI 0.67–0.92).

In the multivariate analysis, people who had experienced an episode of diarrhoea were compared with people who had not had a single diarrhoea episode during the study period for their exposure to the different environmental variables. People could be included more than once if they

Table 2 Incidence rate of diarrhoea by age group and source of drinking water in 200 households in Hakra 6R, May 1998 to April 1999

	Seepage water		Surface water	
Age in years	Person-years	Incidence rate[1]	Person-years	Incidence rate[1]
<1	14.8	6.54	7.3	5.91
1	29.9	5.31	4.6	5.93
2	17.9	5.20	7.8	5.93
3	23.0	2.26	8.6	1.51
4	25.1	1.83	11.8	1.02
5–14	261.6	0.79	77.1	0.53
> = 15	571.7	0.58	191.6	0.61
Total	944.0	1.04	308.8	0.97

[1] Diarrhoea episodes per person year

Table 3 Risk factors for diarrhoea among under fives and people of all ages in 200 households in Hakra 6R, Pakistan

	Under fives				All ages			
	Person-years	Incidence rate	RR	(95% CI)	Person-years	Incidence rate	RR	(95% CI)
Water source								
Seepage	110.7	4.04	1		944.0	1.04	1	
Surface	40.0	3.53	0.87	(0.72–1.06)	308.6	0.97	0.93	(0.82–1.06)
Water availability								
Connected, storage	60.6	2.62	1		495.0	0.76	1	
Connected, no storage	90.4	3.52	1.34	(1.11–1.62)	772.8	1.01	1.33	(1.18–1.51)
Not connected	37.6	5.02	1.91	(1.55–2.36)	286.3	1.34	1.76	(1.54–2.05)
Sanitary facilities								
Toilet	69.8	2.72	1		605.6	0.77	1	
No facilities	118.9	4.00	1.47	(1.24–1.78)	948.5	1.13	1.46	(1.31–1.63)
Hygiene behaviour								
Good	107.8	3.25	1		883.9	0.88	1	
Poor	80.8	3.90	1.20	(1.03–1.39)	670.2	1.14	1.30	(1.18–1.44)
Socio-economic status								
High	81.9	2.88	1		794.7	0.86	1	
Low	106.8	4.03	1.40	(1.19–1.64)	759.5	1.13	1.31	(1.18–1.45)
Mother literate								
Yes	39.5	4.56	1		315.1	1.21	1	
No	149.2	3.26	0.71	(0.60–0.85)	1239.0	0.94	0.78	(0.69–0.87)
Gender								
Female	93.9	2.93	1		753.4	0.89	1	
Male	94.9	4.14	1.41	(1.21–1.65)	793.9	1.01	1.13	(1.02–1.25)
Family size								
<= 6	54.7	3.66	1		410.4	1.07	1	
>6	134.0	3.48	0.95	(0.81–1.12)	1143.7	0.96	0.90	(0.80–1.00)

Incidence rate per person year; RR, relative risk (incidence rate ratio); 95% CI, 95% confidence interval

Table 4 Presence of a water connection and storage facility in relation to presence of a toilet, hygiene standard, and socio-economic status among 200 households in Hakra 6R, Pakistan

	Toilet present		Hygiene standard		Socio-economic status	
Water supply	Yes	No	Good	Poor	High	Low
Connection and storage	46	14	46	14	40	20
Connection, no storage	25	72	49	48	44	53
No connection	2	41	15	28	8	35
Total	73	127	110	90	92	108
	$\chi^2 = 65.40$		$\chi^2 = 19.20$		$\chi^2 = 23.32$	
	$P < 0.001$		$P < 0.001$		$P < 0.001$	

Table 5 Incidence rate of diarrhoea and relative risk (RR) estimates for seepage and surface drinking water sources, stratified by availability of water and toilet facility. The category with good availability of water had a water connection and storage facility in the house. The category with poor availability of water included households with no storage facility, with or without a water connection, and with or without a toilet

	Person-years	Incidence rate[1]	RR	(95% CI)
Good availability of water, toilet present				
Seepage	212.6	0.63		
Surface	108.8	1.06	1.68	(1.31–2.15)
Poor availability of water				
Seepage	738.0	1.24		
Surface	201.7	0.99	0.80	(0.69–0.93)

[1] Diarrhoea episodes per person year

had experienced multiple diarrhoea episodes. For each episode, the drinking water source that was used immediately before the onset of diarrhoea was used as a proxy variable for exposure to good or poor quality water. Those who had been followed up for less than 200 days were excluded from the analysis. Firstly, a logistic regression model was fitted with the source of water (seepage or surface) and the quantity of water available (Model 1 in Table 6). This model showed no effect of water quality but a strong effect of water quantity adjusted for confounding by water quality. Next, hygiene behaviour and the availability of a toilet were added as variables (Model 2 in Table 6). These two variables were determined by the quantity of water that a household had available and were, therefore, mediating factors, not confounders. The effect of quantity of water in Model 2 was not as strong as in Model 1 because it represented the effect of quantity that was not mediated through sanitation and hygiene behaviour. Both poor sanitation and hygiene behaviour remained independent risk factors for diarrhoea when adjusted for the confounding role of quantity and quality of drinking water, although of borderline significance. The effect estimates for water quality, quantity, sanitation and hygiene behaviour changed only marginally when age, sex, socio-economic status and educational level were included. Age, sex, and socio-economic status did not emerge as independent risk factors in the full model but the unexpected association between literacy of the mother and diarrhoea was still significant (data not shown).

Discussion

The results show that relatively good quality water can be provided from canal irrigation systems in brackish groundwater areas by using seepage water. This seepage water has passed through sandy soils that act as a filter for the faecal contaminants. However, good quality water does not result in lower diarrhoea incidence when people have insufficient quantities of water and no toilet facilities.

The study was designed to establish an intensive data collection on diarrhoeal disease and drinking water sources over time. This made it possible to relate diarrhoea episodes to the drinking water source that people were using at the time instead of assigning one source to each household for the whole year. The weekly frequency of the household visits was a compromise between keeping the recall period as short as possible and avoiding too many visits to the households. Similarly, the choice was made to have one enumerator responsible for the same two villages throughout the study. This had the potential for observer bias, however it greatly facilitated rapport between the enumerators and the selected households. In order to reduce observer bias clear case definitions were used and one of the authors regularly joined the house visits to ascertain that the data collection method was consistent in all villages.

There are several issues that make the epidemiology of diarrhoeal diseases in relation to water and sanitation complex. Firstly there are many interactions between variables such as socio-economic status, availability of a water connection and storage facility, presence of a toilet, and hygiene standards. For example poor households

	Model 1		Model 2	
	Odds ratio	(95% CI)	Odds ratio	(95% CI)
Water source				
Seepage	1		1	
Surface	0.96	(0.79–1.18)	0.98	(0.80–1.20)
Water availability				
Connected, storage	1		1	
Connected, no storage	1.38	(1.13–1.68)	1.15	(0.92–1.45)
Not connected	1.99	(1.55–2.54)	1.52	(1.12–2.05)
Sanitary facilities				
Toilet			1	
No facilities			1.30	(1.04–1.62)
Hygiene behaviour				
Good			1	
Poor			1.17	(0.97–1.41)

Table 6 Results of multivariate logistic regression analysis of the relation between diarrhoea and environmental variables in Hakra 6R, Pakistan

generally cannot afford a private water connection and large storage facility and are therefore unable to improve their hygiene standards. The hierarchical interrelationships between the different variables should be taken into account in multivariate analysis (Victora *et al.* 1997). Secondly the occurrence of diarrhoea in an individual could be dependent upon the occurrence of diarrhoea in surrounding houses and the village as a whole. Infection rates in households with good water supply and sanitary facilities may increase because of high infection rates in nearby houses with poor facilities.

The results support the finding from other studies that the quantity of water available for personal and domestic hygiene is more important than the quality of water consumed (Esrey *et al.* 1991). It has also been previously reported that improved water quality reduces diarrhoea only for families living in good sanitary conditions (VanDerslice & Briscoe 1995; Esrey 1996). Safe disposal of faecal material and adequate washing of hands after contact with adult and child stools have been suggested as the most effective means to reduce diarrhoeal disease in children (Curtis *et al.* 2000). This again emphasizes the overall importance of having sufficient quantities of water available in the household.

It has not been sufficiently recognized previously that irrigation water from canals can be the only source of drinking water when there is a poor supply of domestic water from groundwater sources, but abundant water for surface irrigation (van der Hoek *et al.* 1999). Providers of drinking water rarely consider the use of irrigation water as an option because the conventional strategy has been to use groundwater, not surface water, for drinking purposes. In some cases the domestic uses of irrigation water have been considered in the design of irrigation systems, but more often irrigation system designers have tended to focus exclusively on water use in crop production. Even in situations where people are completely dependent upon irrigation water, water allocation decisions are based on crop demands and not on the demands of other water uses. A large gap therefore remains between what takes place in irrigation schemes and what is taken into account in water resource planning and policies. This sectoral approach by the irrigation and drinking water supply sectors makes it difficult to utilise the potential health benefits provided by the large quantities of water available from irrigation canals. A more co-ordinated effort to exploit seepage water could have important benefits. Otherwise, households will find private sector alternatives to meet their needs, often at high economic and environmental cost (Altaf *et al.* 1993).

Scarcity of fresh water will be one of the most critical issues in the 21st Century. Agriculture accounts for around three-quarters of global water consumption and it is often believed that less water use in agriculture would automatically result in more water for other sectors. However, in many areas a shift in agriculture to crops demanding less water, changes in rotational water schedules, and concrete lining of irrigation canals to minimize seepage losses would actually reduce availability of water for domestic use and have a negative impact on human health. It is therefore extremely important that domestic requirements are taken into account in water allocation decisions.

Pakistan has one of the highest under-five mortality rates in the world, caused to a large extent by diarrhoeal diseases (National Institute of Population Studies 1992). We found that children below three years of age had between 5 and 6 episodes of diarrhoea per year (Table 2). This is lower than the 9–12 episodes estimated for the whole country between 1990 and 1994 (Pakistan Medical Research Council 1998) but higher than most figures from other countries (Bern *et al.* 1992).

We found a higher risk of diarrhoea for males than for females. This difference was also reported for children under five years of age in nationwide surveys (National Institute of Population Studies 1992; Pakistan Medical Research Council 1998). This could reflect sex-related differences in childcare but some underreporting of disease episodes of women and girls is also likely.

The higher incidence of diarrhoea in households where the mother was literate was unexpected because female literacy is generally considered one of the strongest determinants of child health. In a nationwide survey the prevalence of diarrhoea was lowest when the mother had followed secondary or higher level education, however a primary education did not lead to lower diarrhoeal prevalence (National Institute of Population Studies 1992). At this stage we can only speculate about the reason for the higher incidence of diarrhoea in more educated households, such as more accurate reporting of diarrhoea episodes, shorter duration of breastfeeding, and earlier introduction of potentially contaminated weaning food.

We feel that there is a critical need to address the problems in areas in which the incidence of diarrhoeal diseases is high but where very few of the standard options to improve water supply and sanitation are applicable. Our data suggest that increasing the availability of water in the house by having a household connection and a storage facility is the most important intervention to reduce diarrhoea in this area of Pakistan. Safe use of canal irrigation water seems possible if households can pump the seepage water to a large storage tank in their house and thereby assure a continuous supply of water for sanitation and hygiene. A large storage facility allows households to cope with the high fluctuations of water availability in irrigation systems.

A problem in the study area and in many other irrigation schemes is the high water table caused by over-irrigation. This can make it impossible to use low-cost sanitary facilities such as pit latrines, therefore a more costly toilet facility with a concrete septic tank is required. Poor households suffering most of the diarrhoeal disease are therefore likely to be unable to improve their water supply and sanitation.

When households cannot afford a storage facility and a toilet, the prevention of in-house contamination of drinking water could still be an important intervention. Inexpensive approaches that have been suggested for developing countries are point-of-use chlorinating and safe water storage vessels (Mintz *et al.* 1995; Quick *et al.* 1996). These and other interventions are currently tested in the study area in Pakistan. Community water supply schemes are expensive to construct and are invariably poorly maintained and provide poor quality water. Their advantage is, however, that large quantities of water can be made available. A clear institutional framework for operation and maintenance of these systems could provide more health benefits.

We conclude that the opportunities offered in irrigation systems to improve drinking water supply have to be taken seriously and that a concerted effort by the irrigation and drinking water supply sectors could result in important health benefits.

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