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NITRATES IN RURAL WELLS OF THE SENEGAL RIVER BASIN[1]

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ABSTRACT: A survey of 34 open hand dug wells was performed in the Senegal River basin of West Africa. Nitrate concentrations were determined on the well water samples over a six-month period. With the exception of two wells, the wells indicated varying levels of nitrate contamination. The range of concentrations was 0.10 to 880 mg/l as nitrate. These data when compared to physical characteristics, land use, and age using a chi-square analysis did not suggest any strong association. The fact that these wells are open and in a semiarid climate may be of such importance that the previously considered factors are of minor relative importance. Contamination may be primarily the result of foreign matter entering the well mouth.
(KEY TERMS: rural wells; nitrate; contamination; West Africa.)

INTRODUCTION

The presence of nitrate in rural wells represents an important potential public health problem. This problem is especially significant in developing countries since shallow wells are commonly used as sources of domestic water. In light of the attention which will be directed at rural water supply as a result of the United Nations Drinking Water and Sanitation Decade it is important that more concern be given to water quality in these water supplies.

Nitrate can cause methemoglobinemia in infants, which is known as "blue baby." This refers to the cyanotic, or bluish pallor that develops in infants as the result of ingesting large amounts of nitrate. In the intestines nitrate is reduced by bacterial action to nitrite, which enters into the circulatory system. The nitrite oxidizes hemoglobin from the ferrous to the ferric form, with consequent production of methemoglobin (Comly, 1945). In response to the health implications associated with high nitrate waters, the World Health Organization has suggested a nitrate limit of 45 mg/l as nitrate for domestic water supplies (World Health Organization, 1971). An excellent discussion of the subject is authored by Deeb and Sloan (1975).

Nitrate is usually the dominant form of nitrogen in ground water. It is formed from the oxidation of reduced nitrogenous compounds (Feth, 1966). Potential sources of nitrate include precipitation, fertilizers, decayed plant and animal matter, and bedrock. Many investigators (George and Hastings, 1951; Williamson and Peterson, 1951; Gilliam and Webber, 1969; Taylor and Bigbee, 1973; Brooks and Cech, 1979) have examined rural wells in temperate climates and have concluded that nitrate contamination reflects such site specific conditions as land use, population density, and water table depth. While shallow wells are easily contaminated by waste materials some wells have naturally high nitrate levels (Feth, 1966).

As part of an environmental assessment of water resource developments in the Senegal River basin, West Africa, rural wells in Senegal, Mauritania, and Mali were sampled. The objective of this paper is to consider the possible relationships between the occurrence of nitrate in shallow wells, the physical characteristics of each well, and the sanitary conditions of the surrounding areas.

DESCRIPTION OF SENEGAL RIVER BASIN

The Senegal River is the second longest river in West Africa. It is over 1800 kilometers in length, has an approximate basin area of 290,000 sq. kilometers, and produces an annual average discharge of 25 billion cubic meters. Average annual precipitation is 2000 millimeters in the headwaters region and 250 millimeters in the northern most area of the basin.

The basin is located in the Sahelian climatological region. The rainy season extends from June until October with virtually no precipitation and therefore very little infiltration and runoff outside of this period.

Hand dug wells are generally dug in soils of alluvial or aeolian origin. These soils are predominantly sand with minor amounts of clay and gravel. They are medium to fine textured, slowly to moderately permeable with very little vegetative cover. These lands are often flooded during the wet season which results in direct recharge of the water table. A more thorough description of the climate, morphology, and hydrology of the Senegal River basin is found in *Le Bassin du Fleuve Senegal* (Rochette, 1974).

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METHODOLOGY

Survey

Thirty-four wells in the Senegal River basin from the upstream region near the Bafing River, a tributary of the Senegal, to the delta region were chosen (Figure 1). These wells were sampled one to three times between December 1977 and June 1978, reflecting changes in precipitation patterns from the wet to the dry season.

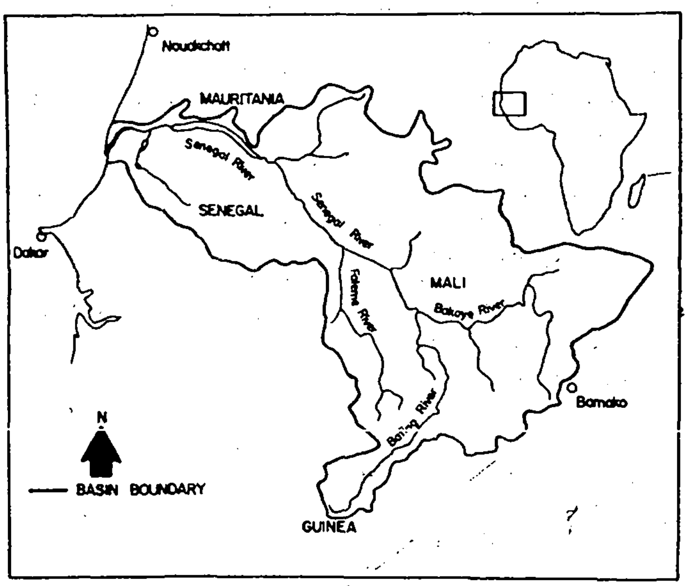

Figure 1. Map of the Senegal River Basin.

During the initial visit to each well, a questionnaire based on visual observations and information provided by the local people was filled out. The purpose was to characterize open hand dug wells and thereby provide baseline data. Physical characteristics, age, susceptibility to flooding, land use, proximity to livestock, means of water withdrawal, population served, and comments concerning water quality were recorded. Water samples were taken for analysis.

Nitrate Analysis

Immediately after collection, well water samples were acidified to pH 2 using concentrated sulfuric acid. Nitrate was later determined by specific ion analysis using an Orion Model 701A digital millivolt meter at the project laboratory in Dakar, Senegal.

RESULTS AND DISCUSSION

Nitrate data were collected for 34 open hand dug wells. Of these 34 wells, 18 evidenced nitrate concentrations greater than the WHO limit (45 mg/l as nitrate) at least once. Of 23 wells sampled two or more times six wells were consistently above this limit. Results of the survey are summarized in Figure 2. A frequency distribution of these results is presented in Figure 3.

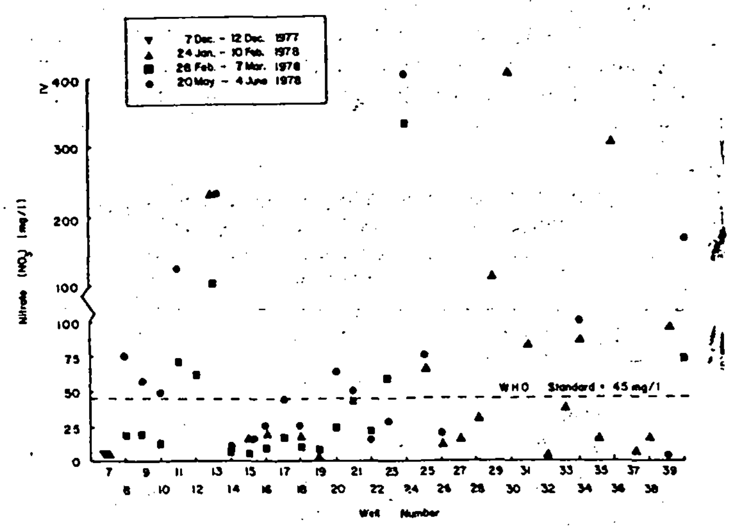

Figure 2. Nitrate Results.

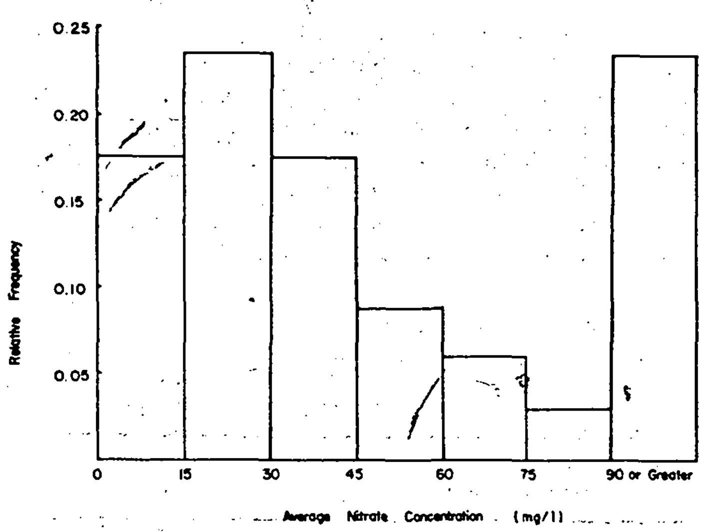

Figure 3. Nitrate Frequency Distribution.

The physical construction of wells varies considerably. The majority are cement lined with the liner extending above the ground surface. Most lined wells have an above ground apron to reduce local puddling and were usually constructed with some government assistance. Unlined wells were usually built without an above ground extension. They are generally shallow and hand dug by the local people. Most wells are between 8 and 15 meters deep but well depth ranges from 3.5 to 55 meters. Age varied from 8 weeks to 47 years.

Survey results were tabulated and 2x2 contingency tables were developed. Chi-square analysis of these tables tests the independence of factors by comparing observed with theoretical frequencies. If the null hypothesis (the factors are independent) is disproved, then there is reason to believe that the factors are related (Box, *et al.*, 1978).

Table 1 contains the results of the chi-square analysis and indicates no strong association (significance: $p<0.01$) of high nitrate well waters with the physical and environmental factors.

TABLE 1. Results of the Chi-Square Association Test for Nitrate Concentrations Greater Than 45 mg/l.

Factor	Chi-Square	Probability
Depth ⩾10 Meters	7×10^{-3}	0.93
Age >10 Years	0.13	0.72
Age >5 Years	0.14	0.71
Lining	0.95	0.32
Extension	1.00	0.30
Apron	0.19	0.66
No Flooding	4.71	0.03
Livestock	0.10	0.75

NOTE: Probability is based on one degree of freedom and represents the probability that the factor is not related to excessive nitrate concentration.

Flooding was inversely associated with nitrate contamination ($p<0.03$). Table 2 is a contingency matrix for flooding. Sixteen of the eighteen wells with high (greater than 45 mg/l) nitrate concentrations were in areas that never flooded. This suggests that flooding lowers nitrate concentrations. Recharge of the water table is predominantly due to direct infiltration during the wet season and therefore may flush nitrate which had accumulated during the dry season.

TABLE 2. Nitrate Contamination Compared With Flooding.

	Nitrate ⩽45 mg/l	Nitrate >45 mg/l
Floods	8	2
Does Not Flood	8	16

Further data analysis indicates that liners do not necessarily protect wells from contamination. The two contaminated wells in areas which flood had liners. Of the eight uncontaminated wells in areas which flood, four had liners, four did not. Fourteen of the eighteen wells with high nitrate concentrations in areas which do not flood had liners. Therefore the effect of flooding on nitrate concentration does not appear to be affected by the presence of a liner.

Liners are usually built because they give physical integrity to the well, provide safety to the diggers, and minimize contamination from polluted surface water (Wagner and Lanoix, 1959); however they do not appear to protect wells from nitrate contamination. A contingency table for liners is included (Table 3).

TABLE 3. Nitrate Contamination Compared With Well Liners.

	Nitrate ⩽45 mg/l	Nitrate >45 mg/l
Lined	10	14
Not Lined	6	4

It is apparent that factors other than the physical structure or the susceptibility of the area to flooding are responsible for nitrate contamination. Previous workers (George and Hastings, 1951; Williamson and Peterson, 1951; Feth, 1966; Brooks and Cech, 1979) have suggested that nitrate contamination was primarily a problem with shallow wells. Williamson and Peterson (1951), however, found that well depth did not correlate with nitrate concentration in shallow wells. Our results indicate that a weak relationship ($p<0.07$) exists between nitrate contamination and the shallow (⩽ 10 meters) wells. Figure 4 is a plot of depth versus nitrate concentration. The inverse relationship between well depth and nitrates for wells in the Senegal River basin is weak and not unexpected in view of the semiarid conditions.

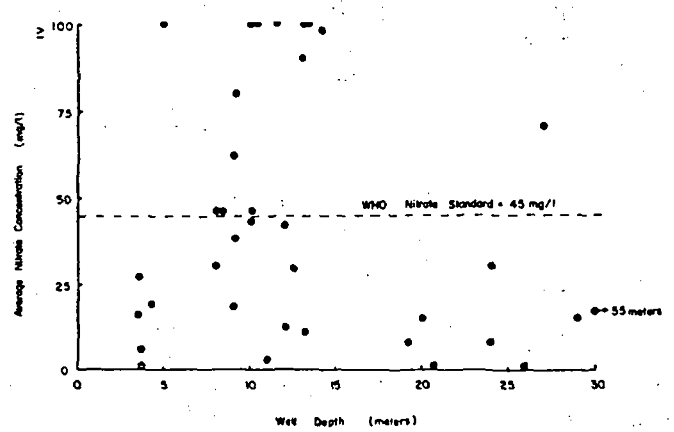

Figure 4. Average Nitrate Concentration as a Function of Well Depth.

Taylor and Bigbee (1973) suggested that in areas of high animal density and low infiltration of water (semiarid regions) the incidence of nitrate contamination is low. This is consistent with our survey results in that the presence of livestock did not appear to affect nitrate concentration. Studies in temperate climates have shown that livestock concentrations can result in nitrate contamination of wells (Gillham and Webber, 1969; Stewart, *et al.*, 1967; Walker, 1969).

An important factor to consider is that all the surveyed wells are open with no covers. If contamination is primarily caused by foreign matter entering the well mouth, the fact that these wells are not covered may be of such importance that the previously considered factors are of minor relative importance. We believe this to be the case. An examination of the nitrate data indicates that with only two exceptions wells in the Senegal River basin are contaminated with varying amounts of nitrate. Although the results of this survey do not conclusively prove nitrate contamination to be the result of the wells being open, our results support this interpretation.

CONCLUSIONS

Nitrate contamination appears to be associated neither with physical characteristics or age of the well nor with the proximity of livestock; however, it is inversely associated with flooding and does appear to increase from the wet to the dry season. While no final conclusion can be drawn, it is apparent that rural well programs in developing countries should emphasize the value of both permanently covering hand-dug wells and encourage the construction of bored wells where appropriate.

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Fertilizer?