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Water sources are associated with childhood diarrhoea prevalence in rural east-central Mali

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Summary BACKGROUND Water supply improvements generally reduce the incidence of diarrhoea. However, populations with limited access to a safe water supply may continue to draw water from unimproved sources, thereby increasing their risk of diarrhoea. Furthermore, young children who are not breastfed may be even more susceptible to water-borne diarrhoeal pathogens. Our study explored the interactive protective effects against diarrhoea of exclusively using improved water sources and breastfeeding among children in rural Mali.

METHODS Interviews were conducted with parents or guardians of children under 7 years of age in seven villages with access to a variety of water supplies. Water sources used, breastfeeding status, demographics and recent diarrhoea symptoms were determined for 1117 children. The cross-sectional findings were used to compare diarrhoea prevalence among exclusive and non-exclusive users of improved water sources. Variation in prevalence by age and exclusive breastfeeding status was evaluated using chi-square and multivariate analyses.

RESULTS Children whose water was drawn exclusively from wells had a significantly lower prevalence of diarrhoea as compared with children whose water was drawn from a spring or stream (5.9% *vs.* 8.7%; $P = 0.04$). The exclusive use of improved water sources had no impact on diarrhoea prevalence among children who were exclusively breastfed. Similarly, the strongest protective effect was observed among children who were not exclusively breastfed.

CONCLUSIONS Our results indicate that using surface water as a primary or secondary water source exposes children to greater risk of diarrhoeal disease than using only improved sources such as wells. It is particularly beneficial for young children who are not exclusively breastfed to be supplied with water drawn from improved sources.

keywords infectious disease epidemiology, risk factors, waterborne disease, tube well, dug well

Introduction

A variety of interventions have been shown to significantly reduce diarrhoeal morbidity in developing countries. These include improving water quality, introducing sanitation facilities and increasing the quantity of water used by households (Esrey *et al.* 1985; WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation 2000). Water quality improvements reduce the risk of exposure to diarrhoeal pathogens through community water sources. As exposure may also result from vehicle-borne transmission within households or from direct faecal-oral transfer, water quality improvements are most beneficial when accompanied by improvements in sanitation and in the quantity of available water (Esrey & Habicht 1986; Lewin *et al.* 1997; Gasana *et al.* 2002). Water supply improvements tend to enhance both the quality and availability of water (Esrey & Habicht 1986).

Diarrhoeal pathogens tend to be less common in improved water sources than in those that are unimproved, because the former are more protected from faecal contamination (Spira *et al.* 1980; Esrey *et al.* 1985). For example, an assessment of the impact of a water development project in Lesotho found that *Escherichia coli*, a widely used marker of faecal contamination, was significantly less common in improved water sources as compared with unprotected traditional water sources (Kravitz *et al.* 1999).

Water supply improvements generally reduce the incidence of diarrhoea. In a large longitudinal study in rural China, for example, diarrhoea incidence was more than five times higher among those whose drinking water source was a river as compared with those who used wells (Chen *et al.* 1991). Incidence among people served by piped water was still lower than that of well-users. Unhygienic living conditions, overcrowding and poverty were also associated with increased diarrhoea incidence. Another study involving only improved water supplies in rural India showed that people using street taps were at greater risk for laboratory-confirmed shigellosis than those using wells, while others with in-home water taps had the lowest risk (Rajasekaran *et al.* 1977).

Water improvement projects also have been shown to improve health of children in various settings. A longitudinal study during 1984–85 of children in Lesotho compared growth and diarrhoeal morbidity rates of exclusive and non-exclusive users of improved water sources. Microbes associated with diarrhoeal disease were detected less frequently among exclusive than non-exclusive users, and height and weight gain were greater among exclusive users (Esrey *et al.* 1988). Similar methodology was used in Bangladesh to demonstrate higher infection rates for *Shigella dysenteriae* and *Sh. flexneri* among families drawing from both open and closed water sources, as compared with those using only closed sources (Khan & Shahidullah 1980). Lastly, a case-control study in Sri Lanka observed reduced diarrhoeal morbidity among children under 5 years of age who used protected traditional wells as compared with users of unprotected traditional water sources (Mertens *et al.* 1990).

The relationship between water source and diarrhoea risk partly depends on the transmission mode of the diarrhoeal pathogen. For example, a longitudinal study of *Sh. dysenteriae* found the use of unprotected water sources and lack of latrine access to be the primary determinants of increased transmission (Khan *et al.* 1979). However, risk of giardiasis from *Giardia lamblia* in developing countries has been associated with inadequate water quantity rather than water source type or latrine access. That waterborne giardiasis outbreaks are rare suggests that transmission is often foodborne or direct faecal-oral, consistent with the observation that increased water availability effectively reduces *G. lamblia* infections (Esrey *et al.* 1989). Another study in Burkina Faso found that women who had a water faucet in their yard were more likely to practice proper hygiene with their children's faeces than other women who sought water from a well (Curtis *et al.* 1995).

Poor water quality is an even more important risk factor for childhood diarrhoea where the protective effect of breastfeeding is lacking (Esrey *et al.* 1988). Exclusive breastfeeding reduces exposure to contaminated drinking water and conveys maternal immunity to the infant (VanDerslice *et al.* 1994). A cohort study of infants in the Philippines demonstrated that exclusive breastfeeding was protective against diarrhoea, and that risk increased with supplemental provision of water or solid food (VanDerslice *et al.* 1994). The protective effects of exclusive breastfeeding are greater in environments with abundant faecal contamination, poor sanitation and inadequate water supply (VanDerslice *et al.* 1994; Onyango *et al.* 1999).

Both breastfeeding and water supply improvements appear to lower diarrhoea risk among children, particularly in urban or peri-urban settings. Breastfeeding protects young children, while water supply improvements may benefit all age groups. However, these relationships are not well understood in impoverished rural conditions. The presence of faeces in the environment offers other routes of contamination that may minimize the benefits of water source improvements (VanDerslice & Briscoe 1995). As sanitation services, including sewage management, are less common in rural than urban settings throughout the developing world (UNICEF 1999), health benefits from improved water supplies may be limited there. In rural settings, other sources of exposure to diarrhoeal pathogens may be more important than exposure from the primary drinking water source (Esrey *et al.* 1988). Accordingly, we studied the interactive protective effects of water supply improvement and breastfeeding among children in rural east-central Mali. In particular, we evaluated associations between exclusively using improved water sources, exclusive breastfeeding and diarrhoea frequency.

Methods

Study population and water sources

This study was part of a broader investigation of public health and human biology among the Dogon initiated by B. I. Strassmann in 1984. The current research on diarrhoea in seven villages was part of a longitudinal study of morbidity and mortality in nine villages during the period 1998–2001. Collectively known as Sangha, these villages are situated in the district of Bandiagara in the semi-arid Sahel region south of the Sahara desert (Fig. 1). The majority of residents are subsistence farmers belonging to the Dogon ethnic and linguistic group. Previous work at this site found that 43% of children died by the age of 5 years (Strassmann & Gillespie 2003; see also Strassmann 1997), which is comparable with the national child mortality rate in Mali in 1960. Mali's current child mortality rate of 237 deaths per 1000 live births is the fifth highest in the world (UNICEF 1999). Although 60% of Malian children are breastfed up to 2 years of age, only 13% of infants younger than 3 months exclusively receive breast milk (UNICEF 2002). Exclusive breastfeeding is more common among the Dogon, as described below.

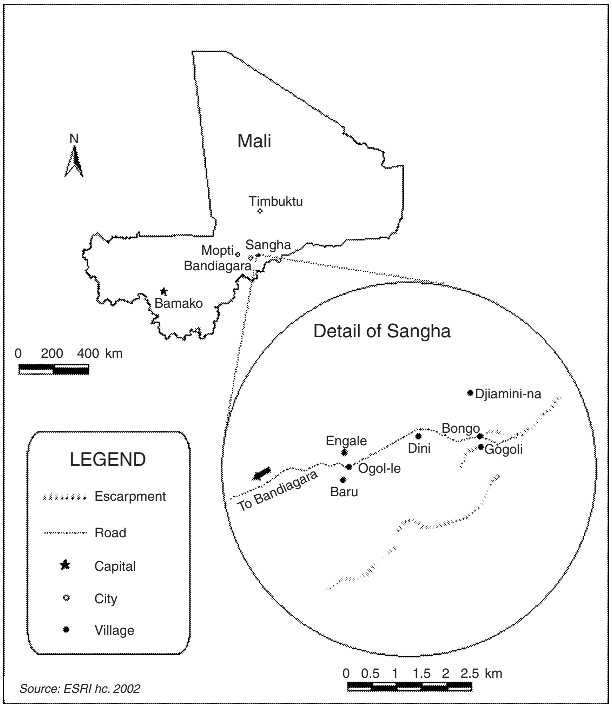

Figure 1 Map of the study region in east central Mali showing the seven villages.

Seventy per cent of Malians reside in rural areas, where less than two-thirds of the population have access to an improved water supply (UNICEF 2002; World Bank 2002). Water development projects have tapped abundant groundwater reserves in the region of the study, but access and usage vary widely. Preliminary observations indicated that residents of the seven villages used a variety of water sources including pump-driven tube wells, dug wells, springs, streams, ponds, and temporary rock pools. All water sources were described and photographed. Only half of the wells provided water throughout the year. In two of the seven villages, the only year-round water source was a spring or stream. Most of the dug wells were constructed of concrete, uncovered and protected by a concrete rim. The tube wells were fully enclosed and were operated by a hand-powered or solar-powered pump.

Demographic and water use questionnaire

The human subjects protocol used in this study was approved by the University of Michigan Health Sciences Institutional Review Board and the Centre National de Recherche Scientifique et Technologique in Bamako, Mali. During summer 2000, trained native Dogon speakers orally administered a 33-item questionnaire to all consenting mothers or guardians of children aged 7 years or younger. This involved evaluation of the health status of each child, including nourishment and breastfeeding, a 5-day history of diarrhoea symptoms, and a 10-day history of water sources used. Children who were breastfed and who were receiving no supplemental nourishment were considered to be exclusively breastfed.

A census was conducted to determine membership in previously-identified 'work-eat groups' (WEGs), defined as the individuals who worked together in the millet fields and ate together during the rainy season (Strassmann 1997). Additional census variables included age and sex for all children in the study.

The mother or guardian was asked to name the main (primary) source of water for the child and a secondary source, if any. All water sources used by more than five children were included in the analysis. As recently classified by WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (2000), tube wells and dug wells were categorized as improved water sources and surface water sources (e.g. springs, streams, ponds, temporary pools) were considered unimproved. Children were dichotomized as exclusive or non-exclusive users of improved water sources (Esrey *et al.* 1988). Non-exclusive users included all children whose primary or secondary water source was unimproved.

Data management and analysis

Analyses were performed using SPSS and SAS. Odds ratios were calculated to measure the association of predictor variables with diarrhoea in individual children. Validity of logistic regression models was reported as the *P*-value from a chi-square test for any significant parameter, the Hosmer-Lemeshow test of the model's goodness-of-fit to the experimental data and the Nagelkerke adjusted R^2 statistic indicating the predictive power of the model. To measure associations among predictor variables, chi-square tests and one-way analysis of variance (ANOVA) were used to calculate Pearson statistics and F statistics, respectively. To assess clustering by WEGs, *P*-values from likelihood ratio tests and score tests were calculated to evaluate the significance of individual predictor variables, and the Pearson correlation coefficient was used to indicate the degree of clustering among observations.

Results

Population and water sources

Complete demographic data were collected for 1200 children (97.7% of the study sample). The 28 children

Table 1 Characteristics of the study children from Dogon country, Mali during summer 2000, and for comparison of the same characteristics from 1999

Variable	Value	2000 N (%)	1999 N (%)
Sex		1200	878
	Male	643 (53.6)	468 (53.3)
Age (years)		1200	878
	0	206 (17.2)	153 (17.4)
	1	189 (15.8)	188 (21.4)
	2	204 (17.0)	132 (15.0)
	3	148 (12.3)	144 (16.4)
	4	159 (13.3)	135 (15.4)
	5	145 (12.1)	113 (12.9)
	6+	149 (12.4)	13 (1.5)
Village of residence		1200	878
	Baru	123 (10.2)	81 (9.2)
	Bongo	175 (14.6)	119 (13.6)
	Dini	127 (10.6)	89 (10.1)
	Djiamini-na	154 (12.8)	118 (13.4)
	Engale	137 (11.4)	105 (12.0)
	Gogoli	69 (5.8)	51 (5.8)
	Ogol-le	415 (34.6)	315 (35.9)
Primary water source type†		987	–
	Tube well	218 (22.1)	
	Dug well	531 (53.8)	
	Spring	85 (8.6)	
	Stream	153 (15.5)	
Exclusively used improved sources†		1117	–
	Yes	828 (74.1)	
	No	289 (25.9)	
Breastfed exclusively		1129	878
	Yes	195 (17.3)	145 (16.5)
	No	934 (82.7)	733 (83.5)

† Water source data were not collected in 1999.

Table 2 Water source use characteristics during summer 2000 of 1117 children in seven villages, including 828 who exclusively used improved sources and 289 who used unimproved sources

Variable	Used improved sources only N (column %)	Used unimproved sources N (column %)
Sex: Male	455 (55.0)	150 (51.9)
Average age (years)	3.27 (–)	3.45 (–)
Village of residence		
Baru (122)	78 (9.4)	44 (15.2)
Bongo (157)	130 (15.7)	27 (9.3)
Dini (117)	117 (14.1)	0 (–)
Djiamini-na (153)	0 (–)	153 (52.9)
Engale (130)	130 (15.7)	0 (–)
Gogoli (65)	0 (–)	65 (22.5)
Ogol-le (373)	373 (45.0)	0 (–)
Breastfed exclusively	148 (17.9)	44 (15.3)

whose birthdates were unknown were excluded from the analysis (2.3% of the study sample). Male and female children comprised nearly equal proportions of the study sample (Table 1). There were more children in age groups below 3 years of age than in older age groups. The sample sizes varied considerably among villages, with the largest village accounting for more than one-third of the total sample.

Water source usage was determined for 1117 children in the study (91.0%). Residents of the seven villages used 21 separate water sources as their primary or secondary water source during the study period. These included four pump-driven tube wells, 10 dug wells, two springs, two streams, two ponds and two temporary rock pools. Residents used 12 wells, two streams and one spring as a primary source of water. In two villages, a spring or stream served as the main source of water for all residents. No child in the study used a temporary rock pool or pond as a primary water source.

Three-fourths of the children used wells as their primary water supply rather than unimproved sources such as springs or streams (Table 1). Among these children, most used only improved water sources. However, exclusive use of improved water sources varied considerably among villages (Table 2). Two villages had children who exclusively used wells and other children who did not; in the five remaining villages, all children were homogeneous by exclusive use. In all villages with access to a well, users of solely improved sources outnumbered non-exclusive users. Age, sex, and exclusive breastfeeding did not differ significantly by exclusive use.

Diarrhoea prevalence and improved water source use

Overall, 74 children were reported to have had diarrhoea on at least one occasion during the 5 days prior to questionnaire administration (6.2% of the study sample). The age distribution of diarrhoea in children (age range 7 days–7 years) was skewed, with higher prevalence among younger children (Fig. 2). Prevalence was highest among children aged 12–16 months, with another small peak at $3\frac{1}{2}$ years of age. Diarrhoea prevalence was significantly higher among children under 4 years of age than among children in the oldest age group (Table 3).

Diarrhoea prevalence was about one-third lower among children who used only improved water sources (5.9%) than among non-exclusive users of improved sources (8.7%), a statistically significant difference after age adjustment (Table 3). This protective effect of

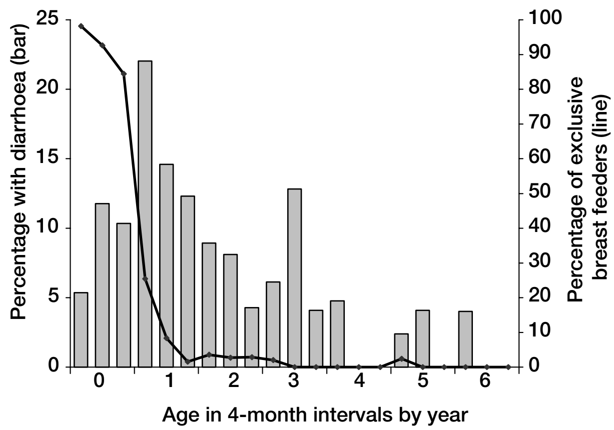

Figure 2 Prevalence of diarrhoea and exclusive breastfeeding by age.

Table 3 Odds ratios for associations of diarrhoea prevalence with demographic and water use characteristics

Variable	Value	Odds ratio	(95% CI)	*P*-value*
Sex	Male	0.89	(0.56–1.42)	0.629
Age (years)	<1	**7.27**	**(1.63–32.01)**	**0.009**
	1	**13.71**	**(3.21–58.63)**	**<0.005**
	2	**5.40**	**(1.21–24.15)**	**0.027**
	3	**5.59**	**(1.20–26.00)**	**0.028**
	4	0.93	(0.13–6.68)	0.941
	5	1.55	(0.26–9.45)	0.632
	6+	Ref.	–	–
Improved water source	Crude rate	0.66	(0.40–1.10)	0.108
	Age-adjusted†	**0.58**	**(0.35–0.97)**	**0.040**
Breastfed exclusively	Crude rate	1.54	(0.88–2.67)	0.126
	<2 years old	0.55	(0.29–1.04)	0.060

* Bold indicates $P \leq 0.05$.
† Mantel-Haenszel estimate of the common odds ratio among age groups.

exclusive use of improved sources was not seen among children less than 1 year of age, and was strongest for 2–4-year olds (Fig. 3). The age-specific odds ratios for exclusive use of improved sources were homogeneous despite the elevated diarrhoea prevalence among 3-year-old children (Breslow-Day chi-square = 2.92, $P = 0.819$; Fig. 2). The protective effect of improved sources was evident in a logistic regression model after adjusting for age in years (Table 4). Interestingly, other variables such as sex, overall effect of village and age-exclusive use interaction were not significant determinants of diarrhoea in logistic regression models of exclusive use of improved sources.

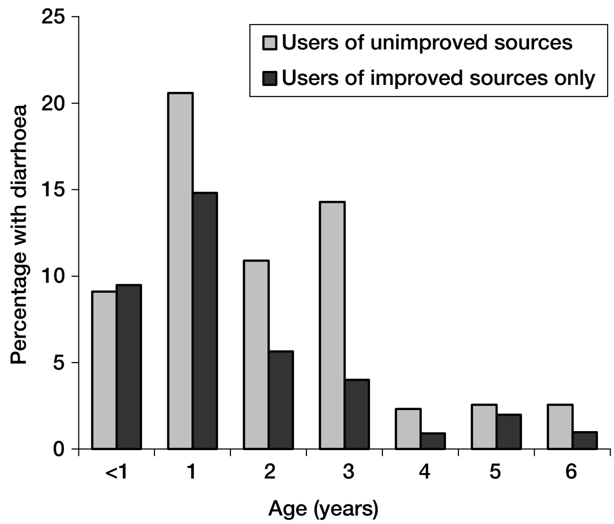

Figure 3 Diarrhoea prevalence by use of improved sources among age groups.

Breastfeeding

Exclusive breastfeeding was reported for 195 children (17% of the study sample) (Table 1). Exclusive breastfeeding was not significantly protective against diarrhoea when considering all children regardless of age (Table 3). This may have been an artifact of the elevated prevalence of diarrhoea among younger children, regardless of breastfeeding status. In addition, other factors were more strongly associated with diarrhoea in children older than 2 years of age, among whom exclusive breastfeeding was very uncommon. In children less than 2 years old, increasing diarrhoea prevalence was correlated with a decreasing proportion of children who were exclusively breastfed (Fig. 2). When we examined the age (year)-specific association of exclusive breastfeeding and diarrhoea, small cell sizes resulted in unstable Pearson chi-square estimates and prevented odds ratio calculations. Among children younger than 2 years of age, diarrhoea prevalence was marginally lower for those who were exclusively breastfed (Table 3).

Exclusive use of improved water sources was significantly protective among children who were not breastfed exclusively, but was not protective among exclusive breastfeeders (Table 4). Although children less than 1 year old appeared not to be protected by exclusive use of improved sources (Fig. 3), exclusive breastfeeding in this age group (Fig. 2) may have limited the beneficial effects of using improved water source. In addition, exclusive breastfeeding marginally reduced diarrhoea prevalence in

Table 4 Logistic regression model results for prediction of diarrhoea risk in children

Model Predictors†	Odds ratio	(95% CI)	*P*-value*	Adjusted R^2	Goodness of fit§
Model 1			<0.001	0.111	0.994
Improved water sources	**0.58**	**(0.35–0.97)**	**0.039**		
Age (years)	‡		**<0.001**		
Model 2			<0.001	0.122	0.564
Village of residence	‡		0.199		
Age (years)	‡		**<0.001**		
Model 3: Stratified: Exclusively breastfed			0.823	0.024	0.927
Improved water sources	1.06	(0.33–3.43)	0.917		
Age (years)	‡		0.968		
Model 4: Stratified: Not exclusively breastfed			<0.001	0.150	0.993
Improved water sources	0.48	**(0.27–0.87)**	**0.016**		
Age (years)	‡		**<0.001**		

† Sex, village and age* main effect interaction terms were insignificant in all models.
* Bold terms indicate significance at $P \leq 0.05$.
‡ Odds ratios cannot be calculated for multi-level categorical variables.
§ Hosmer-Lemeshow test.

children less than 2 years old (Table 3), which may have obscured any association of diarrhoea and exclusive use of improved sources in this age group. Small sample sizes, however, made it impossible to examine the age-specific association of diarrhoea with exclusive use of improved sources among exclusive breastfeeders compared with non-exclusive breastfeeders.

Age and village in regression models

Diarrhoea prevalence decreased significantly with increasing age (Cochran-Mantel-Haenszel $\chi^2 = 29.671$; $P < 0.001$). As the distribution appeared non-linear (Fig. 2), age was included as a categorical rather than as an ordinal variable in logistic regression models (Table 4). This improved the goodness-of-fit based upon the Hosmer-Lemeshow test, and increased the predictive power as measured by the adjusted R^2.

Diarrhoea prevalence varied considerably among villages (range in 2000: 4.5–10.7%; 1999: 5.9–14.4%), but the overall effect for village was not significant with or without adjustment for age (Table 4). The distribution of water sources was strongly patterned by village (Table 2), and exclusive use of improved sources was significantly correlated with village (Pearson correlation coefficient = 0.85; $P = 0.005$). As a result, inter-village variation in diarrhoea was partially accounted for by the exclusive use of improved sources. As village would be collinear with exclusive use of improved sources in a logistic regression model and the overall effect for village was not a significant predictor of childhood diarrhoea, village was excluded from analyses of exclusive use of improved sources.

Comparison of diarrhoea prevalence in 1999 and 2000

Diarrhoea was significantly more prevalent (11.0%) among the 878 children in 1999 than among children studied in 2000 (6.7%) ($\chi^2 = 11.50$, *P*-value = 0.001). However, the distribution of age-specific diarrhoea prevalences among 19 4-month age categories was similar for these 2 years ($R = 0.664$, $P = 0.002$; Fig. 4). This suggests that data collected in 2000 were representative of diarrhoea prevalence in the population. In addition, it

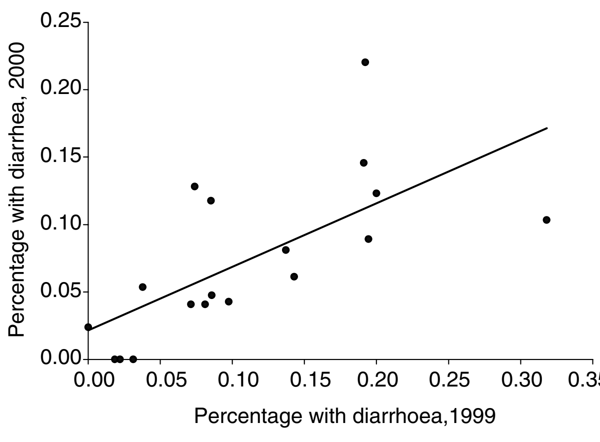

Figure 4 Correlation of diarrhoea prevalence in 1999 and 2000 among 4-month age groups.

supports the validity of age-adjustment as used in our analyses.

Clustering within work-eat groups (WEGs)

Children in the sample were grouped into 342 WEGs, 332 (97.1%) of which were used in analyses of water source usage. (10 WEGs with 28 children were excluded because the children's ages were not known.) The number of children per WEG ranged from 1 to 24, (mean = 3.5). For analyses involving exclusive use of improved sources as the exposure variable, we hypothesized that diarrhoea cases were non-randomly distributed among WEGs (i.e. that cases clustered within WEGs). With very few exceptions, all children in each WEG used the same water sources. Thus, insofar as water source usage predicted diarrhoea, a child's diarrhoea risk would be similar to the risk of other children in the same WEG, but independent of the risk of other children outside his or her WEG.

The degree of clustering was assessed using Proc Genmod (SAS). Diarrhoea prevalence among children in the same WEG was uncorrelated ($R = 0.035$) based upon a logistic regression model predicting diarrhoea with exclusive use, adjusted for age in years, using the repeated subjects statement to incorporate WEG-level clustering. Therefore, observations were assumed to be independent for all analyses of water source usage.

Discussion

Implications of the results

Children who exclusively used improved water sources had significantly fewer cases of diarrhoea than children using unimproved water sources. Among children younger than 1 year, exclusive breastfeeding had more impact on reduced diarrhoea prevalence than did water-source use. These results have important implications for water supply development, behavioural interventions and other efforts to improve child health in the region.

Our results demonstrate that use of unprotected surface water as a primary or secondary source exposes children to greater risk of diarrhoeal disease than if only improved water sources are used. Encouraging people to solely employ improved sources is particularly important when a pump or protected well is more distant than a stream or spring, as was the case for certain households within the villages we surveyed. In addition, other studies have shown that the quantity of water used may be important in preventing diarrhoeal diseases associated with poor hygiene practices (Esrey *et al.* 1991). Further research is needed to determine whether there are appropriate uses of surface water sources for personal and domestic hygiene.

The most highly improved water sources at the study site in Sangha were pump-driven tube wells, and dug wells were the most widely used improved source. Previous studies have indicated that improvements in which water is piped directly into dwellings generally have a greater impact on diarrhoea incidence than do wells and standpipes, even though wells do reduce cases (Esrey *et al.* 1991). It is likely that the convenience of piped water effectively eliminates the use of less improved and unimproved water sources, even as secondary sources.

Among children younger than 2 years of age, diarrhoea prevalence was lower among those who were exclusively breastfed. This was probably because of the beneficial immune effects of breastmilk and reduced exposure to foodborne and waterborne pathogens. It suggests that the impact on child health of water supply improvements may vary according to the prevalence of exclusive breastfeeding in the local population. This is an important consideration when designing and evaluating water supply interventions.

Young children who were not breastfed exclusively and who used traditional, unimproved water sources were particularly likely to experience diarrhoea. Indeed, drawing water solely from wells and other improved sources appears to be even more important for children younger than 2 years old who are not exclusively breastfed than for older children. Previous research supports this finding and emphasizes the special importance of exclusive breastfeeding in areas with widespread faecal contamination and limited access to improved water sources.

Diarrhoea prevalence, seasonality and water sources

Diarrhoea prevalence was highest among children between 12 and 16 months of age. Lower prevalence among infants less than 12 months old may have resulted from the protective effects of breastfeeding or from higher mortality rates in these youngest children. Diarrhoea prevalence declined among children more than 2 years old, a period when immune response capacity develops.

The study was conducted during the rainy season, which is when water quality is likely to be particularly poor and when diarrhoea prevalence peaks in many regions of the developing world. Precipitation runoff tends to increase faecal contamination of unprotected surface water sources (Weniger *et al.* 1983; Kistemann *et al.* 2002). Protected wells and other improved water sources may also be subject to groundwater contamination after heavy rains (Kravitz *et al.* 1999). Furthermore, variation in water source usage in the study villages is greater in the rainy season as a result of water collection from temporary streams and rock pools, whereas during the dry season residents are forced to rely more heavily on dug wells and tube wells. The investigators documented the monthly availability of water from each water source used throughout the year, as reported by the residents of each village. It was observed that nearly all of the available water sources were in use during the period of the study.

As water sources were not tested for faecal contamination, we have no direct evidence that water sources represented the main source of diarrhoeal infection. Nonetheless, the observed difference in diarrhoea prevalence between exclusive and non-exclusive users of improved water sources suggests significant variation in water quality among water sources. Visual inspection of many of the traditional surface water sources suggested that they were frequently exposed to diarrhoeal pathogens. Improved dug wells were protected by concrete rims elevated above the surrounding terrain, whereas most streams, springs and ponds lacked such protective barriers. As a result, the latter were exposed to runoff water from nearby villages that lacked latrines or other effective sanitation measures to dispose human and animal faeces. Runoff water often contained excrement from sheep, goats and other livestock, and it potentially transmitted human pathogens as well. We observed that streams were generally stagnant or slow-flowing and often contained abundant organic matter.

The quantity of water used by a household has been inversely associated with diarrhoeal morbidity, particularly when accompanied by measures to improve sanitation (Esrey *et al.* 1992). Most of the improved water sources are located nearer to the villages than unimproved sources as their increased depth allows them to access the water table at more convenient locations. Therefore, it is likely that improved water sources increase the quantity and quality of water available to residents of the study villages.

Methodological considerations

Our analysis was based on complete data gathered for a large proportion of children born since 1993 in the seven study villages in Sangha, Mali. Our investigation sought to study the entire population of children, thereby avoiding problems of selection bias resulting from sampling techniques. Because many mothers knew that the study was concerned with their children's health, few declined to participate.

Five of the seven villages in the study had access to tube or dug wells. In those villages, nearly all residents used this improved water supply as their main source of water. Yet many residents also used unimproved water supplies as secondary sources. The exclusive use variable accounted for the potential increase in risk caused by the use of secondary water sources.

Diarrhoea symptoms in children were reported for the 5 days prior to the interview. Water sources used in the previous 10 days were reported, which allowed for an incubation period up to 10 days that was appropriate for the most important causative pathogens of diarrhoeal diseases endemic in Mali (e.g. *Entamoeba histolytica, Escherichia coli, Giardia* spp., *Shigella* spp., and*Vibrio cholerae*) (De Clercq *et al.* 1994; Chin 2000). The reported episodes of diarrhoea may have resulted from one or more of these pathogens, and are likely to have corresponded to exposures from recent water consumption.

The study sought to identify all children who had experienced one or more episodes of diarrhoea during the 5 days prior to the interview. Although some case definitions used in retrospective studies require multiple diarrhoea episodes over a shorter recall period, our case definition was simple enough to allow for accurate recall over a period of 5 days. In addition, as the Dogon week is 5 days in length, local residents are culturally accustomed to thinking in 5-day blocks of time.

Our study was primarily concerned with symptomatic diarrhoeal infections. However, it should be noted that subclinical infections may also contribute to ongoing disease transmission.

Village of residence was a potential confounder of the association of water source usage and diarrhoea. As the overall effect of village was not a significant independent predictor, there was minimal residual confounding from inter-village variation that was not accounted for by the water source usage variable. Nonetheless, the impact on diarrhoea prevalence of exclusively using improved water sources could not be accurately determined if confounding village effects were not controlled. Inter-village confounding could arise from variation in wealth, domestic animal populations, hygiene practices or sanitation measures. In addition, diarrhoea cases resulting from person-to-person transmission are likely to cluster within villages. Including these factors in the analysis would isolate sources of inter-village variation that might affect diarrhoea risk, and would lessen the problem of collinearity that resulted when both village and water source usage were included in the model.

Conclusion

The findings of this study should enable more refined public health interventions that include technological and behavioural changes aimed at reducing incidence of diarrhoeal disease. Our findings support structural interventions to improve access to improved water sources and behavioural interventions to promote the exclusive use of improved water sources through education about the health dangers of even occasional use of unimproved water sources. Promotion of exclusive breastfeeding of infants and young children is particularly important in areas where access to improved water sources is limited and unlikely to improve in the immediate future.

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