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The relationship between rainfall and well water pollution in a West African (Gambian) village

BY R. A. E. BARRELL* AND M. G. M. ROWLAND

Medical Research Council Dunn Nutrition Unit,
Keneba Laboratories, The Gambia, and
Dunn Nutritional Laboratory, Milton Road, Cambridge CB4 1XJ

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SUMMARY

Water pollution was monitored in six Gambian village wells over a period of 8 months spanning the 5-month monomodal rains and the pre- and post-rains dry periods. Faecal coliform (FC) and faecal streptococci (FS) counts were high throughout and there was a massive increase associated with the onset of the rains, maximum counts exceeding 5×10^5/100 ml. This pattern was largely sustained throughout the rainy season. Some individual variations in patterns of pollution could be ascribed to well design, in particular lining of the shaft, but no well was protected from the seasonal increase in faecal pollution. The source of the increased pollution appeared to be a flushing in of faecal material of indeterminate or mixed human and animal origin, probably over considerable distances. Peaks of pollution not associated with rainfall episodes could have resulted from the practice of communal laundering in the near vicinity of the wells. Specific pathogens including *Salmonella* spp. were isolated only intermittently. Attention has been drawn to a problem complicating the standard method for assessing FC counts.

INTRODUCTION

The role of water in the spread of enteric infections has been recognized for over 100 years, since the observations of Snow (1855) and Budd (1856, 1873) relating to outbreaks of cholera and typhoid respectively. Since then there have been many reports of water-borne diarrhoeal diseases often due to the introduction of a pathogen not previously present (Holden, 1970). These reports relate to public and semi-public supplies in which contamination or a breakdown in treatment has occurred and to untreated supplies. Whilst most reports are concerned with typhoid, paratyphoid and cholera there have been recent reports of water-borne outbreaks in the USA caused by enterotoxigenic *E. coli* (Morbidity & Mortality, 1975) and *Campylobacter fetus* (Morbidity & Mortality, 1978).

In many rural areas of the developing world there is a considerable increase in diarrhoeal illness at the time of the rains. It has been argued that one epidemiological link is the pollution of water supplies due to the flushing in of faecal material,

* Present address: Public Health Laboratory, Withington Hospital, Manchester M20 8LR.

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particularly at the onset of the rainy season such as has been described by Moore, de la Cruz & Vargas-Mendez (1965). Despite the potential importance of this concept in the field of public health few sustained projects have been undertaken to examine on a regular basis the relation between water pollution and rainfall (Draser, Tomkins & Feachem, 1978). Previous studies have been mainly concerned with the pollution of streams and rivers (Kunkle & Meiman, 1967, 1968; Feachem *et al.* 1978). Other studies on surface waters such as ponds and wells (Tomkins *et al.* 1978) and embracing other sources (Bradley & Emurwon, 1968; Gracey *et al.* 1976) have not been related to rainfall.

The study described here was carried out in Keneba, a rural Gambian village, where the monomodal rains are associated with the main seasonal peak in diarrhoeal illness in children (McGregor *et al.* 1970; Rowland & Barrell, 1979). The bacteriology of well water has been closely monitored during an 8-month period encompassing the rainy season to determine the nature and degree of faecal pollution and its relation to rainfall.

MATERIALS AND METHODS

Keneba is an isolated subsistence farming village with a population approaching 1000. It is in The Gambia, West Africa, situated in an area of orchard savannah surrounded by saline creeks and brackish swamps. Detailed descriptions are available elsewhere (McGregor, 1976; Tully, 1978). The village occupies an area of 0·25 km^2 and water is supplied exclusively by six wells all within the village perimeter. The wells, which have been dug in laterite soil, are less than 20 m in depth and approximately 1 m in diameter. Two only are lined by concrete rings down to water level. All were topped with a concrete parapet $\frac{1}{2}$–1 m in height and a rough concrete plinth about 1 m wide. The plinths of all wells were poorly constructed, particularly in well D where surface waters could drain directly into the well shaft. Though all wells were used to some extent for cooking and drinking some were preferred for this purpose. The well and water characteristics have been summarized in Table 1. The temperature of the water in the wells was generally in the range 28–30 °C. Water is drawn by hand from the wells using ropes and buckets of plastic, metal or improvised from rubber inner tubes. Peak collection times varied through the year but were usually between 07.00–10.00 h and 16.00–20.00 h, when as many as six women would be drawing water from any one well at the same time.

Water was carried from the wells in large bowls or tubs to replenish the earthenware storage pots in the household compounds. The wells were between 10 and 30 m from the nearest houses. Washing of laundry and pots and pans often took place in the clearing in which the well was situated, resulting in water-logging of the surrounding ground during the period of established rains. Livestock had free access to this area, only one well (K) being fenced off.

Sanitary facilities were largely non-existent, adults defaecating on the periphery of the village or, at the beginning of the farming season, in the fields. Small children defaecated on the ground often within the compounds.

Samples and culture methods

Bacteriological examination of water from all wells was carried out during 1977 from 23 May to 22 July and 12 August to 28 December. Frequency varied between 4 or 5 times per week during the dry period preceding the onset of the rains to daily or more at the start of the rainy season and falling to weekly towards the end of the rains and the following dry spell. All water samples throughout the study period were examined for faecal coliforms (FC) and faecal streptococci (FS) using membrane filtration. At least 100 ml water was collected and between 23 May and the onset of the rains on 22 June 1 ml subsamples diluted with 40–50 ml of phosphate buffer were filtered. After the first rainfall, 1 ml and 0·1 ml subsamples diluted as above were filtered.

FC were counted on M-FC agar (Difco) incubated at 44 °C for 24 h and FS on m-enterococcus agar at 37 °C for 48 h. A selection of blue colonies on M-FC agar (Difco) were confirmed as FC on the basis of gas production in brilliant green bile (2 %) broth (Oxoid) incubated at 44 °C for 24 h.

During part of the study examination was also carried out for *Salmonella*, total colony count, *Bacillus cereus*, *Clostridium welchii* and *Staphyloccus aureus*. The presence of *Salmonella* was determined in 100 ml samples of water from each well once a week until the middle of the rains (22 August). The waters were incubated with an equal volume of double-strength selenite broth (Oxoid) at 41 °C for 24 h followed by subculture on deoxycholate citrate agar (Hynes's modification) (Oxoid) incubated at 37 °C for 24 h. Colonies characteristic of *Salmonella* were examined for biochemical reactions using Kohn's I and II media (Oxoid) and for agglutination with *Salmonella* polyvalent H-specific and non-specific antiserum (Burroughs Wellcome).

Once a week from 14 June to 22 August waters were examined for total colony count at 37 °C on plate-count agar (Oxoid), for *B. cereus* on phenol red egg-yolk agar plus polymixin (Mossel, Koopman & Jongerius, 1967) and for *Cl. welchii* by anaerobic incubation on blood agar plus 2 drops (approx 0·6 ml) neomycin per plate. Colony counts were performed by the method of Miles & Misra (1938). Plates were incubated at 37 °C and characteristic colonies of the above organisms confirmed by biochemical and/or serological tests. In addition, 0·1 ml subsamples of water were plated on the selective agars for *Staph. aureus*, *B. cereus* and *Cl. welchii*.

Since 1961 various meteorological recordings have been made at Keneba, including rainfall records that were made on a 24 h basis throughout the period of study described here.

RESULTS

The rainfall distribution in 1977 was quite typical of the area though the total precipitation was low, being between half and two-thirds of that experienced in the preceding 3 years. The monthly pattern is illustrated in Table 2. The first rainfall occurred on 22 June and the last on 16 October.

Though considerable day-to-day variation in bacteriological findings occurred within and between wells a clear pattern emerged with respect to counts of FC and

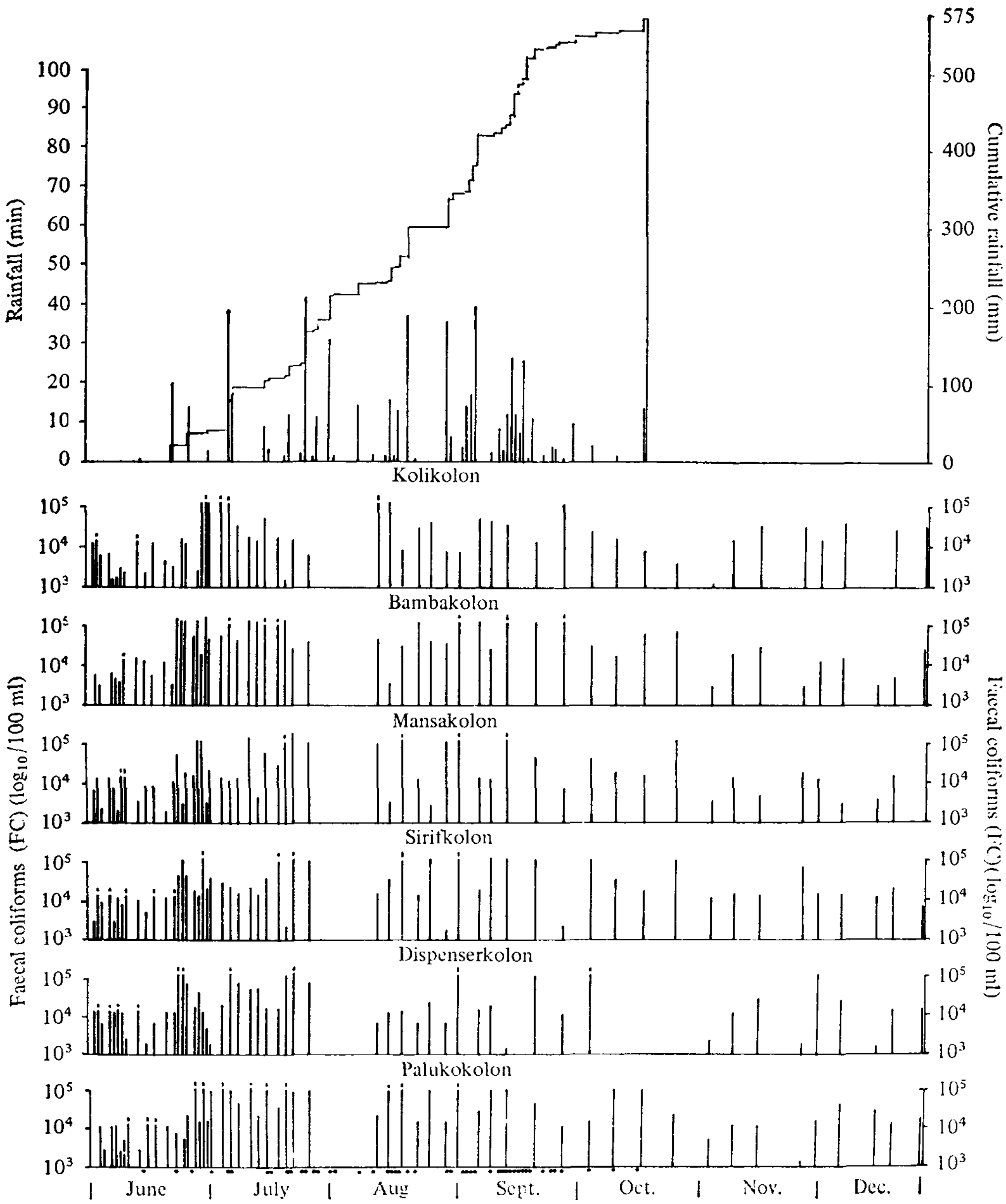

Fig. 1. Relation between daily rainfall (mm), cumulative rainfall (mm) and daily well pollution (FC $\log_{10}$/100 ml) in six Keneba village wells from June–December 1977. Interrupted bars denote FC counts in excess of indicated values but not precisely determined.

Table 1. *Keneba well characteristics*

Designation*	Well depth (m)		Water: Depth before rains, June 1976	Character	Use
M	18·1	Lined	1·4	Clear	Drinking and cooking
P	17·2	Lined	1·9	Clear	Cooking and washing
K	15·1	Unlined but fenced	1·1	Clear	Cooking
S	18·7	Unlined	1·4	Occ. turbid	Drinking
B	14·8	Unlined	0·2	Turbid	Occasional cooking
D	18·3	Unlined	0·6	Turbid	Occasional cooking

*M, Mansakolon; P, Palukokolon; K, Kolikolon; S, Sirifkolon; B, Bambakolon; D, Dispenserkolon.

Table 2. *Keneba rainfall, May–November* 1977

Month	Rain (mm)	No. of wet days
May	0	0
June	35·1	4
July	172·9	12
August	131·3	11
September	209·5	19
October	20·8	3
November	0	0

FS. For the sake of simplicity the data on FC only are illustrated in detail in Fig. 1, counts being expressed as $\log_{10}$/100 ml. Before onset of the rains counts were relatively low and rarely exceeded 2×10^4/100 ml though unexplained sporadic peaks occurred affecting different wells at different times. A dramatic increase in counts by 10- or even 100-fold followed the onset of the rains over a period varying between 1 and 6 days, depending on the well. The most rapid rise occurred in wells B and D and the slowest in well P. Counts of 5×10^5/100 ml were recorded and high counts were consistently found over the early weeks of the rains. Thereafter, though more fluctuation occurred, they remained generally elevated throughout the duration of the rainy season. After the rains they fell slowly and erratically and had still not fallen to pre-rains counts by December. Once again during this post-rains period there were occasional spikes of pollution in individual wells which could not be explained by rainfall episodes. During the course of the study one well temporarily dried up, a fairly common annual event with two of the six wells. It was significant that there was no evidence of any 'concentration' effect producing a rise in pollution at the time, such as has been postulated in explaining some cases of dry season diarrhoeal epidemics (Drasar *et al.* 1978).

This relation between rainfall and FC counts in all six village wells has been illustrated on a daily basis in Fig. 1.

It has been suggested that the differential die-off rates of FC and FS of animal and human origin offer a method of determining whether or not faecal pollution is primarily from animal or human sources (Feachem, 1975). Fluctuating values of FC:FS ratios were obtained for all wells, most falling within the range 0·7–4·0, indicating pollution of uncertain or mixed origin. Values of less than 0·7 (animal) and more than 4·0 (human source) were obtained on occasions from all wells.

Total colony counts for all wells fell within the range 5×10^2/ml to 5×10^5/ml. Most were in the range $1–9 \times 10^4$/ml and showed no obvious change in association with onset of the rains.

Salmonella was isolated on only two occasions from the same well (K) in July.

B. cereus was isolated on at least one occasion from wells B, M, K and P with a maximum count of 60/ml.

Cl. welchii was isolated on one occasion from well B (50/ml) and well P (60/ml).

DISCUSSION

High counts of FC and FS were obtained in all village wells throughout the study period indicating year-round faecal pollution of considerable dimensions. The unequivocal rise in counts of these organisms with the onset of the first measurable rainfall strongly supports the concept of faecal material from the neighbourhood of the wells being washed through the porous laterite or directly round the well shaft itself leading to pollution of the contents. Some degree of protection seemed to be afforded by lining the wells as adjudged by the relatively delayed rise in counts after the onset of the rains in wells M and P and the generally lower counts obtained in M. The very obvious defect in the plinth surrounding well D, allowing direct seepage from the surface into the shaft may well have accounted for the rapid rise and high counts of faecal organisms observed. No well could be described as satisfactorily protected.

Some of the sporadic increases in pollution not associated with rainfall may have been due to the communal laundry activities which characteristically occur at the well side. It is quite possible that sufficient local flooding occurs during some of these sessions to leach contaminants into the well itself. The individual use of ropes and buckets to extract water is also a continual potential source of introduced contaminants.

Consideration of the FC:FS ratio gave no indication of the relative importance of animal or human sources of faecal contamination, most results falling in the mid-range 0·7–4·0 even when samples were examined soon after a rapid rise in counts. Fresh samples of faeces from cows and goats were found to have ratios of less than 0·7 and the 2 human samples examined had ratios of 3·6 and 3·8 and were thus in reasonable agreement with Feachem's (1975) observations. If our results are interpreted as positive evidence of mixed human and animal pollution rather than being equivocal then they suggest that flushing in or percolation of human faecal material must occur over quite long distances in the Keneba laterite soil.

Spot checks on well water in three adjacent villages yielded counts of FC and FS similar to those in Keneba and were about the same as those described in village wells in Chad (Buck *et al.* 1970).

Protection of surface waters such as springs can reduce the degree of pollution (Bradley & Emurwon, 1968; R. G. A. Feachem, unpublished data) and our own findings suggest that some degree of protection was afforded by lining village wells. During the survey period the same bacteriological monitoring programme was applied to two wells 22 and 24 m in depth within the 3-acre enclosed site on the fringe of the village used by the Medical Research Council for work and residential purposes. These two separate wells differed considerably from the traditional village wells in that both were enclosed at the top by cement-floored pump-houses though only one well shaft was lined. Water was extracted by diesel pumps usually thrice daily. Both wells suffered considerably less pollution than village wells as adjudged by counts of FC and FS (usually less than 10^3/100 ml), and although a rainy season increase was observed it was very small and briefly sustained. Paradoxically at least two strains of *Salmonella* were isolated on no less than 11 occasions (6 in the unlined and 5 in the lined well) but this may well have resulted from periodic overloading of inappropriately sited septic tanks, the nearest of which was only 20 m distant. In addition the wells were periodically entered for repairs. Whatever the cause it does suggest that, at least where Keneba type soils are present, even protected wells should be regarded as vulnerable to pollution over quite considerable distances.

Finally one technical problem arose with the bacteriology which is of general relevance to studies using similar techniques based on those of Geldreich *et al.* (1965). At the beginning of the study 154 blue colonies on M-FC agar from 6 water samples were confirmed as FC on the basis of gas production in brilliant green bile (2%) broth (Oxoid) incubated at 44 °C in 94% of cases with a range of 90–100% per water sample. A change of morphology of the blue colonies at the end of the study prompted a further check; of 61 colonies from 3 water samples 67% were confirmed as FC with values of 45%, 77% and 81% for the three samples examined. A similar experience has been described by workers in Tanzania (R. G. A. Feachem, personal communication) and there is clearly a need for general awareness of this problem.

For the confirmation of FC in the tropics the production of indole from peptone at 44 °C is necessary to exclude strains of coliform organisms capable of producing gas from lactose at 44°C but incapable of producing indole. Though rare in temperate climates, these organisms are common in faeces in the tropics. The findings described above are probably the results of a fall in the number of FC in polluting material after the rains.

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