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Effects of water quality and water quantity on nutritional status: findings from a south Indian community

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Quantitative assessments of the relative effects on health of various aspects of water supply are virtually absent from the literature. Despite the lack of information, resources are being allocated throughout the developing world, for projects related to water and sanitation. The present study was designed specifically to overcome many of the methodological problems that other researchers have faced. Data were collected concerning the nutritional status of 627 children in three urban communities in South India. Information was also collected on water quality, water quantity, household sanitation, socioeconomic conditions, and housing. A statistical technique is presented that allows for controlling potential confounding factors in the analyses. The results, in general, indicate that at young ages (i.e., under 3 years old) water quality is relatively more important as a determinant of nutritional status, while at older ages water quantity is relatively more important.

With the designation of the 1980s as the United Nations Water and Sanitation Decade (*1*), water and sanitation improvements have become a priority in most developing countries. There remain, however, many unanswered questions concerning the relative effects of the various factors that influence sanitation. Geographical location, seasonal and political factors, water distribution patterns, standards of living, and actual water usage behaviours must be taken into consideration when evaluating the relative importance of the quality versus the quantity of a water supply. The object of the present study is to evaluate the relative effects of the quantity or availability of a water supply and its quality on the nutritional and health status of children.

Several reviews in the literature discuss these problems in terms of the relative effects of the various characteristics of a water supply (*2, 3*).[a] Three underlying issues, however, have made it virtually impossible to draw definite conclusions, even within the context of particular study situations. The first of these is the control of confounding factors, both in the design of studies and in the analyses (*4-6*). The second is concerned with selection of an estimator of health status that is not prone to severe recall bias and different interpretations (*6, 7*). The last involves measurement of all the sanitation-related variables of potential interest, including those related to water usage.

The characteristics of a water supply are nearly always associated with the factors that affect health status (*8*).[b] These characteristics are also related to one another (*9, 10*), so it is important to describe them accurately so as to assess which aspect of water supply is responsible for a given effect. Since the characteristics of a water supply are themselves alleged to be affectors of health status, the issue of confounding must be considered (*11*). If confounding is ignored, as it usually is (*2*), then the results of such a study are doubtful.

To compensate for the difficulty of proper and consistent field reporting of morbidity, there has been increased interest in using anthropometry to estimate a child's health status (*12, 13*).[c] The anthropometric measurements of children are easily monitored and reliable, if done correctly, and they can easily be

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[a] Report of a WHO Scientific Working Group on Environmental Health and Diarrhoeal Disease Prevention, Kuala Lumpur, 1979 (WHO unpublished document, DDC/80.5, 1980).

[b] ISELY, R. B. *Relationships among improved water supply and sanitation, diarrhoeal morbidity, and nutritional status.* Unpublished report of a Working Meeting on 17 December 1982, Washington, DC.

[c] RAHAMAN, M. M. *Research protocol for water and sanitation intervention project, Teknaf, Bangladesh.* Unpublished report of the International Center for Diarrhoeal Disease, Dhaka, 1980.

compared with reference values that have been well described and are available to a wide audience.

There have been two main objections to the use of anthropometric indices to define health and/or nutritional status. One is that the various ethnic groups have different genetic potential to grow so that use of comparators from groups with different genetic make-up may be inappropriate (*14, 15*). The tendency of children from well-nourished, affluent groups in the less developed countries and of immigrants to the developed countries to grow to the level of US children, however, argues strongly against the importance of genetic factors (*16, 17*). Also, the reference values may be used, as they are here, within a genetically homogeneous group for purposes of comparison only.

The second objection to the use of anthropometric indices is that growth *per se* may not be of critical importance as a health outcome. Human growth is the product of genetic, metabolic, endocrine, and environmental factors. It is an extremely complex phenomenon for which only a few causal linkages are known with any certainty. While it is recognized that large size is not necessarily a desirable condition, numerous studies show that children who are ill or have a poor diet over short periods of time may be light for their height or length (*18, 19*). Poor diet may make a child prone to illness (*20, 21*) whereas an ill child can suffer nutritionally through food wastage (*22, 23*), metabolic losses (*24*), or anorexia (*25*). Insufficient nutrients or diversion of nutrients due to illness can, in turn, cause deviations of growth from what would otherwise be expected. Children who have many acute episodes or protracted periods of illness or food deprivation may be stunted (i.e., have low height or length for their age) (*26, 27*). Stunting, however, may indicate either a status of equilibrium in which a child may be quite healthy despite being short for his age, or ongoing stunting which is associated with current nutritional or health problems.

The present study was designed to test the relative effects of water quality and water quantity on human anthropometric status. In view of the multiple intercorrelations of parameters important in determining health, it is imperative to account for many variables simultaneously. There has therefore been an explicit aim to control for more than one covariate at a time.

MATERIALS AND METHODS

The study was conducted in Madras, the capital of Tamil Nadu state in South India (Fig. 1), which is located on the Bay of Bengal, approximately 12.8° north of the equator, and is the fourth largest city in India. Situated on a broad coastal plain, the Madras area receives over three-quarters of its precipitation during the north-east monsoon, from October to January. This is also the coolest time of the year, with temperatures averaging 22–24 °C.

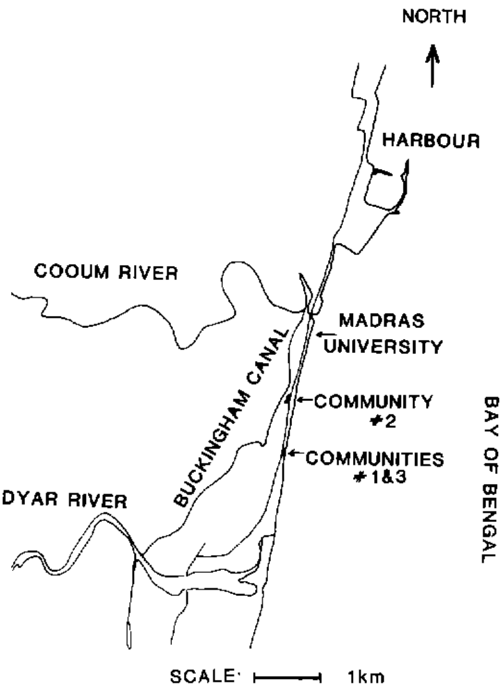

Fig. 1: Map of Madras to show location of the three communities.

Many communities in the city are caste homogeneous, reflecting a near uniformity in food choice, hygienic behaviour, and occupation. To minimize the variability of behaviours related to eating and washing, it was decided to limit sampling to a single caste. In the three communities chosen (Fig. 2 and 3), over 95% of the people were from the Pattinavar caste. Most of the heads of the households were engaged in fishing, the traditional occupation of the caste; relatively little migration was thought to occur because the people occupied as fishermen had the advantage of an intimate knowledge of the local coast and markets.

Two of the areas were composed of tenement housing which had replaced the traditional stick-and-mud huts. These buildings, which were about ten years old, were three or four storeys high and made of concrete. Each unit contained approximately 46.5 m^2 of living area. The third community was adjacent to the first (Fig. 2). It was composed mainly of

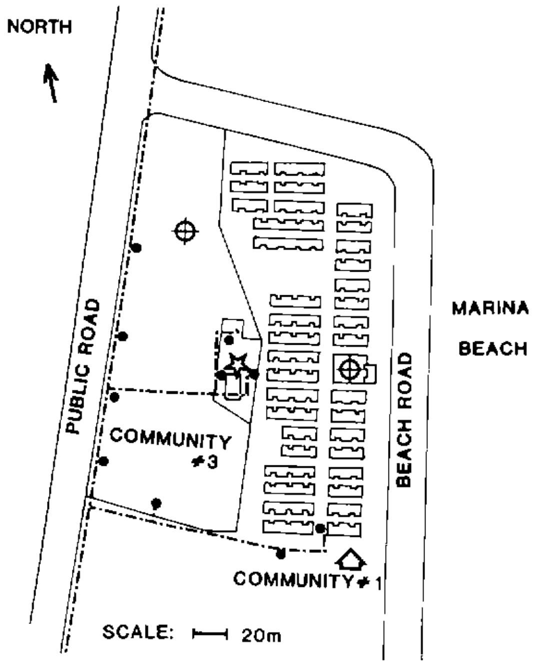

Fig. 2: Map of Communities 1 and 3.

—·—·—·—·— = water mains ⊕ = on-site well

• = water tap ✫ = public latrine

traditional huts built of mud and sticks, although there were a few multistorey homes of finished rock and plaster.

The water supply

Madras has significant variation in water quality and quantity. During the short north-east monsoon season, water tends to be abundant. During the rest of the year, the city's shallow reservoirs, which supply most of the water for the system, lose approximately half their total storage volume as a result of evaporation alone (*28*). The maximum of 220 million litres of water that can flow through the system daily during the wet season would allow for 70 litres per person per day. This assumes the water to be equally available during all seasons and to all the inhabitants of the city. However, many areas are severely under-served, especially during the dry season.

The water supply system for the city of Madras became the responsibility of the Madras Metropolitan Water Supply and Sewerage Board (MMWSSB) in 1978, the year that this study began. Previously, the water supply had been the responsibility of the Madras City Corporation whose policy had been not to increase the number of taps in the distribution system. The new organization departed from this policy and undertook to increase the number of services by about 10% per year (T.S. Daivamani, personal communication, 1978) without any increase in the storage or pumping capacity to keep pace. Communities located far from the distribution centre, such as the study communities, were therefore at a distinct disadvantage, especially in the year 1978–79 which was very dry.

The primary source of cooking- and drinking-water for the three communities was the piped water system of the Madras Metropolitan Water Supply and Sewerage Board. Water was provided from valveless taps in undrained subterranean access pits which functioned for approximately 3 hours each morning. Owing to the scarcity of water, there was always someone collecting water at the taps whenever the water was running.

An alternative source of water was from local shallow wells. Access to these dug wells could be gained either directly by bucket and line, or the water could be pumped to overhead tanks which were provided in the tenement buildings. Pumping,

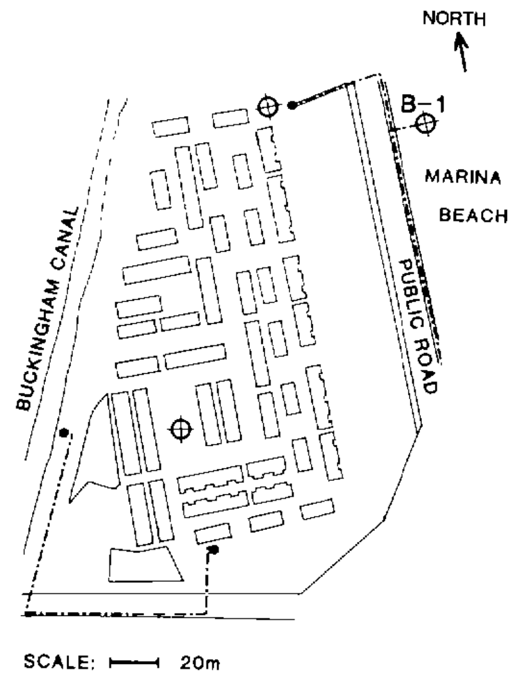

Fig. 3: Map of Community 2.

—·—·—·—·— = water mains ⊕ = on-site well

• = water tap

however, was erratic, although it was more frequent in community 2 than in community 1. Water from the wells was used mainly for washing and flushing latrines. It was generally brackish, and therefore was not used for cooking and drinking. The one well that was an exception was located in community 2. The water from that well (B-1 in Fig. 3) was considered by the residents to be of good enough quality to be used for cooking and drinking. This well was a source of water for the distribution system, through a small pumping station, and was also accessible by bucket and line.

Timing of the study

The study was conducted longitudinally from November 1978 to January 1980. Water quality data were collected every two weeks throughout this period. Children aged 6 years and under from randomly selected households were followed from the post-monsoon measurement of January 1979 to a mid-monsoon period ending in December 1979.

Selection of the children

Census data were unavailable for the three communities. The exact number of households in the communities, however, was known and an estimate of the average number of children under 6 years of age per household was available from local agencies. The tenement populations were easily sampled, as each apartment and building was numbered; 191 random numbers were chosen and the households in the apartments corresponding to those numbers were enrolled in the study. The traditionally housed community 3 was smaller, consisting of 245 households, and it was not numbered in a way that enabled proper random sampling. All the households there were included in the study. A total of 662 children were eligible to be enrolled in the study. Of these, 627 were actually enrolled and measured at least once; 219 from community 1, 200 from community 2, and 208 from community 3.

Data collection forms

A questionnaire was prepared and presented orally in the local language by native speakers. Information was collected on the demography of the communities and the standard of living of the household; the ages, health histories, and educational and occupational status of the household members; and their socioeconomic status and behaviours relating to food and hygiene. This questionnaire was based on one used previously by Faigenblum[d] in Guatemala and a "level-of-living" scale devised by Belcher (*29*) for cross-cultural comparisons. The questionnaire was pre-tested on ten households.

Anthropometric techniques of the field staff were standardized in early December 1978. A validity check of the survey was carried out on a random subset of the participating households after the first measurements were made. Over 95% of the responses on the validity check agreed with the responses given on the original questionnaire.

Personnel

The field support staff consisted of two medical social workers, one part-time assistant, and four full-time assistants. The social workers were recruited from the School of Social Work at the University of Madras. They were fluent in both Tamil, the language spoken in the communities, and English, the language in which the questionnaire answers were recorded.

The social workers administered the questionnaire orally, as most of the members of the communities were illiterate. They were also responsible for measuring the children and updating the responses to items on the questionnaire at the time of subsequent anthropometric measurements.

The five field assistants were responsible for assisting the social workers in making the anthropometric measurements, verifying the accuracy of the answers to items on the questionnaire, ascertaining the location of the water tap that the household was actually using, and helping to estimate the quantity of water stored by the household.

Water quality data

Sampling for water quality was carried out approximately once every two weeks by the author. The first samples were taken in November 1978 and the last ones in early January 1980. Sterile sample bottles were filled directly from the flowing taps with the exception of water from well B-1 (see Fig. 3), where the sample was drawn from the dug well using a bottle with a line attached. The multiple tube fermentation technique was chosen as the assay for monitoring contamination of the water sources (*30*).

The faecal coliform procedure was done as the second stage, or the confirmatory test, for all positive tubes in the first stage of the test. The concentration of faecal organisms was derived from the most probable number (MPN) table based on the statistical probability of finding the concentration of microorganisms given a number of positive tubes. The natural logarithms of the coliform concentrations (MPN) were taken, and the averages of the log concentrations were derived for the interval between

[d] FAIGENBLUM, J. M. *The level of living in two rural Guatemalan communities and its relationship to health.* PhD dissertation, University of North Carolina, Chapel Hill, 1978.

the beginning of the study and the first measurement and for the intervals between measurements for each pair of consecutive child measurements available in the study.

Water quantity data

Water quantity data were recorded at the beginning of the study and were updated each time the children were measured. Since cooking/drinking-water and domestic water for washing were from two distinct supplies, information concerning both types of water was recorded. The volume of cooking- and drinking-water was readily estimated by actually measuring the household storage containers and questioning the head female of the household as to the proportion of capacity used daily. The mean volume of water per person per day was used in our analyses. When the study was originally planned, it was hoped that the interval estimates of water quality and water quantity would correctly reflect the long-term quality and quantity estimates. Changes in the water supply system, however, led us to believe that this was not the case. Therefore another term, the estimate of cooking/drinking-water quantity at the beginning of the study, was added to the height-for-age model.

The quantity of water for washing, which could not be measured as accurately, was graded on a scale from 1 to 3, where "1" indicated no direct access (i.e., through an overhead tank) and no separate storage facilities for such water in the household, "2" indicated no direct access but with a separate storage supply for such water, and "3" indicated a ready supply of water for washing from an overhead tank or, rarely, from a well.

Other variables

In addition to water quantity, other variables that could change during the intervals between anthropometric measurements were recorded. These included changes in withholding food during the two weeks preceding the anthropometric measurement and breast-feeding status, Information was also collected and used in analyses on the children's bathing and defecation habits, the family's socioeconomic status (indicated by the mother's and father's educational level, family income, and food cooking equipment), household sanitation (indicated by clothes washing, and the parents' washing and defecation behaviours), quality of housing (type of construction of walls and floors, water storage facilities, and presence of a latrine), food-related variables (food expenditure/person/day, facilities for food storage and

Table 1. Distribution of continuous variables used in analyses

Variable	Value	Frequency (%)	Mean	S.D.
Mother's education (years)	none	62 2	2 06	3.08
	1–4	12.5		
	5–8	19.8		
	> 8	5 5		
Father's education (years)	none	30 8	4 10	3 45
	1–4	18 2		
	5–8	39 5		
	> 8	11 6		
Family income (rupees/person/month)	< 22 25	23 6	37 07	21.99
	22.25–31 24	24.8		
	31.25–44 99	26 1		
	> 45	25.5		
Food expense (rupees/person/day)	< 0.86	25 2	1.09	0.30
	0.86–1.00	30 8		
	1.01–1.25	22.0		
	> 1.25	22 1		
Drinking-water use[a] (litres/person/day)	< 6.66	19.9	10.84	6.57
	6.66–9.99	28 4		
	10.00–13.33	31.0		
	> 13.33	20 7		
Water quality[a] (mean log coliform organisms/100 ml)	< 1.33	23 7	2.97	1 69
	1.33–2.99	26 2		
	3.00–4 32	24 2	(geometric mean = 19.49)[b]	
	> 4.32	25.9		

[a] This variable is used in the second stage of analysis.

[b] This represents the antilog of the overall mean log coliform concentration.

Table 2. Distribution of other variables used in analyses

Variable	Frequency (%)
Cooking equipment:	
Open fire/ground level	31.5
Mud hearth/knee level	19.0
Concrete hearth/knee level	38.5
Charcoal/kerosene stove	11.0
Floor construction:	
Earthen	14 9
Plaster over brick	33.7
Concrete	51 4
Roof construction	
Palm leaves	17 7
Tin	14.9
Concrete	67.4
Water storage in overhead tank:	
None	59.2
Some	40.8
Food preservation:	
None	89.5
Some	10.5
Father's occupation:	
Fisherman	53.8
Not fisherman	46.2
Proximity to sea:	
25–150 metres	36.2
151–300 metres	36.3
> 300 metres	27.5
Plumbing wastepipes:	
Not present	16.8
Present	83.2

Variable	Frequency (%)
Child's bathing:	
Away from home	50.1
At home	49.9
Child's defecation:	
Near home	25.7
Away from home	37.4
Use of latrine	36.9
Mother's defecation	
No latrine	9.0
Use of latrine	91.0
Father's defecation:	
No latrine	57.5
Use of latrine	42.5
Washing of clothes:	
Away from home	49.9
At home	50.1
Washing-water availability:[a]	
No separate supply	39.9
Separate supply/hand carry	23.0
Overhead tank	37 1

	Percentage by age category		
	0–18 months	19–36 months	> 36 months
Breast-feeding:			
No	30.9	86.9	99 2
Yes	69.1	13.1	0.8
Withholding food:			
No	18 9	25.4	24 9
Yes	81.1	74 6	75.1

[a] This variable is used in the second stage of the analyses.

preservation), proximity to the sea, and the father's occupation. A complete list of the variables used in the analyses and their distributional characteristics are shown in Table 1 for continuous variables, and Table 2 for other variables.

Anthropometric measurements and age determination

Age was determined by direct questioning. In cases where it was not known, reference was made to the astrological chart and the birth date was determined accurately to within a day in most cases.

All measurements were performed in the household by the medical social workers. Weight was measured using Salter scales which could be hung from hooks in the ceilings of the tenements. Paediatric slings were also provided. The scales were adjusted to zero twice daily and were recalibrated once a week. Weights were recorded to the nearest 100 grams. Children were weighed without clothing or, for ambulatory children, with a light cotton shirt and pants only. Height or length was measured according to the guidelines outlined by Jelliffe (*31*).

Measurements were begun in late January 1979 and the final measurements were made in December 1979. The average interval between the first and second measurements was 5 months and between the second and third was 3½ months. For each set of measurements, the weight of a child was compared with the median weight of children of the same height or length in the NCHS and WHO reference series.[e, f] The percentage weight-for-height (or length) was found by dividing the actual weight by the reference median weight and multiplying the quotient by 100. Height-for-age and weight-for-age were derived by similar methods.

STATISTICAL METHODS

Each child could contribute up to three measurements depending on the number of times he or she was measured. Since the mean age of termination of breast-feeding in this population was found to be 18 months, the data were stratified by age so that children under 18 months old were in one age group, those aged 18–36 months in a second group, and those over 36 months old in the third age group.

The four water-related variables used in the models were the average log coliform counts, availability of water for washing (on the scale described above), quantity of cooking/drinking-water in the interval preceding a child's measurement, and quantity of cooking/drinking-water at the beginning of the study.

The analyses were carried out in two stages. In the first stage a linear predictor score was computed after each anthropometric index was regressed on all the non-water-related summary variables (socioeconomic, housing, household sanitation, and food-related), along with the child's defecation and bathing habits, breast-feeding, withholding of food, proximity to the ocean, and the father's occupation (see Annex for a complete description of the analysis technique). The linear predictor score accounts for the combined effect of all the non-water-related variables used in the model.

The second stage of the analyses consisted of regressing the anthropometric indices on this linear predictor score plus all of the water-related variables, as denoted in Tables 1 and 2. The regression coefficients of the water-related variables then represent the effects of those variables after controlling for the linear predictor score. All coefficients and corresponding *P* values are based on Type III sums of squares (*32*), i.e., the analysis accounts for the test variable with all the other predictors in the model.

RESULTS

Completeness of follow-up

In order to use all the information available for the intervals it was necessary to accumulate the anthropometric indices for all three measurement times. Since there may have been different losses to follow-up in the three communities, the children who were lost in any measurement interval were compared with those who provided a full set of measurements.

For all the indices, the children who were not measured a second or third time were similar to children who were measured all three times. Their age distributions were also very similar. The weight-for-height index showed the greatest difference. Even for this index, the test for difference between proportions of children in the tails of the distributions was insignificant. Nor were the means different (92.75 ± 9.89 vs 95.54 ± 8.55). Comparison of the children's anthropometric indices by community revealed no significant differences at any of the three measurement times. The age distributions were also the same.

Regression analyses

In Tables 3 to 5 the mean value of each variable is listed along with its regression coefficient. In order to give the reader a better understanding of how the variable affects the predicted value of the anthropometric index, the products of the regression coefficient with the 25th and 75th percentile values are also shown. The influence of the variable in the model can be estimated by comparing these fitted values.

Results of the weight-for-height model for all three age groups (0–18 months, 19–36 months, and over 36 months) are shown in Table 3. Except for the average log coliform score, the predictor variables are associated with positive coefficients. In the youngest age group the linear predictor score, which estimates the combined effect of the twenty-one variables listed in the Methods section, has an insignificant regression coefficient ($P = 0.21$). Neither of the water quantity variables is significant. The average coliform concentration, however, is significant at $P = 0.05$, and the difference between the fitted values, $\beta X_{(75)}$ and $\beta X_{(25)}$, shows more of an impact on the predicted value of weight-for-height than the other water-related variables (-3.23 versus 1.20 for washing-

[e] *NCHS growth charts, 1976* Rockville, MD, National Center for Health Statistics, 1976.

[f] Reference data for the height and weight of children. In: *Measurement of nutritional impact.* Unpublished document WHO/FAP/79.1, 1979, Annex 3, pp. 53-85.

Table 3. Model of weight-for-height measurements

Age and variable	Mean value	ß	P value	$ßX_{(25)}$[a]	$ßX_{(75)}$[b]
0–18 months:					
Intercept		95.77			
Average coliform count	2.92	−1.09	0.03	−1.46	−4.69
Washing-water quantity	2.02	+0.60	0.50	+0.60	+1.80
Cooking-water quantity	10.73	+0.15	0.30	+1.00	+2.00
Linear predictor score	−3.30	+0.55	0.21	−2.67	−0.94
			Model $R^2 = 0.06$ $n = 218$		
19–36 months:					
Intercept		106.80			
Average coliform count	3.13	−0.53	0.05	−0.71	−2.40
Washing-water quantity	1.94	+0.24	0.65	+0.24	+0.72
Cooking-water quantity	11.33	+0.07	0.32	+0.51	+0.93
Linear predictor score	−11.74	+1.01	0.0001	−13.35	−9.92
			Model $R^2 = 0.10$ $n = 348$		
Over 36 months:					
Intercept		93.42			
Average coliform count	2.91	−0.13	0.39	−0.17	−0.56
Washing-water quantity	1.97	+0.25	0.37	+0.25	+0.75
Cooking-water quantity	10.66	+0.12	0.004	+0.80	+1.60
Linear predictor score	−0.14	+1.04	0.0001	−5.05	−1.78
			Model $R^2 = 0.03$ $n = 847$		

[a] $ßX_{(25)}$ represents the product of the estimate in the regression model times the twenty-fifth percentile value of the variable.
[b] $ßX_{(75)}$ represents the product of the estimate in the regression model times the seventy-fifth percentile value of the variable.

Table 4. Model of weight-for-age measurements

Age and variable	Mean value	ß	P value	$ßX_{(25)}$[a]	$ßX_{(75)}$[b]
0–18 months:					
Intercept		74.63			
Average coliform count	2.92	−1.06	0.04	−1.42	−4.84
Washing-water quantity	2.02	+1.04	0.26	+1.04	+3.12
Cooking-water quantity	10.73	+0.17	0.26	+1.13	+2.27
Linear predictor score	5.73	+0.68	0.02	+2.47	−5.11
			Model $R^2 = 0.08$ $n = 220$		
19–36 months:					
Intercept		81.88			
Average coliform count	3.13	−0.63	0.06	−0.84	−2.71
Washing-water quantity	1.94	+0.26	0.70	+0.26	+0.78
Cooking-water quantity	11.33	+0.09	0.29	+0.65	+1.20
Linear predictor score	−2.88	+1.03	0.0001	−4.92	−0.54
			Model $R^2 = 0.13$ $n = 351$		
Over 36 months:					
Intercept		71.06			
Average coliform count	2.91	−0.31	0.14	−0.41	−1.33
Washing-water quantity	1.97	+1.37	0.0003	+1.37	+4.11
Cooking-water quantity	10.66	+0.20	0.0003	+1.33	+2.67
Linear predictor score	1.76	+1.39	0.0007	+1.86	+3.07
			Model $R^2 = 0.04$ $n = 850$		

[a] $ßX_{(25)}$ represents the product of the estimate in the regression model times the twenty-fifth percentile value of the variable.
[b] $ßX_{(75)}$ represents the product of the estimate in the regression model times the seventy-fifth percentile value of the variable.

water quantity and 1.00 for cooking-water quantity).

In the 18–36-month age group the linear predictor score is highly significant ($P = 0.0001$). The water-related variables, however, exhibit the same pattern that they did for the younger children; the coliform count is relatively more important than quantity of water; the difference between the fitted values $\beta X_{(75)}$ and $\beta X_{(25)}$ is -1.69 for average coliforms versus 0.48 for washing-water quantity and 0.42 for cooking-water quantity. For the children in the oldest age group, cooking- and drinking-water volume is the only water-related variable that is significant ($P < 0.005$). The difference between its fitted values, $\beta X_{(75)}$ and $\beta X_{(25)}$, is also larger (0.80 versus 0.50 for washing-water quantity and -0.39 for average coliform concentration). The linear predictor score persists as a significant variable in the model.

Table 4, which presents the weight-for-age model in a form analogous to the weight-for-age model of Table 3, shows a very similar pattern. The signs of the coefficients all behave as in the previous model. Average coliform concentration is the only water-related variable which comes close to being significant in the two youngest age groups ($P = 0.04$ and $P = 0.06$, respectively). Again, it is the variable with the largest impact in terms of the difference in fitted $\beta X_{(75)}$ and $\beta X_{(25)}$ values (-3.42 and -1.87, respectively, in the two youngest age groups). The linear predictor score is significant at all ages. In the oldest age group, however, both washing-water quantity and cooking/drinking-water volume are highly significant ($P = 0.0003$) while the coliform count is not. The difference between the fitted values is also larger for each of the water quantity variables (2.74 for washing-water quantity and 1.34 for cooking-water quantity) than for average coliform concentration (-0.92).

Table 5 shows the results for the height-for-age model. A fifth variable was added to the model, the original volume of water used per person. This variable was added because it was thought that height, which measures long-term nutritional status (*26*), would be best predicted by variables that indicate exposures over a long period of time. The original volume of water was felt to be a better estimate of long-term usage than estimates from later periods. For children under 36 months old, only the

Table 5. Model of height-for-age measurements

Age and variable	Mean value	β	P value	$\beta X_{(25)}$[a]	$\beta X_{(75)}$[b]
0–18 months:					
Intercept		88.00			
Average coliform count	2.92	−0.11	0.60	−0.15	−0.47
Washing-water quantity	2 02	+0.36	0.41	+0.36	+1.08
Cooking-water quantity	10 73	+0 005	0.95	+0.03	+0.07
Original water quantity	12 93	+0.03	0.59	+0.20	+0.43
Linear predictor score	5 25	+0.75	0.002	+3.03	+4.97
			Model $R^2 = 0.06$		
			$n = 218$		
19–36 months:					
Intercept		84.25			
Average coliform count	3.13	−0.12	0.48	−0.16	−0.54
Washing-water quantity	1.94	+0.08	0.83	+0.08	+0.24
Cooking-water quantity	11 33	+0.04	0.35	+0.29	+0.53
Original water quantity	13.76	−0.02	0.17	−0 13	−0.30
Linear predictor score	4.93	+1.05	0 0001	+3.77	+6.47
			Model $R^2 = 0.11$		
			$n = 350$		
Over 36 months:					
Intercept		85 77			
Average coliform count	2.91	−0.09	0 43	−0 12	−0.39
Washing-water quantity	1.97	+0.86	0.0003	+0.86	+2.58
Cooking-water quantity	10.66	+0.02	0.54	+0.13	+0.27
Original water quantity	12.91	+0.07	0 006	+0.47	+1 05
Linear predictor score	1.43	+1 19	0.004	+1.31	+1.91
			Model $R^2 = 0.04$		
			$n = 853$		

[a] $\beta X_{(25)}$ represents the product of the estimate in the regression model times the twenty-fifth percentile value of the variable.

[b] $\beta X_{(75)}$ represents the product of the estimate in the regression model times the seventy-fifth percentile value of the variable.

linear predictor score is significant. For no variable other than the linear predictor score is the difference between the fitted values $\beta X_{(75)}$ and $\beta X_{(25)}$ greater than 0.75 and the average difference is approximately 0.28. For children over the age of 36 months, the quantity of washing-water and the average volume of cooking/drinking-water, as reported at the beginning of the study, are significant ($P=0.0003$ and $P=0.006$). The differences between the fitted values of these variables also have the greatest impact on the predicted values of height-for-age (1.72 for washing-water quantity and 0.58 versus -0.27 for average coliform concentration and 0.14 for cooking/drinking-water quantity). All coefficients behaved as in the previous models with the exception of the original volume estimate for the second age group, which was negative.

DISCUSSION

For children aged 3 years or older the findings of this study are consistent with the notion that water quantity is a relatively stronger determinant of child health than is water quality. For younger children, however, these data support the opposite view. That is, for the children under 3 years of age water quality tends to be a stronger predictor of nutritional status than either washing- or cooking/drinking-water volume or availability.

The fact that the log coliform concentration does better in predicting weight-related indices than the water quantity variables may indicate several things. First, there may be a real age-specific difference in terms of effect. This would be easier to detect using labile weight-based indices in young children for whom the interval between measurements is a relatively larger proportion of their lives. Second, young children at the time of weaning tend to be very prone to intestinal diseases and diarrhoea (*33*). Water quality could be an important factor during this period of vulnerability and this fact could account for the significant regression coefficient. A third explanation might be that water quality is an important factor all along; the lack of significance in the over 3 year olds may reflect the failure of the interval quality measurement to account for exposure to water contamination over much longer periods of time.

Statistical considerations

Consistent with the experience of others studying environmental determinants of health status (*34*, *35*), these models had low R^2 values. The inability to explain the variability in the dependent variables may have two causes. One reason may be that the homogeneity of these groups made detection of real differences for a range of determinants more difficult than it would have been in a very heterogeneous group.

A second possible reason for the low R^2 has to do with the "noise" in such systems. Many of the real determinants of nutritional status are extremely difficult to measure with the accuracy of properly performed anthropometric measurements. The use of interval measurements that are much shorter than the length of a child's lifetime compounds this problem.

The signs of the regression coefficients, with the exception of the coefficient for original water quantity in the height-for-age model (19–36 months), behaved as one would expect. Increased contamination of water reduced the size of the predicted value of the anthropometric index while high scores for the quantity variables and the linear predictor score increased the predicted value of the index. The consistency of these findings show through the "noise" and indicate that, despite the low R^2 value, the model may be appropriate. Extensive examination of the residuals also indicated that the assumptions of the general linear model were not violated.

The linear predictor scores, which are composed of nineteen variables, tend to behave very differently in the three age categories of the weight-for-height model. Among the children who are not breast-feeding the negative effects of living far from the ocean, living in tenement buildings, and having food withheld in the period preceding measurement weigh heavily in forcing the value of the $X_{(i)}$ to be negative (see Table 2). The model of weight-for-age (see Table 3) shows a negative $X_{(25)}$ and $X_{(75)}$ value only for the children in the period just following the age at which half the children have terminated breast-feeding. The other age categories are associated with positive $X_{(i)}$ values.

Strengths and weaknesses

The appropriateness of using this study group was, in one sense, validated by its remarkable homogeneity for factors typically considered to be important determinants of children's nutritional status. Values of the water quality and quantity parameters were also uncorrelated with these other variables. The study group provided a certain amount of inherent "control" for variables which are usually confounded with sanitation. The technique of fitting the model in two stages provided an additional way to account for confounding factors while making it possible to focus on the variables of interest in the analyses.

One weakness of the study is that the children were followed for only eleven months. To estimate the effects of changing factors on the nutritional status of preschool-aged children much older than 11 months of age is, perhaps, expecting too much. For height-for-age this is even more a problem than it is for weight-based indices. Another, more general, problem is that there are many other true determinants of nutritional status which are difficult to identify and usually very difficult to measure.

An important consideration in any longitudinal study is loss to follow-up. While any loss is regrettable, it was shown that the children who left the study were essentially the same as those who stayed on. The amount of out-migration during the time of the study was surprisingly high. This may be, in part, due to the general instability that is quickly becoming characteristic of the Tamil villages of the Coromandel coast (*36*). The water availability problem may also have contributed to this out-migration.

Policy implications

At present, it is the convention that, when there is a choice, water quality is sacrificed for water quantity. Yet, it is known that the most vulnerable group consists of children below the age of 3 years. In absolute numbers and with regard to age-specific mortality rates, this is typically the target group of greatest interest.

If the findings of this study are validated in future work, then an important policy issue is raised. It may be necessary to reconsider the relative merits of improving water quality or water quantity. It is hoped that the techniques and findings described here will motivate other researchers to look at the issue of assessing the health effects of particular aspects of sanitation in other populations.

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RÉSUMÉ

INFLUENCE DE LA QUANTITÉ ET DE LA QUALITÉ DE L'EAU SUR L'ÉTAT NUTRITIONNEL: OBSERVATIONS FAITES DANS UNE COLLECTIVITÉ DU SUD DE L'INDE

Devant le manque de données scientifiques permettant d'évaluer l'influence relative de la qualité et de la quantité (ou disponibilité) de l'eau d'approvisionnement sur la santé des enfants, on a été amené à mettre sur pied une étude sur ce point dans l'Inde du Sud. Les trois collectivités retenues sont composées pour l'essentiel (à plus de 95%) de membres de la caste Pattinavar et sont implantées sur les bords du Golfe du Bengale, dans les limites de la ville de Madras. Pour la plupart, les chefs de famille travaillaient comme pêcheurs, la principale profession exercée par leur caste.

Pour éviter les problèmes que pose l'emploi d'indicateurs de morbidité, par exemple l'incidence des maladies diarrhéiques, on a choisi comme paramètres des indicateurs anthropométriques de l'état nutritionnel Les hypothèses intervenant dans l'emploi de ces indicateurs ont été longuement étudiées. Les enfants ont été pesés et mesurés trois fois, la première après la mousson de 1978-79 et les deux autres au cours de la saison sèche puis de la mousson suivantes.

La qualité de l'eau, estimée d'après sa teneur en coliformes fécaux, a été mesurée en moyenne une fois tous les 15 jours. Le volume d'eau utilisé pour la boisson et la cuisine a été déterminé au début de l'étude, une mise à jour des chiffres étant effectuée chaque fois que l'enfant était mesuré. Faute de pouvoir la mesurer avec la même précision, on a estimé la quantité d'eau utilisée ou disponible pour se laver et pour faire la lessive d'après un barème allant de 1 à 3.

Parmi les autres variables dont on sait qu'elles influent sur la santé ou l'état nutritionnel de l'enfant, bon nombre ont été mesurées et utilisées comme déterminants dans les analyses. Certaines des variables importantes ont été condensées sous forme d'un score récapitulatif décrivant la situation socio-economique de la famille, les installations sanitaires a sa disposition, son logement et diverses variables en rapport avec l'alimentation. On a également noté, et utilisé pour les analyses. les pratiques en matière d'alimentation maternelle, de constitution de stocks alimentaires, d'hygiène individuelle, de défécation, ainsi que la proximité du logement par rapport à la mer et la profession du chef de famille.

L'analyse statistique a comporté deux stades. Dans le premier, on a étudié la régression de l'indicateur anthrométrique de l'état nutritionnel en fonction de tous les

paramètres sans rapport avec l'eau. On a ainsi pu obtenir une variable récapitulative qualifiée de score prédictif linéaire. Dans un second stade, on a étudié la régression de l'indicateur anthropométrique en fonction du score prédictif linéaire et de toutes les variables en rapport avec l'eau.

Ces analyses ont montré que, pour les enfants de moins de 36 mois appartenant à la population considérée, la qualité de l'eau conditionne la valeur des indicateurs anthropométriques fondés sur le poids davantage que la quantité d'eau stockée pour la boisson et la cuisine ou que la quantité d'eau disponible pour se laver et faire la lessive. Dans le cas des enfants plus âgés, la quantité d'eau disponible pour se laver et faire la lessive et la quantité d'eau utilisée pour la boisson et la cuisine influent de façon relativement importante sur les mensurations de l'enfant, contrairement à la qualité de l'eau.

Les résultats de cette étude, la première où l'on ait essayé de réduire l'influence des facteurs parasites, posent un problème de politique générale puisque, jusqu'ici, on était convenu de sacrifier la qualité à la quantité en matière d'approvisionnement en eau, quand ce choix était inévitable. Or, on sait que le groupe le plus vulnérable chez les enfants est celui des "moins de trois ans". Si les observations faites ici se révèlent plus générales, il faudra peut-être remettre en question l'intérêt respectif d'une amélioration de la qualité ou d'une amélioration de la quantité de l'eau distribuée aux populations.

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Annex

THE LINEAR PREDICTOR SCORE

Here, the outcome variable, Y, the anthropometric index, is assumed to be linearly related to the water supply variables, $X=(X_1,\ldots,X_p)$, and to the household and behavioural variables, $Z=(Z_1,\ldots,Z_q)$. The true model may be represented as follows:

$$Y=\alpha+\sum_{i=1}^{p}\beta_i X_i+\sum_{j=1}^{q}\Theta_j Z_j+\text{error} \qquad (1)$$

With regard to testing hypotheses concerning the water-related variables, the other variables can be regarded as "nuisance" variables. Therefore the effect of the household and behavioural variables is summarized by means of a linear predictor score, Z_0. This is done by constructing a model,

$$Y=\alpha_0+\sum_{j=}^{q}\Theta_j Z_j \qquad (2)$$

and letting

$$Z_0=\sum_{j=1}^{q}\Theta_j Z_j \qquad (3)$$

The final model, which now includes the water-related variables, is given by:

$$Y=\alpha+\sum_{i=1}^{p}\beta_i X_i+\Theta_0 Z_0 \qquad (4)$$

Θ_0 is the coefficient that allows correlation of the linear predictor score with X_i. If Z_0 were uncorrelated with X_i, then Θ_0 would equal 1.

This approach has the advantage of summarizing the "nuisance" variables into a single score, of reducing the number of variables in the final model, of taking into account the variables known to influence child growth, and of focusing the attention on the water-related variables of interest.

It has been established, by a simulation technique, that the full model (equation 1) and the final model (equation 4) yield virtually identical values for the predicted value of the coefficients, β_i, and their standard deviations, when the true β values are 0 (Dr Martin Larson, personal communication, 1983). That is, if water supply variables do not affect anthropometric variables, the use of linear predictor scores will not change the type I error rates, i.e., the probability of claiming an effect of water supply variables when none is actually present. Furthermore, this holds true whether or not the X and Z variables are correlated.

If the true β values are non-zero, using equation 4 instead of equation 1 still yields nearly identical estimates of β_i though their standard deviations may be increased. With the large sample sizes in this study, the effect on significance levels of the β terms is not likely to be important.