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FAECAL CONTAMINATION OF RURAL WATER SUPPLY IN THE SAHELIAN AREA

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Abstract—The present expansion of water improvement programmes in developing countries is hardly adapted to provide rural areas with an adequate supply of drinking water. Quality control measures encounter many technical difficulties and are not often performed. A study of the microbiological quality of 982 rural water points was undertaken in the Sahelian region of Burkina Faso. A mobile laboratory was developed for this work. Bacteriological analyses were performed using the membrane filtration method and the results measured according to WHO potability standards. Surprisingly, results showed a faecal contamination in 7.7% of boreholes. Possible risk factors of pollution were analysed, leading to recommendations for technical improvement. The responsibility for eliminating these risk factors, in the main, lies with the consumers through health education. This study highlights the place of sanitary education programmes as a priority among the objectives of health policies.

Key words—drinking water, faecal pollution, analytical method, risk factors, sanitary education, West Africa

INTRODUCTION

As part of the Drinking Water Supply and Sanitation Decade (1980–1990), a number of village water programmes are being implemented in developing countries, particularly in West Africa. Systems designed to exploit underground water rescources are progressively meeting the requirements of rural populations. However, the potability of this water has not been well established, since bacteriological quality control is hampered by the fact that laboratory techniques are ill adapted for conditions in the field.

A survey was conducted to determine the microbial quality of 982 water points in rural areas of Burkina Faso (Guillemin, 1985). This was possible by way of the development of a simple, low cost, analytical technique, applicable in the field. Factors contributing to water pollution were consequently analysed.

MATERIALS AND METHODS

General situation

The granitic subsoil in Burkina Faso presents a network of faults, fractures and fissures draining away the rainwater. Recent borehole techniques have made these reserves accessible (BRGM, 1985) and provide a permanent supply, unaffected by seasonal droughts. Villages are generally dispersed clusters of houses within a 10 km^2 area. Several water supplies, not exceeding some 100 m from each cluster, are available in this area, where cattle can graze freely. Wells are usually dug near ponds and boreholes are constructed on lines of faults often corresponding to underground ponds or rivers.

Programmes for such boreholes were developed over the decade. More than 10,000 boreholes have already been dug in Burkina Faso. These will progressively replace the common traditional wells (Awad *et al.*, 1985).

Scientific equipment and training

Due to transport difficulties (rough roads and tracks), the analytical equipment had to be compact and sturdily built. It had to withstand extreme temperature conditions (45°C) and hygrometric variations (0–99%).

Since the equipment had to be of small dimensions, analyses were limited to those required for determining potability, according to the WHO standards (WHO, 1984). We used culture media dried onto cardboard (Sartorius). Hermetically sealed, they were protected from hygrometric variations and stored, undamaged, at room temperature. Media were rehydrated at the time of use.

The average cost of one test was assessed by taking into account the following four items: logistics, scientific equipment, personnel and operating expenses.

Technical staff from the Burkinabe Health Ministry were trained, so that local technicians would be able to perform water quality control tests. Training consisted of instruction in analytical methods applicable in the fields and in the determination and elimination of factors causing pollution of boreholes.

Analytical methods

The membrane filtration technique was used as a basis for most field analyses to detect indicators of faecal contamination. The mobile analytical laboratory was either installed in a village dispensary or in another building. Water samples from all the neighbouring villages, stored in iceboxes, were brought to the analytical unit in less than 6 h. All water sources (boreholes, wells, etc...) within a 30 km radius were examined. The equipment consisted of a filtering system joined to a vacuum pump connected to a generator. Water (100 ml) was filtered through membrane filters (pore size:

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0.45 μm) which were then deposited on culture media already rehydrated with 2–3 ml of sterile water and placed in a portable incubator. The following four tests were carried out:

—Standard plate count (SPC) was made by the pour plate method after 24 h incubation at 37°C in nutrient agar (Institut Pasteur) inoculated with a 1 ml water sample. When the water was highly contaminated, dilutions (1/10, 1/100 or 1/1000) were initially performed.
—Detection of total coliforms (TC) was done using Tergitol TTC medium (SM 14056 N-Saratorius) incubated for 24 h at 37°C.
—Identification of faecal coliforms (FC) was carried out on Tergitol TTC medium incubated at 44°C for 24 h. Doubtful colonies were isolated on purple bromocresol lactose agar (BCP agar—Institut Pasteur) at 37°C for 24 h, followed by biochemical identification on API 20 E galleries (API System) after 24 h at 37°C.
—Identification of faecal streptococci (FS) was conducted on Azid medium (SM 14051 N-Sartorius) incubated for 48 h at 37°C. The morphological and biochemical characteristics of these bacteria facilitated their identification by Gram staining and catalase reaction.

These four tests were conducted for each water sample. After analysis, sampling vials were sterilized and the used material was destroyed in a portable autoclave (13 l.—Prosciences).

Laboratory checking of the dried media method

The reliability of our method was confirmed at the Laboratoire d'Hygiène et de Recherche en Santé Publique in Nancy (France). Thirty water samples (11 drinking water, 11 bathing water and 8 wastewater) previously tested in the mobile laboratory were re-analysed using the membrane filtration method, and the Sartorius dried media were compared with usual agar media.

Detection of TC was obtained on Tergitol 7 Agar (5471-Merck) medium, incubated for 24 h at 37°C. FC were detected after 24 h at 44°C using the same medium. Doubtful colonies were isolated on Hajna–Kligler medium (Institut Pasteur) after 24 h at 37°C. Their identification was obtained on Schubert medium—24 h, 44°C—(Institut Pasteur) and API 20 E gallery—24 h, 37°C—(API System). For detection of FS, membrane filters were deposited on Slanetz medium (5262-Merck) and incubated for 48 h at 37°C. Doubtful FS colonies were isolated on Esculine agar (Institut Pasteur) for the research of specific hydrolysis, after 24 h at 37°C. Incubation times and procedures were the same as those used in the field.

Potability standards

The drinking water standards adopted correspond to those of the WHO (1984). For unpiped water sources, the following is recommended: less than 10 total coliforms per ml of sample and the absence of faecal coliform and faecal streptococci per 100 ml.

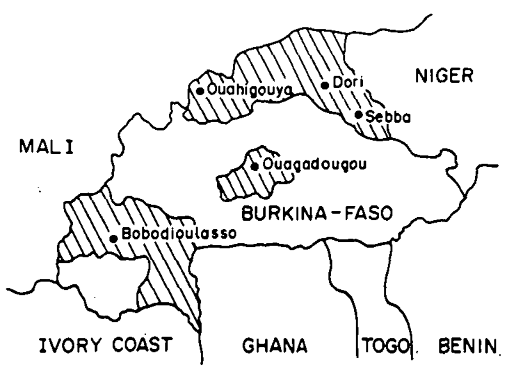

Fig. 1. Intervention areas in the survey.

Table 1. Comparative rates of faecal contamination indicators in 30 water samples detected by the fresh agar method and by the dried medium method

	Agar medium method (%)	Dried medium method (%)	P value
TC 100 ml	46.6	36.6	NS
FC 100 ml	46.6	50	NS
FS 100 ml	36.6	46.6	NS

NS, non significant, by the chi^2-test.

Water sampling

The survey concerned 982 water sources distributed over four provinces: two in the Northern Sahel, one in the vicinity of the capital (Ouagadougou) and one in the south-west (Fig. 1).

This comprised an area of about 2/5 of the national territory. The bacteriological quality of drinking water from 688 boreholes was compared with that of 250 concrete wells and of 44 traditional wells. In attempt to identify the main polluting factors, each water source was examined for:

—the existence and cleanliness of protective devices surrounding the base of the pump;
—the presence of leaks in the gasket at the base of the pump;
—the environmental sanitary conditions (i.e. proximity of latrines);
—systems designed to deter cattle from the water supply area;
—defects in the pump requiring re-priming with water of doubtful quality.

In addition, the influence of rainfall on the quality of subterranean water was studied in 76 boreholes from the Sahel region (Sebba), north of the 500 mm pluviometry line. Two series of analyses were conducted within a 6 month period. The first investigation took place during the dry season (March–April), the second at the end of the wet season (October).

Statistical analysis

The reliability of the dried medium method and rainfall effect were determined using chi^2 paired tests. The contamination rate of the different water sources were compared using the chi^2-test. The correlation coefficient calculation was used to assess the relation between FC and FS levels for each water sample.

The study of each variable, as assumed risk-factors of pollution, was first conducted separately using the chi^2-test, then analysed in a stepwise logistic regression adjusted to each survey area. All analyses were performed using BMDP software (BMDP, 1983).

RESULTS

Validity of the dried media

Water analysis results obtained using our method were comparable with those from the specialized laboratory—Nancy (Table 1). The number of contaminated waters detected by both methods did not differ significantly. Regardless of the bacteria involved, water pollution analysis revealed no statistically significant difference. Nor did the pollution levels assessed by both methods differ, as far as TC, FC or FS are concerned.

Table 2. Results of the survey (982 water points): rates of pollution, according to the WHO standards, and details of bacteria counts for each type of contaminated wells and boreholes

Faecal contamination (according to the WHO standards)	Boreholes	Concrete wells	Traditional wells
	7.7% (n = 688)	13.5% (n = 250)	66% (n = 44)
Total bacteria and contamination indicators levels in the polluted samples:			
	Mean ± SE (range)		
SPC/ml	48.5 ± 25.9 (3–500)	344 ± 97 (10–8700)	3500 (10–>3.10)
TC/100 ml	17.3 ± 6.4 (1–380)	23.45 ± 3.23 (4 – 260)	830 (560–10)
FC/100 ml	4.2 ± 0.27 (0–15)	9.2 ± 1.24 (0–57)	527 (267–1320)
FS/100 ml	3.8 ± 1.3 (0–11)	10.5 ± 4.2 (0–220)	454 (122–947)

SPC, standard plate count. TC, total coliform. FC, faecal coliform. FS, faecal streptococci.

Results of bacteriological analyses

Results for the 982 water samples were reported according to the different water sources (Table 2):

—92.3% of the boreholes met the WHO potability standards, leaving 7.7% polluted with an average of 17.3 ± 6.4 TC/100 ml, 4.2 ± 0.27 FC/100 ml and 3.8 ± 1.3 FS/100 ml.

—13.5% of the concrete wells were contaminated with an average of 23.45 ± 3.23 TC/100 ml, 9.2 ± 1.24 FC/100 ml and 10.5 ± 4.2 FS/100 ml.

—66% of the traditional wells presented a mean pollution level of up to 300 TC, FC and FS per 100 ml.

These data emphasize the expected high rate of unsanitary conditions in traditional wells. They also confirm the higher risk a faecal contamination of wells compared to boreholes ($P < 0.05$).

The FC identified were the following: *Escherichia coli* (85%), *Citrobacter freundii* (3.5%), *Enterobacter agglomerans* (1.7%), *Enterobacter cloacae* (1.7%), *Klebsiella oxytoca* (0.8%), *Citrobacter diversus* (0.8%) and 5.2% that could not be identified.

The other pollution indicators (SPC and TC) provided information concerning the importance of bacterial contamination drinking water points: traditional wells are the most exposed.

No correlation could be found between the FC and FS levels for each water source. In a large number of them, a higher level of FS than FC was present (boreholes: 38%; concrete wells: 48%; traditional wells: 100%).

Influence of rainfall

Seventy-six boreholes in the Sebba region were tested for bacteriological pollutants during the dry season (March–April). Nine of them (11.8%) contained FC contaminated water. At the end of the rainy season (October), 16 boreholes (21%) were found to be polluted (Fig. 2). Though the rate of pollution tended to increase at the end of the rainy

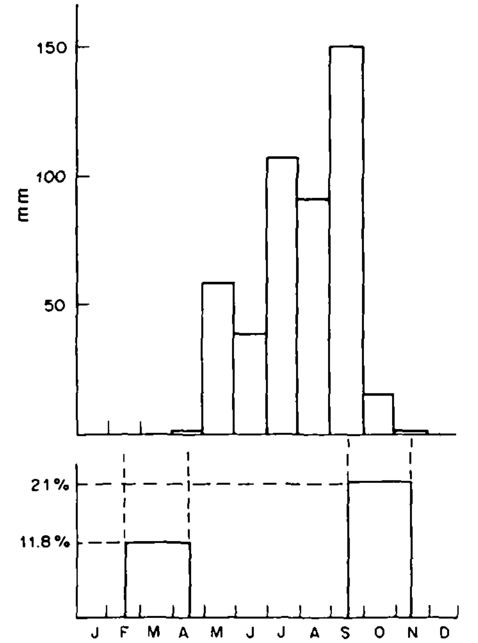

Fig. 2. Rates of faecal contamination indicators in boreholes (n = 76) at onset and end of wet season, compared with monthly rainfall (mm) over 1 yr (1984).

season, the effect of rainfall as a factor leading to pollution was not statistically significant.

Risk factors of pollution

Analysis of the results shows a significant relation between water pollution and each risk factor assessed. After a stepwise logistic regression analysis, the link with each factor persisted independently, whatever the survey area (Table 3). The unsanitary conditions of the proximal environment ($P < 0.001$), the absence of protective devices ($P < 0.001$), hazards in re-priming ($P < 0.001$), leaks in the pump ($P < 0.05$) and the absence of efficient system to keep cattle away from the water supply area ($P < 0.05$) seem to contribute to the non-potability of water.

Although it was not possible to establish a strictly causal relation with these factors, their influence on the water quality of boreholes must be taken into consideration.

Table 3. Risk factors of pollution–stepwise logistic regression (688 boreholes)

Risk factors	N	Odd-ratio	P value
Unsanitary environment	E = 348 NE = 318	2.46	<0.001
Absence of protective device	E = 96 NE = 570	2.76	<0.001
Hazards in re-priming	E = 31 NE = 635	5.12	<0.001
Leaks in the pumps	E = 14 NE = 652	3.54	<0.05
No system to keep cattle away	E = 116 NE = 550	2.20	<0.05

E, exposed; NE, non exposed.

DISCUSSION

This study shows that all drinking water sources in tropical Sudan–Sahel regions may be polluted. Traditional wells were invariably contaminated with very high levels of indicators of faecal contamination, similar to that found in ponds or rivers. Pollution in concrete wells was less frequent. Variations in contamination levels seemed to depend on the protective equipment utilized and on how carefully the technical finish was applied (Lewis and Chilton, 1984). Boreholes were found to be the best safeguard against the transmission of water-borne bacterial diseases (Monjour *et al.*, 1984), since at least 80% of them were free of pollutants, representing a real improvement in drinking water supply. These results were consistent with prior reports on the quality of water in rural African areas (Essien and Osuhor, 1979; Lewis *et al.*, 1980; Viens and Lavoie, 1982; Lewis and Chilton, 1984).

The difference between FS and FC incidence rates is a common finding. Three explanations are proposed for this. Firstly, FS have a longer life span and may indicate a semi-recent pollution (2–4 months previously), whereas FC indicate recent faecal contamination and survive for a shorter period. So, semi-recent contamination by FS is more likely to be detected. Secondly, a higher FS/FC rate is generally related to a pollution of non-human origin, especially if FS/FC exceeds 2.0 (Finstein, 1972). With the frequent proximity of domestic animals and deterioration of protective devices around the pumps, a large part of FS was probably due to livestock contamination. Lastly, the higher FS/FC frequently reported in African field studies may be related to injury of the more delicate coliform bacteria in the aquatic environment, where exposure to stress (i.e. time, nutrient availability) might have sublethal consequences for microorganisms (McFeters *et al.*, 1984). However, according to McFeters *et al.* (1982), recovery of FC may be improved by using adapted time, temperature of exposure and media.

The relation between rainfall and pollution remains controversial. Under subtropical or guinean climates, like Ivory Coast or Malawi (Viens and Lavoie, 1982; Lewis and Chilton, 1984), the pollution increases with monthly rainfall level like the trend we observed. This is assumed to be a consequence of contaminants accumulated in the ground during the dry season being washed by rainfall. Conversely, in countries like Sierra Leone (Wright, 1986), faecal contamination indicators increase at the end of the dry season, possibly due to a concentration effect when water reserves are diminishing. This difference might be related to the filtering capacities of the various water ducts.

The water of boreholes is generally assumed to be potable. In fact, this survey showed that 7.7% of them contain low levels of indicators of faecal contamination. Therefore, boreholes should not be condemned as this would send consumers back to the much more polluted traditional wells. However, while using boreholes, other sanitary programmes must be initiated, since according to the threshold-saturation theory (Shuval *et al.*, 1981) there is no improvement in health status even after further investments in water supply and sanitation as long as these remain below a certain socio-economic threshold.

Another objective was to determine the factors of borehole water pollution. Three factors were identified:

(1) The quality of the equipment (hydraulic pumps or public fountains) should be the prime concern. This means that it should be robust and easy to use. It necessitates the organization of distribution networks for repairs and the training of operators and repair staff. It is essential to ensure that the manufacturer's equipment guarantee is provided, and that it covers a period of at least 2 or 3 years. Indeed, mechanical defects in the pumps forces the users to prime them with water from traditional wells, thereby threatening the underground water with pollution. Another factor favouring contamination is neglect of the technical finish of boreholes and of the water supply area. The addition of a concrete annular gasket surrounded by a concrete base of at least 2 m in diameter supporting the pump would prevent pathogenic infiltration.

(2) Safety is even further improved when supply areas are designed so as to prohibit the access of cattle to the pumps.

(3) Finally, health education remains a priority. This is best prior to the installation of drinking water sources. It should be aimed at the application of simple hygiene in individual and familial life (Feachem, 1984), with greater responsibility of the community in the maintenance and cleanliness of boreholes and the surrounding areas (Roundy, 1985). Safer water supplies will eventually lead to improvement in the health of consumers via a decrease in morbidity and mortality (Monjour *et al.*, 1984; Esrey *et al.*, 1985; Esrey and Habicht, 1986). After the provision of boreholes, health education courses, conducted by health technicians, as part of the primary health care programme, are essential in order to sustain and reinforce their efficiency (Van Damme, 1985; Cyjetanovic, 1986; Briscoe, 1987). All programmes concerning rural water supplies should include investigations into possible causes of pollution. A 1 week instruction in our analytical method for health staff trained in bacteriology is sufficient for microbiological quality control of water. For field analyses of 100

water points three times a year, the cost of one bacteriological assessment amounts to \$20–30. Such expenditure is very low when considering that of setting-up a pump in granitic subsoil amounting to approx. \$15,000.

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