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CHILD HEALTH AND HOUSEHOLD WATER SUPPLY:
A longitudinal study of growth and its environmental determinants in rural Malawi

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The growth of 1029 children under 5 years of age, in rural Malawi, was studied during 1 year before and 1 year after the introduction of a piped water supply system. The study was performed to evaluate the effect of socio-economic and environmental factors, especially water supply, on growth. In general, the first 2 years of life were highly liable to nutritional impairment. The seasonal variation of growth rate was most pronounced in children under 2 years. It was found that crowding, measured both as population density and as members per household, had a negative impact on the growth of younger children. In households utilizing piped water, children did not display significantly better growth when compared with children in households using traditional water sources. Although clean water in itself is vital, it was not enough to improve the growth of young children under the conditions that we have studied. It is suggested that, when providing an improved water supply, sanitation and hygiene education are necessary additions. Other ways of reducing recurrent infections, in combination with effective nutrition during and after episodes of disease, should also be given increased consideration in order to improve growth.

Introduction

Beneficial effects on health of a clean and abundant water supply have long been assumed but have been difficult to prove. Both input and output variables are difficult to identify and measure. There are several pathways between water and health, and the interactions are complex. Water is the vehicle of water-borne diseases but it serves as a medium to prevent water-washed diseases (Feachem, McGarry & Mara, 1977). Furthermore, a good water supply can improve food availability and food hygiene.

Provision of water is an essential but costly developmental measure. The health impact of water can be measured in several ways. The most common method has been to study the incidence or prevalence of diarrhoeal diseases or of specific pathogens (Azurin & Alvero, 1974; Schiffman *et al.*, 1978). It has also been suggested that growth may be used as an indicator of the health effect of improved water supply (Esrey & Habicht, 1986*a*), since growth is strongly influenced by diarrhoeal diseases, which in turn are influenced by water quality. Anthropometric measurements may thus be as sensitive indicators of a decreased exposure to diarrhoea-causing agents as is diarrhoeal rate. Methodologically, it is easier and more reliable to measure growth than to register diarrhoeal morbidity in a community (Esrey & Habicht, 1986*a*).

There are a limited number of systematic studies that evaluate the effects of environmental factors, especially drinking water supply, on the growth of children (Christiansen, Mora & Herrera, 1975; Tomkins *et al.*, 1978; Henry, 1981; Magnani, Tourkin & Hartz, 1984; Hebert, 1985; Rahaman *et al.*, 1986). Growth rate is a more sensitive indicator of health than cross-sectional measurements. It has been shown that changes in increments occur before changes in the respective static parameters (Karlberg, Engstrom & Karlberg, 1981; Brown, Black & Becker, 1982).

The aim of the present study was to investigate, on a prospective and longitudinal basis, the effects that the introduction of an improved water supply system had on the growth of a population of children in a rural African society. The impacts of other relevant environmental factors were studied at the same time. The morbidity and mortality of this population were also studied (Lindskog, 1987).

Subjects and methods

Study area

The study was conducted between February, 1983 and September, 1985 in eleven villages in Chingale in rural Malawi. The area is situated in the rift valley west of Zomba Mountain, at an altitude of about 500 m above sea-level. It has a tropical climate with two seasons: a rainy season lasting from November to April, with an average rainfall of 800–1000 mm, and a dry season, from May to November, with very little precipitation. An improved method of water supply consisting of piped surface water from an unpopulated mountain area was introduced in September, 1984. The water was led by gravity to villages located on the plain below. Community taps, with a maximum distance of 400 m to each household, were installed.

The society is matrilineal and matrilocal, and in 35 per cent of the households the father was not present. The principal occupation is subsistence farming with maize as the main crop. The houses are usually made of mud with a thatched roof and mud floor. Seventy per cent of the households had simple pit latrines, and the rest had no latrine at all. Traditionally, rivers, unprotected wells, and springs were used as sources of household water. More detailed geographic, demographic and socio-economic characteristics of the villages have been described elsewhere (Lindskog, 1987).

The method of child feeding in the area was traditional; children were breast-fed for a mean duration of 19 months. Bottle-feeding was not practised, and industrially produced formulas played little role in the diet of infants. Breast milk was supplemented with a thin, local, maize porridge from about 2 months of age, and from the age of 7–8 months the food gradually changed to a more adult diet.

Study population

All households in the selected villages that had children under 5 years of age were included in the study. Newborns in these households were gradually included, but no new households were added. A total of 1178 children participated during the whole study. At the beginning, the material included 539 households with 810 children under 5 years. By the end of the study, 137 children had died, 340 had passed the age of 5, 346 had been born, 22 had moved into the area and 129 children had moved away, resulting in a final count of 572 children under 5 years. A detailed report on mortality will be published elsewhere (Lindskog, 1987). According to reports by the mothers, death was most commonly associated with diarrhoea, fever, measles and respiratory tract infections.

Study design

A total of about 50 000 people were benefited by the water project. In February 1983, the eleven study villages had a total population of 4139. The number of inhabitants of each village differed: in the analyses some of the smaller villages were treated together, resulting in eight groups. The eleven villages were chosen because prior to the introduction of the new water supply, they were as similar as possible with regard to socio-economic conditions, environmental location, and previous water supply. The population was studied during 1 year before and 1 year after the introduction of the piped water supply (February 1983 — March 1984 and September 1984 — September 1985, respectively). In February 1983 and September 1984, socio-economic and environmental conditions of the households were recorded by the use of questionnaires and observations. Starting in September 1984, the new water supply was gradually introduced into parts of all the study villages. As the new water supply came into use, households shifted from the comparison to the intervention group. Households that received piped water were compared with those that did not; types of water sources and amounts of water used were recorded every fortnight.

The morbidity data for the children were collected by fortnightly home interviews made by seven field assistants with secondary school education. In almost all cases mothers were interviewed regarding symptoms of disease which had been noted during the last 24 h, but in 6 per cent of the interviews mothers were not present, and then fathers or grandmothers were interviewed.

Anthropometric data

The children under 5 years of age were measured anthropometrically twice a year, in March and in September (Table 1). During the entire study, 1029 children were examined. On average, 504 children were examined at each session, ie, 80–85 per cent of all children included in the study at that time. Twenty-one per cent of the 1029 children were examined once, 21 per cent twice, 14 per cent three times, 14 per cent four times, 17 per cent five times and 12 per cent six times.

The children were examined using standard field procedures (Jelliffe, 1966), which meant that mothers with the children were called to a central place in the village. Weight, height (length), upper arm circumference (UAC), and triceps skinfold thickness (TS) were measured. The lightly clothed children were suspended in a cloth sling on a MP 25 spring scale (Weighing Equipment Ltd, London) and weighed to the nearest 100 g. The scale was standardized against known weights before each weighing session. The length of children below the age of 2 years was measured to the nearest 0.1 cm in a recumbent position on a wooden platform with a sliding headboard; children older than 2 years were measured standing up. Upper arm circumference and TS were measured midway

Table 1. *Number of children under 5 years of age examined anthropometrically during the different seasons 1983–1985.*

Season	Age (months) 0–5	6–11	12–17	18–23	24–35	36–59	All
March 1983 Rainy season	84	82	79	54	149	171	619
Sept. 1983 Dry season	71	76	74	55	115	198	589
March 1984 Rainy season	33	49	63	46	95	166	452
Sept. 1984 Dry season	50	33	42	63	97	199	484
March 1985 Rainy season	42	38	37	50	103	186	456
Sept. 1985 Dry season	29	40	42	35	101	199	446
All seasons	309	318	337	303	660	1119	3046

between the left acromion and olecranon processes, with the arm hanging loosely at the side. Upper arm circumference was measured to the nearest 0.1 cm with a plastic measuring tape, and TS with a Harpenden caliper, to the nearest 0.1 mm. The weight and height measurements were made by specially trained field assistants.

Reliability of measurement methods

In order to check the reliability of the weight and height data, 280 children measured by field assistants were immediately measured again by a paediatrician (UL), who was unaware of the results obtained by the assistant. The s.d. of the measurement error between the first and second examination was 0.08 kg for weight and 0.49 cm for height. The measurement error was 1.8 per cent of the biological variation for weight and 2.8 per cent for height. Analysis of variance showed no correlation between the age of a child and the amount of the weight difference when using measurements taken by the paediatrician and the assistant. For height, however, there were significant differences between the age groups with the largest difference, 6.6 mm for 6 to 12 month-old infants, and the smallest, 2.4 mm for 2 to 5 year-old children. The measurement errors, as determined by differences in values obtained by the assistant and the paediatrician, were similar to those of other field studies (Trowbridge, 1979; Brown *et al.*, 1982).

Age determination

The date of birth for each child was recorded by the field assistants on two occasions, in January and in August 1983, in order to make age determination as reliable as possible. All children for which an incongruity of more than 3 months arose between the birth dates reported to the assistants, ie, 118 children, were visited by one of the authors, and a repeated thorough interview about the date of birth was made. In several cases some kind of record could be produced, mostly a health card from an under fives' clinic. Occasionally, a calendar of events was used. After this procedure, the ages of twelve of the children were still uncertain, and they were therefore excluded from the final analyses. For children born in January 1983 or later, the exact date of birth was known, since the households were visited every fortnight.

Statistical analysis

Reference values

Weight and height data were compared with those of the National Centre for Health Statistics reference population (NCHS, 1977; WHO, 1983). Each case was given a standard deviation score (s.d. score) of weight for age (W/A), height for age (H/A) and weight for height (W/H) by comparison with the reference data (Waterlow *et al.*, 1977). Data of TS were compared with the data from Tanner & Whitehouse (1975) and UAC with smoothed curves derived from Wolanski's data (Burgess & Burgess, 1969). For UAC and TS the data were expressed as percentages of the mean of the reference materials. Growth was calculated as changes in s.d. scores per unit of time for W/A, H/A and W/H and as changes in percentage of the mean per unit of time for UAC and TS. The anthropometric parameters of this material, including the differences of the deviations from the reference mean, had an essentially normal distribution.

Morbidity data

Morbidity data were classified as total morbidity, diarrhoeal diseases, respiratory infections, and skin and eye infections. Morbidity was expressed as percentage of visits in which a child was reported ill out of the total number of visits to that child; visits were grouped in 8-week periods.

Analyses

The significance of the differences of various mean values was tested by Student's *t*-test. Regression analyses were carried out with changes of s.d. scores of H/A, W/A, and W/H during the last year as dependent variables in order to test the explanatory capacity of a number of socio-economic variables. Sixty-eight explanatory variables were used in the analyses, some of which were partially related to each other. Since a large number of variables were analysed, a significance level of 0.01 was used to reduce falsely positive associations. Data on socio-economic and environmental conditions were missing to a varying extent for the children. Therefore, the multivariate analyses were made in two steps; the first consisted of stepwise multiple regression analyses in which the zero-order correlations were estimated deleting the missing information pairwisely (Nie *et al.*, 1975). The variables reaching statistical significance ($P < 0.01$) in the stepwise analyses were then reanalysed in multiple regression models excluding the children for whom data were missing for any of these variables (listwise deletion of missing observations).

Multiple regression analyses were performed to find the explanatory capacity of usage of piped water on variance of growth. Changes of s.d. scores of W/H and H/A and changes in percentages of the mean of the reference for UAC and TS for the whole after-intervention year (September 1984–September 1985), for the first

6-month period (from dry season, September 1984, to rainy season, March 1985) and for the second 6-month period (March 1985–September 1985), were used as dependent variables, with standardization for age. In addition, analogous analyses were made with the cross-sectional measurements of growth in September 1984 and in March 1985 as dependent variables for examination of the similarity of the nutritional status of the groups before the intervention. Except for socio-economic variables, village of residence was adjusted for by the use of seven dummy variables. All the tests of significance were based on multiple regression analyses. The use of piped water was measured as a percentage of fortnightly home-visits during which a household had used the piped water out of the total number of fortnightly visits; some had used it during the entire after-intervention year, some during part of the period and some not at all.

Results

Seasonal and age variations of growth

Anthropometric data in relation to age and season are shown in Figs 1–3. Weight for age was close to the mean of the reference during the first 6 months (Fig. 1). Thereafter, it deteriorated drastically until the age of 18 months, and after the age of 3 years there was some improvement. Height for age was already below the mean of the reference during the first 6 months of life (Fig. 2). After the age of 6 months, H/A deteriorated progressively until the age of 2 years. Thereafter, the s.d. scores remained unchanged or decreased slightly. Weight for height during

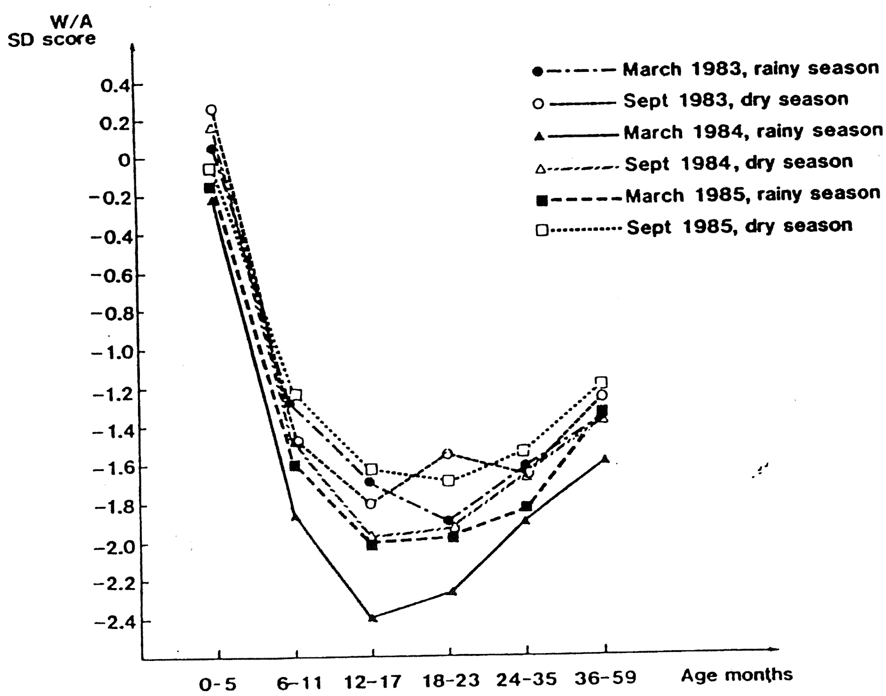

Fig. 1. *Weight for age s.d. scores in relation to age during three rainy and three dry seasons.*

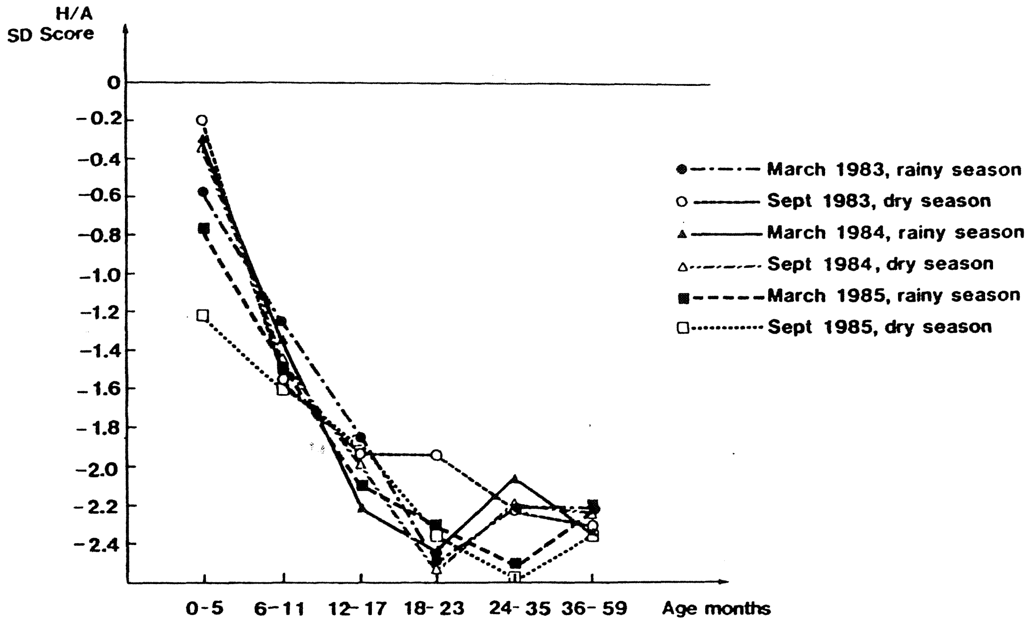

Fig. 2. *Height for age s.d. scores in relation to age during three rainy and three dry seasons.*

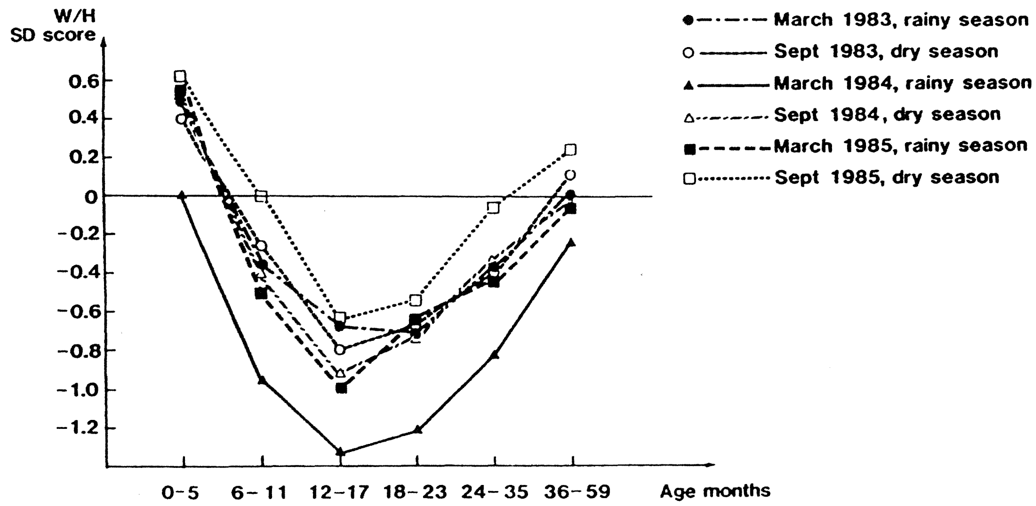

Fig. 3. *Weight for height s.d. scores in relation to age during three rainy and three dry seasons.*

the first 6 months was above the reference values during both dry and rainy seasons (Fig. 3). From 6 to 18 months of age, there was a sharp decrease in W/H, which did not steadily improve until after the age of 2 years. The same pattern could also be seen in UAC and TS.

Generally, the growth was better during the dry seasons than during the rainy seasons. The cross-sectional, anthropometric values showed trends in this direction. However, most of the seasonal differences were not statistically

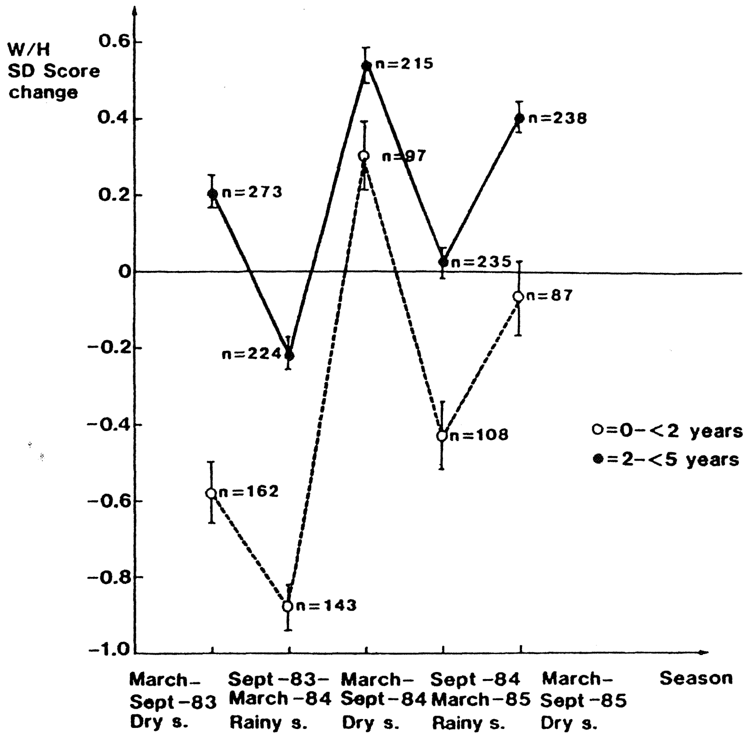

Fig. 4. *Seasonal variation of changes in weight for height s.d. scores for children 0–< 2 and 2–< 5 years of age, mean values ± s.e.m.*

significant, except for growth rate which varied significantly ($P < 0.01$ or 0.001) between all consecutive seasons (Fig. 4). During the dry seasons (March to September) the growth rate was faster than during the rainy season (September to March). There were predominantly reductions in the s.d. scores of W/H for children under 2 years of age, but for children above this age values usually increased, even during rainy seasons. Height for age showed no seasonal variation. Growth was not affected by sex, and therefore, the sexes were combined in the analyses.

Relationship between morbidity and anthropometric measurements

During all seasons, W/H, UAC and TS were significantly correlated ($P < 0.05$–$P < 0.001$), with a range of coefficients from -0.1 to -0.3, to both total morbidity and diarrhoeal diseases during the 8-week period just before the examination and occasionally even to morbidity during earlier periods. Total morbidity and diarrhoeal diseases were most frequent from 6 to 18 months of age (Fig. 5). There was a seasonal variation of morbidity with the highest levels of both total morbidity and diarrhoeal diseases during the rainy seasons. The changes of s.d. scores of W/H during 1 year (September 1984–September 1985) were significantly correlated to total morbidity and diarrhoeal diseases during that year ($P < 0.01$), after standardization for age.

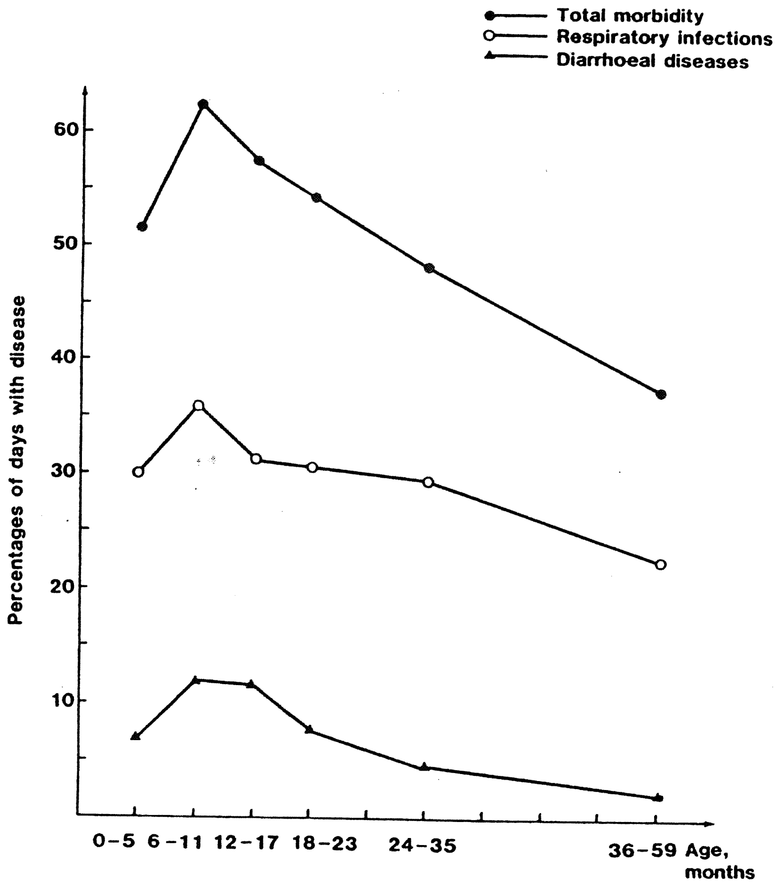

Fig. 5. *Morbidity in relation to age, mean values from three dry and three rainy seasons.*

Socio-economic determinants

Multiple regression analysis showed, as expected, that age was the supreme determinant for growth. Only a few socio-economic variables could explain variance in growth; crowding seemed to have a negative impact on weight gain: distance to other houses ($P < 0.0001$) and size of the household ($P < 0.0006$) proved to be explanatory variables (Table 2). The rate of growth of children in the different study villages varied considerably ($P < 0.001$), and, when adjusting for this 'village effect,' the correlation between crowding and W/H increase was somewhat reduced.

Impact of improved water supply

The mean amount of water carried to households was 12.8 litres per person per day before the intervention and 15.5 litres at the end of the intervention year, regardless of water source. This increase in water use was statistically significant ($P < 0.001$). The mean distance from household to water source before the intervention was 410 m. At the end of the after-intervention year, the mean distance to the tap for those using piped water was 270 m. During the first 6

Table 2. *Relation between change in weight for height s.d. score, Sept. 1984–Sept. 1985, and distance to other houses and size of household, respectively.*

		Change in W/H s.d. score	
Distance to other houses[a]	*n*	*Mean*	*s.e.m.*
< 50 m	180	0.07	0.07
50–99 m	152	0.23	0.06
> 100 m	59	0.49	0.10
No. of members in household			
2–4	175	0.31	0.06
5–7	186	0.13	0.07
8–15	62	0.07	0.11

[a]The geometric mean of distances to the nearest house and to the 3rd, 5th, 7th, and 9th nearest houses.

months after intervention 15 per cent of the home interviews indicated that the examined children were using the new water supply. This increased to 46 per cent during the second 6-month period and was 34 per cent for the entire after-intervention year.

No differences of increases in W/H or H/A during the after-intervention year were found to be effects of piped-water usage (Table 3). For UAC increments values tended to be better for those who used the improved water supply, but differences were not statistically significant. Children using the improved water supply for a longer period of time during the first 6 months gained significantly more weight, but, on the other hand, increased less in height. After standardization for village, these differences in growth patterns persisted for increase in height but not for weight gain. For all cross-sectional growth parameters there were no differences for children using and those not using piped water.

Discussion

This study in Malawi confirms many earlier observations that the growth of children in poor communities is influenced by infectious diseases (Scrimshaw, Taylor & Gordon, 1968; Mata, 1978). It has been shown that growth is especially influenced by diarrhoeal diseases and malaria (Mata, 1972; Martorell *et al.*, 1975; Cole & Parkin, 1977; Rowland, Cole & Whitehead, 1977; Black *et al.*, 1982). Malaria is hyperendemic in the present study area. However, it was beyond the scope of this investigation to study this disease, but there was no reason to believe that morbidity due to malaria had changed during the study period.

The seasonal variation of growth coincided with the seasonality of morbidity, especially that due to diarrhoeal diseases (Lindskog, 1987). Seasonal variation of morbidity has also been shown in other societies (Black *et al.*, 1982). The low correlation coefficients between morbidity and growth may be explained by the facts that the severity of disease was not measured and that respiratory tract infections, which comprised about 50 per cent of the total morbidity, do not essentially influence growth (Martorell *et al.*, 1975). Further, nutrition after infections has not been taken into account. Growth rate was correlated to

Table 3. *Relationship between change in nutritional status and frequency of piped-water usage during the after-intervention year (Sept. 84–Sept. 85) for children 0–< 5 years of age.*

Frequency of piped-water usage[a], *Sept. '84–Sept. '85.*	*Change in W/H s.d. score*			*Change in H/A s.d. score*			*Change in percentage of the mean of reference for UAC*		
	n	*Mean*	*s.e.m.*	*n*	*Mean*	*s.e.m.*	*n*	*Mean*	*s.e.m.*
0%	113	0.31	0.09	113	−0.50	0.07	113	0.3	1.0
1–49%	80	0.10	0.10	81	−0.39	0.10	77	−0.2	1.3
50–100%	102	0.30	0.09	103	−0.38	0.09	101	2.2	0.8
Test of correlation		n.s.			n.s.			n.s.	

[a]See text for definition.

morbidity during 1 year rather than 6 months, since more morbidity data were then obtained.

The measurements were taken during March (rainy season) and September (dry season) with the intention of representing extremes in nutritional status; it has previously been demonstrated that rainy seasons are associated with poor nutritional status compared with dry seasons (McGregor *et al.*, 1970; Brown *et al.*, 1982). In our study only growth rate showed statistically significant differences between all consecutive seasons, thus being the most sensitive measure of nutritional status. Even if food was relatively lacking during most rainy seasons, this might not have affected the children in this society, since children seemed to have high priority with regard to food.

In the present study, the relationship between age and growth reflects an age-related morbidity pattern with a peak of infections between 6 and 18 months. At this age nutritional requirements are high. In the population studied, the weaning food has a nutritive content that is too low to meet the extra nutritional demands during and after infections. This combination makes 6 to 24 month-old children especially vulnerable from the nutritional point of view. The low height for age during the first 6 months of life can probably be explained by intrauterine growth retardation. Height for age did not show any sign of 'catch up' during this period as did weight for age. The degree of stunting increased as the children got older, stressing the importance of the effects of the exogenous factors on height development.

Even if studies in different parts of the world are not strictly comparable, the growth and the socio-economic conditions of children in rural Malawi seem to show less variation than those of, for example, populations in suburban slum areas in other countries (Christiansen *et al.*, 1975). In the present study the only social variables that significantly influenced growth were distance between houses and family size. The effect of crowding might be mediated by increased transmission of certain pathogens. In addition, population density could influence food availability, since fewer houses might mean that larger areas of land can be cultivated per household and that smaller families would have more food per person.

Our finding that very few socio-economic conditions influencing growth could be identified is in disagreement with results from other studies (Christiansen *et al.*, 1975; Victoria *et al.*, 1986), in which a number of socio-economic variables, eg, education of the parents, family income, and sanitation, were related to growth. However, in another study from Africa, although performed in an urban society (Pickering, 1985), only a weak association between socio-environmental factors and growth was found. It is probable that the society we studied was too homogeneous with regard to socio-economic and environmental conditions to allow identification of any particular factors. The normally low level of education, which is not particularly health-orientated, might not have been sufficient to improve behaviour related to health and hygiene. Even if latrines were present, young children, who are the main propagators of gastro-intestinal infections (Freij *et al.*, 1978), did not use them. Thus, there was considerable faecal contamination of the environment. The bacteriological quality of the piped water was better than that of water from traditional sources, but considerable contamination occurred during storage (Lindskog, 1987). This deterioration of the quality is an effect of the environmental contamination and stresses the importance of hygiene education and improved sanitation.

No impact of improved water supply on the growth of children was found after standardization for village. During one period, significantly different increments of weight or height were found without this standardization, indicating varying growth rates for the different villages. However, there was no 'village factor' influencing the nutritional impact of piped-water usage. Regarding morbidity, there was no noticeable relation between piped-water usage and change in total morbidity or diarrhoeal morbidity when comparing the year before the intervention with the entire after-intervention year. When only the second half of the after-intervention year was compared with the first year a significant trend of lower morbidity with increasing piped-water usage was seen ($P = 0.013$), but this was not observed for diarrhoeal diseases ($P > 0.2$) (Lindskog, 1987). However, the decreased morbidity did not result in improved growth.

It has been argued that the use of increased quantities of water might be more important in affecting health than is improving water quality (Feachem *et al.*, 1977; Esrey & Habicht, 1986*b*). In the studied villages, the amount of water used did increase after the intervention, probably because installation of community taps meant shorter distances to draw water. However, this increase was fairly modest, amounting to about 3 litres per person per day. Under poor conditions even moderate increases in the amounts of water used may reduce diarrhoeal rates (Herbert, 1985), but in general, it is likely that substantial increases in quantities of water used, at least 20 litres per head per day (USAID, 1982), is needed to improve health.

Only a few studies have used growth as a health indicator when evaluating the health benefits of water and sanitation. In non-intervention studies, populations already using different water supplies have been compared (Christiansen *et al.*, 1975; Tomkins *et al.*, 1978; Hebert, 1985). The results of some of these studies are difficult to interpret.

In the present study, the lack of beneficial effects on growth by the improvement of water supply is in accordance with results from studies in the Philippines (Magnani *et al.*, 1984) and in Bangladesh (Rahaman *et al.*, 1986). However, in a study in St Lucia (Henry, 1981) some ambiguous results were found, but here three villages were compared and possible impacts of other processes in these villages cannot be discounted. In addition, compared with the intervention in the present study, a considerably higher level of service was provided in St Lucia (individual household taps and water-seal latrines), which is likely to influence the outcome.

In spite of sensitive measurements, it was not possible to show any nutritional impact of an improved water supply system in the present study. Good water is an essential commodity for all effective intervention programmes. However, under the conditions of this study, clean water alone was not enough to improve growth of children. This is perhaps not surprising, since water-borne diseases that influence growth represent only a limited proportion of the total disease load. Furthermore, the aetiology of gastro-intestinal infections and malnutrition are multifactorial, and this has to be considered in evaluating intervention projects. It is likely that improvement of a water supply needs to be combined with other interventions such as sanitation and health education programmes, since these are essential for better environmental hygiene and personal cleanliness. Probably more important, however, is effective nutrition of children during and after episodes of diarrhoea and other diseases in order to improve growth.

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