

Environmental impact on the bacteriological quality of domestic water supplies in Lagos, Nigeria

Impacto ambiental sobre a qualidade bacteriológica do abastecimento domiciliar de água em Lagos, Nigéria

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Keywords

Water supply, analysis. City planning. Water quality. *Escherichia coli*, isolation & purification. Water analysis. Environmental impact. Basic sanitation. Rain. Water pollution.

Abstract

Objective

To assess the impact of town planning, infrastructure, sanitation and rainfall on the bacteriological quality of domestic water supplies.

Methods

Water samples obtained from deep and shallow wells, boreholes and public taps were cultured to determine the most probable number of *Escherichia coli* and total coliform using the multiple tube technique. Presence of enteric pathogens was detected using selective and differential media. Samples were collected during both periods of heavy and low rainfall and from municipalities that are unique with respect to infrastructure planning, town planning and sanitation.

Results

Contamination of treated and pipe distributed water was related with distance of the collection point from a utility station. Faults in pipelines increased the rate of contamination ($p < 0.5$) and this occurred mostly in densely populated areas with dilapidated infrastructure. Wastewater from drains was the main source of contamination of pipe-borne water. Shallow wells were more contaminated than deep wells and boreholes and contamination was higher during period of heavy rainfall ($p < 0.05$). *E. coli* and enteric pathogens were isolated from contaminated supplies.

Conclusions

Poor town planning, dilapidated infrastructure and indiscriminate siting of wells and boreholes contributed to the low bacteriological quality of domestic water supplies. Rainfall accentuated the impact.

Descritores

Abastecimento de água, análise. Planejamento de cidades. Qualidade da água. Escherichia coli, isolamento. Análise da água. Impacto ambiental. Saneamento básico. Chuvas. Poluição da água.

Resumo

Objetivo

Avaliar o impacto do planejamento urbano, da infra-estrutura, do saneamento e dos índices pluviométricos sobre a qualidade bacteriológica do abastecimento domiciliar de água.

Métodos

Foi realizada cultura de amostras de água obtida de poços superficiais e profundos, fossos e água corrente de bicas públicas para determinar o número mais provável de Escherichia coli e coliformes totais por meio da técnica de múltiplos tubos. Patógenos entéricos foram detectados pelo uso de meios diferenciais e seletivos. Amostras

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foram coletadas durante os períodos de seca e de chuvas intensas em municípios com características singulares de infra-estrutura, planejamento urbano e saneamento.

Resultados

A contaminação de água tratada ou encanada esteve relacionada à distância do ponto de coleta com relação à estação de tratamento. Defeitos na canalização aumentaram o índice de contaminação ($p < 0,5$), principalmente em áreas densamente povoadas com infra-estrutura arruinada. Os despejos de bueiros representaram a principal fonte de contaminação da água encanada. Houve maior contaminação em poços superficiais do que em fossos e durante os períodos de chuvas intensas ($p < 0,05$). E. coli e outros patógenos entéricos foram isolados de fontes de abastecimento contaminadas.

Conclusões

A falta de planejamento urbano, as más condições de infra-estrutura e a localização indiscriminada de poços e fossos contribuíram para a baixa qualidade bacteriológica do abastecimento domiciliar de água. As águas das chuvas agravaram o impacto.

INTRODUCTION

Water remains the major source of transmission of enteric pathogens in developing countries. Notified cases are mostly in children especially those under 5 years of age¹⁶ in whom gastroenteritis usually manifests as acute diarrhea and often may require hospitalization. The conditions are usually less severe in adults and may resolve without serious medical attention. In Nigeria, there is a high incidence of childhood diarrhea despite the intensive activities of the National Diarrhea Control Program. This is due to the unavailability of potable water especially in rural communities, and mothers usually obtain water from unhygienic sources for preparing weaning foods. Babaniyi⁴ (1991) in reviewing the prevalence of diarrhea in Nigerian children over a period of 9 to 12 years observed that 315,000 children under the age of 5 years died annually from this disease condition. Also, children within this age range (0-5 years) are reported to experience on average 4.3 episodes of diarrhea annually.¹⁶ Studies across the country have shown that viruses, bacteria, protozoa, and helminthes are variously responsible for diarrhea diseases in children.^{1,10,15} In one study, bacteria caused 48.6% of the diarrhea cases, 30.6% were caused by viruses, 8.2% by enteric parasites (protozoa and helminthes), and 6.9% were of dual etiology.¹

Supply of treated pipe-borne water in Lagos, a densely populated state, is erratic with acute shortage experienced mostly in the dry months. In Nigeria, water pipes are laid underground and most of them are decaying due to lack of maintenance. Moreover, most of them run through drainage system increasing the chance of contamination. During periods of water shortage, people buy water of doubtful source from vendors. Others resort to borehole or well for water.

Considering the ever-increasing population of Lagos, it has become paramount to investigate the impact of environmental factors on the bacteriological quality of domestic water supplies.

METHODS

Demography of municipal areas studied

Lagos is a highly urbanized state with a population of 5,725,116 people by the 1991 national census figures.²³ It is referred to as the commercial nerve centre of Nigeria. Its unique location brings it in close proximity to many West Africa countries for easy flow of commerce. Its accessible sea route makes Lagos one of the busiest seaports along the West Africa coast. The bustling commercial activities of this State coupled with the notion that Nigeria's wealth is located in Lagos remain a stimulus for the constant influx of people from neighboring states especially of rural areas. The resultant effect is that the State with its limited land space can no longer provide adequate infrastructure to meet the teeming demand of over population. Where they are available, their life span is short due to vandalism. Other noticeable problems in Lagos especially in the densely populated areas inhabited by peasants and low-income earners are the absence of rational town planning and the lack of maintenance of existing infrastructure. However, there are urbane areas as in other States or countries.

For ease of description, Lagos State is divided into two main ecological regions: island and mainland. The island is encompassed by Lagos lagoon and some areas do experience seasonal flooding due to high waters. Though above sea the mainland level receives its water supply from the lagoon through rivers, creeks and canals. The three municipalities

studied are located in the mainland area though Apapa is located close to the lagoon (Figure 1). The populations of the three municipalities Apapa, Mushin and Surulere were 155,019, 539,783, and 589,947, respectively.²³

Though the three municipalities share a number of features, there are certain distinctive differences. Mushin is basically residential and highly overcrowded. Trading is the main occupation, followed by carpentry, woodwork factories, and mechanic workshops. The area is generally filthy and refuse heaps are commonly seen sometimes even covering part of the motorway. Drainage systems are blocked - an eyesore as they have been covered with domestic and industrial wastes. Surprisingly, pipelines supplying water to homes and public taps run along or across the drainage systems. Apart from pipe-borne water supply, residents also obtain water for domestic use from wells and boreholes. Surulere is a low-density area with good structural and architectural planning. Medium scale business such as fast food centers, boutiques, and government offices characterize this area. Except for a few communities the locality can be described as clean. Apapa is mainly an industrial area. A long stretch of road or street may harbor just a handful of residential quarters. Drainage systems in this area are usually wide and deep. Pipe-borne water is the major source of water to this community, wells

and boreholes are not common as their water is salty and unsuitable for domestic use.

Sampling

Water was collected from three sources: treated pipe-borne distribution system, wells and boreholes. Also, wastewater was collected from drainage system through which burst water pipelines run. The classification of wells was based on depth, (i) for deep and (ii) for shallow. A well was classified as deep if it is difficult to draw water out of it with a cord 10 meters long even after heavy rainfall, and as shallow if there is considerable upwelling after heavy rainfall. Wells were also grouped into A, B and C based on the quality of the well and its location. Class A wells have high concrete elevation (0.3 to 0.5 meters) above ground level with covers made of corrugated iron sheets. The catchment's area is cemented and the wells are not located near a refuse dump or septic pits. Class B wells are similar to Class A in design but their catchments have no cemented pavement. Class C wells have high elevation concrete walls but no covering lid. Their catchments are not cemented and their locations are usually within 3 meters to a refuse heap or septic pit. Certified chlorinated waters were collected from water utility stations (waterworks), public taps and taps supplying homes. Collection points for pipe-borne water were determined based on the absence or presence of leaks in pipelines supplying such locations.

Water samples were collected from 20 boreholes and 30 wells servicing private homes and small communities from November 1998 to October 1999. The 30 wells were sub-grouped into classes Ai, Aii, Bi, Bii, Ci and Cii, each class containing 5 wells. Water samples were collected every fortnight from each source. Thus, 12 samples were collected per source from November to April (the dry season) and from May to October (the wet season). Water samples were collected into sterile bottles in 250 ml amounts and processed within 2 hours of collection. For treated pipe-borne water, samples were collected weekly per point for one year. The distance of each collection point from a feeder utility station was determined and categorized as within 500 meters to it or beyond. Wastewater was collected on every sampling day from drainage at points where there is a leak in pipeline. Heat sterilized bottles containing a sufficient volume of sodium thiosulphate (0.1 ml of 1.8 g/100 ml sample) to neutralize the bactericidal effect of residual chlorine was used to collect water from a chlorinated supply. The mouths of taps and hydrants were flamed to prevent environmental contamination. After col-

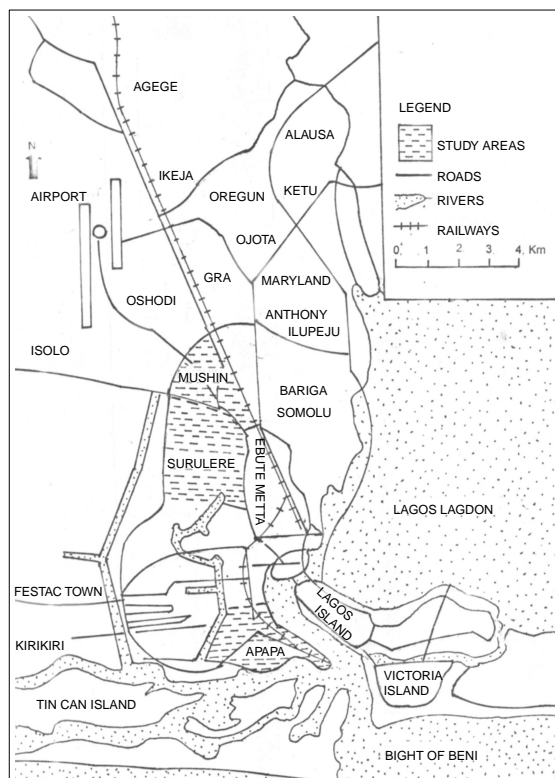


Figure 1 - A maps of Lagos State.

lection, the bottles were stoppered and labeled with full details concerning source, time and date of collection. The samples were kept in coolers packed with ice and transported to the laboratory within 2 hours and protected from light.

Bacteriological analysis

MacConkey broth was used to determine the most probable number of *Escherichia coli* and other coliforms in 100 ml of sample water using the multiple tube technique. Presumptively positive tubes were subcultured on eosin methylene blue agar and observed for black colonies with metallic green sheen. Selective isolation of some enteric pathogens was attempted. Deoxycholate citrate agar was used for isolating *Salmonella* and *Shigella* species, ampicillin-dextrin agar for the isolation of *Aeromonas hydrophila*²⁴ and thiosulphate citrate bile-salt sucrose agar for the isolation of *Vibrio spp.* Butzler-type medium (made up of blood agar base, 5% lysed defibrinated horse blood and bacitracin 12,500 IU, cycloheximide 25 mg, colistin sulphate 5,000 IU, cephalosporin sodium 7.5 mg, novobiocin 2.5 mg) and Bolton medium (which contains the following antibiotics: vancomycin 20 mg, cefoperazone 20 mg and cycloheximide 50 mg in 1000 ml preparation) were used for the selective isolation of campylobacters.^{6,8} Inoculated broth and agar media were incubated at appropriate temperatures (range: 37°C to 42°C) and room temperatures. Bolton and Butzler-type media were incubated at 42°C in 10% CO₂ for 72-96 hours. Isolated bacteria were identified by conventional morphological and biochemical test methods.¹¹

Statistical analysis

Data presented in Tables 1 and 3 were analyzed using Chi-square contingency table methods. Accordingly, the associations between rainfall and the

bacteriological quality of pipe-borne water and underground water were evaluated. The impact of breaks in pipelines and their locations near municipal drain system on the bacteriological quality of pipe-borne water was also determined using Chi-square tests.

RESULTS

Chlorinated pipe-borne water samples obtained from water utility stations in the three municipalities contained no coliforms per 100 ml. The results obtained revealed that the farther a feeder point is from a utility station the greater the chances of contamination. Fault in pipelines increased the rate of contamination (p < 0.5). Samples collected from points of leak were more frequently contaminated with *E. coli* or other coliforms than those collected some distance away. The farther the collection point is from the leak the lesser the chances of isolating coliforms. Wastewater from drains was found to contain coliforms and intermittently *E. coli*; and was the source of contamination of faulty pipelines that run across it (p < 0.05). The proportion of samples yielding coliforms during wet months though higher than in dry months do not reveal any strong association between rainfall and the bacteriological quality of pipe-borne water (p > 0.05) (Tables 1 and 2).

Table 2 - Significance testing using chi-square (X²) to determine the effect of rainfall and fault in pipeline on the bacteriological quality of pipe-borne water on one hand and the possibility that contamination of water pipeline originated from drainage water on the other hand.

Bacteriological quality	Mushin	Surulere	Apapa
Rainfall ^a	0.43	7.66	0.96
Faulty pipeline ^b	1.99*		
Drainage system ^b			
water quality at point of leak	5.10**		
water quality some 500m away	0.16		

Degree of freedom (a) = 5;

Degree of freedom (b) = 1.

*Strong correlation (P < 0.5);

**Strong correlation (P < 0.05).

Table 1 - Bacteriological quality of treated pipe-borne water at utility stations and consumer points in three municipal areas in Lagos, Nigeria.

Collection point	Number of samples with coliform (<i>E. coli</i>) per 100 ml of water					
	Mushin		Surulere		Apapa	
	Dry months*	Wet months**	Dry months	Wet months	Dry months	Wet months
Intact pipeline						
within water works	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
PT/homes within 500 m	2 (0)	2 (0)	0 (0)	0 (0)	0 (0)	0 (0)
PT/homes beyond 500 m	5 (2)	5 (1)	1 (0)	2 (1)	0 (0)	2 (0)
Burst pipeline						
point of leakage	19 (8)	22 (12)	11 (5)	13 (7)	10 (4)	11 (4)
drainage supply	24 (10)	24 (13)	24 (8)	24 (9)	24 (7)	24 (9)
PT/homes within 500 m	8 (3)	10 (5)	4 (1)	5 (3)	3 (0)	5 (1)
PT/homes beyond 500 m	5 (2)	9 (3)	2 (1)	5 (1)	2 (0)	3 (0)

*The months November to April represent the dry months i.e. period of little or no rainfall;

**The months May to October represent the wet months i.e. period of heavy rainfall;

PT = Public tap located at strategic areas servicing inhabitants of one or more streets;

Sample size: a total of 24 samples were collected per point per season (i.e. 6 months) per location.

Table 3 - Seasonal influence on the bacteriological quality of borehole and well waters.

Water type	Number Studied (samples) positive for coliform	Sampling Sample* size	Dry Months		Wet Months	
			Number of borehole or well (samples) positive for coliform	Mean coliform counts/100ml	Number of borehole or well	Mean coliform counts/100ml
Borehole	20	240	0 (0)	0	2 (24)	8
Well water						
Class Ai	5	60	0 (0)	0	0 (0)	0
Class Aii	5	60	0 (0)	0	1 (12)	20
Class Bi	5	60	1 (12)	10	1 (12)	18
Class Bii	5	60	1 (12)	15	2 (24)	36
Class Ci	5	60	2 (24)	48	3 (48)	64
Class Cii	5	60	3 (36)	52	5 (60)	72

*Represents the number of samples collected per season.
i = Deep well; ii = Shallow wells.

Table 4 - Significance testing using chi -square (X²) to determine the effect of rainfall on the bacteriological quality of underground water.

	Wells/borehole ⁿ	Samples
X ²		
Calculated	1.97	22.00*
Tabulated	12.59	12.59

Degree of freedom = 6.

N = sum of well and borehole = 50.

n_i = sample size = 1,200.

*Strong correlation (P<0.05).

All 240 water samples collected from 20 boreholes during the period of little or no rainfall were free from coliforms. However, two of these boreholes were consistently positive for coliform bacteria in the months of heavy rainfall. Class C wells with defective architectural designs and located near refuse and septic tanks were more prone to contamination and yielded higher growth of coliforms. For all classes of wells, the shallow ones were at higher risk of contamination (Table 3). The bacteriological quality of underground water was strongly correlated with rainfall (p<0.05) (Table 4).

Figure 2 and Table 3 show the incidence of six enteric pathogens in the three sources of domestic water and wastewater. *Vibrio spp.* was not isolated from any of the domestic water supplies during dry months but it was isolated from a well in Class Cii during rainy season that was consistently positive for fecal coliforms. Pathogens isolated from well water in all seasons were in order of occurrence: *Aeromonas hydrophila*, *E. coli*, *Salmonella spp.*, *Shigella spp.*, and *Campylobacter spp.* Pipe-borne and borehole waters were free from *Campylobacter spp.* in all seasons but seen occasionally in well water. All six enteric pathogens were isolated from wastewater obtained from drainage system. *Escherichia coli*, *A. hydrophila*, and *Salmonella spp.* occurred more frequently in water bodies. Borehole waters were free from enteric pathogens during the dry season but occasional contamination with *E. coli*, *A. hydrophila*, and *Salmonella spp.* was observed during the rainy season.

DISCUSSION

Treated water ready for distribution at each utility station was of excellent quality. Where pipelines are intact, this quality was maintained for a distance of about 500 meters beyond which occasional contamination with coliforms was observed. At Mushin, a highly overcrowded residential area, contamination with fecal coliforms was evident a few meters away from the utility station. More consumer points were contaminated farther along the distribution line. This finding suggests the presence of faults in pipelines, which were not yet evident. Leaks of this nature that are sequestered may represent a major health risk.^{7,19} Therefore, routine checks on water distribution network should be incorporated to the operational programs for supplying potable water to consumers.

Faults in pipeline, probably resulting from illegal tapping into distribution system and pipes aging, along with their location near or across a drainage system were strongly correlated with the high level contamination of pipe-borne water supplies (p<0.05). Though broken pipes facilitated contamination, the degree of such contamination was magnified where the breach on the pipes occurred in highly polluted area as a waste drain. In contrast to observations for pipelines with no detectable faults, it was found that as the distance from the source of contamination increased the chances of recovering *E. coli* or other coliforms from the water supply decreased. This may

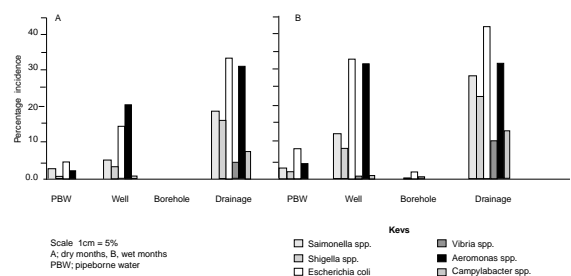


Figure 2 - Incidence of enteric pathogens in municipal drain water and public water supplies.

be the case only where there is a single leakage along the distribution line. The results presented in Table 1 show a slight increase in the level of contamination of pipe-borne water during rainfall. Yet this difference was not statistically significant ($p > 0.05$). While rainfall may not singularly influence the bacteriological quality of pipe-borne supply, it may play a contributory role in dirty localities with decaying distribution pipelines.

Rainfall was an important factor for the bacteriological quality of underground water ($p < 0.05$). For example, water samples obtained from two of the 20 boreholes were consistently positive for coliforms after heavy rainfall. Since these same boreholes were free from coliform contamination before rainfall, they might be located near a septic pit or sewage outlet from which occurs seepage after rainfall. Stukel et al²⁷ (1990) have associated increase rainfall with the preponderance of *Pseudomonas aeruginosa*, *A. hydrophila*, coliform bacteria, and heterotrophic mesophilic bacteria in underground water. Still Nola et al²⁴ (2000) in studying the influence of hydrological, physical and meteorological factors on microbial dynamics in well water in Yaounde, Cameroon, observed that increase in water column thickness was inversely proportional to the amount of isolated bacteria. Their finding was ascribed to the dilution phenomenon. Acknowledging this phenomenon, it is important to analyze several samples collected after rainfall using methods that allow the use of large volumes of water. This approach may help overcome the dilution effect, which may mistakenly suggest absence of enteric bacteria contamination. A number of factors actually may be responsible for underground water rainfall contamination (Table 3) accentuating the effect. Shallow wells were more prone to contamination and the degree of contamination was influenced by prevailing physical and hydrological factors as previously discussed.^{22,24} Some researchers have questioned the validity of the coliform test for assessing the potability of drinking water. They argued that apart from *Escherichia*, the other genera (*Klebsiella*, *Enterobacter*, *Serratia*, and *Citrobacter*) comprising the coliform group are widely found in the environment and are not associated with fecal contamination.^{12,13} Though this is quite sound, it should not suggest a discontinuation of the total coliform test. The presence of coliforms other than *E. coli* in treated and pipe distributed water may indicate either fault along the distribution system providing access to contamination or low disinfectant concentration and sufficient build up of assimilable organic compounds promoting re-growth.^{19,20} Thus, while total coliform test on its own may not be conclusive,

its low cost and simple methodology renders it a screening test for impending health hazard. When coliforms are found in water, detailed investigations should be carried out to detect the presence of *E. coli* or pathogens.

Six genera of enteric pathogens were isolated from domestic water supplies and their occurrences varied according to water source and rainfall. As mentioned before, rainfall influenced the bacteriological quality of underground water but not necessarily pipe-borne supply. All six bacteria genera were seen in both seasons of the year in municipal drainage wastewater, and may be the source of contamination of underground water and decaying distribution systems. Borehole waters showed the highest bacteriological quality. It is evident because they supply private homes or small communities, and are therefore well protected especially from vandalism. *Escherichia coli* and *Aeromonas hydrophila* were the two frequently isolated pathogens and occurred where and when other pathogens were absent. The frequent presence of *E. coli* in polluted water supplies even when other pathogens were not isolated justified its use as a biological indicator of drinking water contamination.¹⁴

The presence of *E. coli* in water does not only indicate contamination of fecal origin but it is in itself a major health concern. For example, verocytotoxin-producing *E. coli* (VTEC) serogroup O157, a major cause of hemorrhagic colitis, is acquired predominantly through the waterborne route.^{9,17} Le Chevallier et al¹⁸ (1982) reported the survival of *Aeromonas sobria* in chlorinated drinking water. Together with the preponderance of hydrophila in domestic water supplies in our environment they showed that *Aeromonas spp.* is increasingly becoming a major contaminant of water bodies.

Vibrios and campylobacters were occasionally isolated from well water. The few wells contaminated with these organisms are located in highly populated slums characterized by overcrowding, poor sanitation and absence of pipe-borne water. The inhabitants of these areas rely mainly on well water for drinking and other domestic activities. It is quite evident that this finding signals a possible outbreak of cholera and/or campylobacter epidemics in the affected areas. Cholera outbreak due to *Vibrio cholerae* O1 El Tor, serotype Ogawa was reported in Kampala, Uganda, and slum areas were mostly affected.²¹ The fact that overcrowding and poor sanitary habits may predispose to underground water contamination was validated by the frequency with which all enteric pathogens were isolated from wastewater in this study. In-

discriminate dumping of feces and domestic waste is a common practice in overcrowded urban areas where toilet facilities are grossly inadequate.

There is no notification or surveillance system for *Salmonella* and *Shigella* in Nigeria. However, individual studies and laboratory records in many specialized hospitals revealed that typhoid fever and bacillary dysentery are endemic in Nigeria.^{2,5,25} Adding up to this problem is the emergence of *Salmonella* strains resistant to chloramphenicol and cotrimoxazole,^{2,26} two antibiotics routinely prescribed for the treatment of typhoid fever. Multiple antibiotic resistant strains of *Shigella flexneri* and *S. dysenteriae* were recently reported in Ethiopia.³ Therefore the presence of *Salmonella* and *Shigella* species in domestic water supply systems is of public health concern. These enteric pathogens together with others reported may be present in water intermittently following contamination with human or animal feces. They may also be present in slight number or state making their detection by conventional methods dif-

ficult. Thus, the total and fecal coliform tests become significant as predictive test values for assessing the bacteriological quality of drinking water.

In conclusion, the present study was carried out because of increasing concern on the quality of drinking water in Lagos, Nigeria. The results reported have clearly showed the depleted state of the water distribution network system. Alternative sources of drinking water were equally exposed to contamination with enteric pathogens. Poor town planning, overcrowding, unhygienic environment, aged and faulty pipelines were identified as man-associated factors predisposing to contamination of domestic water supplies. The establishment of mini-utility stations to decentralize the duties of a parent body will ensure effective monitoring and maintenance of distribution lines. In addition, a clean environment established through provision of adequate infrastructure for disposal of refuse and feces will reduce the level and frequency of contamination of water supply systems.

REFERENCES

1. Alabi SA, Audu RA, Oyediji KS, Mafe AG, Uhuangho JE. Viral, bacterial and parasitic agents associated with infantile diarrhea in Lagos. *Nig J Med Res* 1998;2(1/2):29-32.
2. Animashaun T, Odugbemi T. Observation on *in-vitro* activities of chloramphenicol, co-trimoxazole and ofloxacin against *Salmonella*. *Nig Med Pract* 1991;21(3/4):37-8.
3. Aseffa A, Gedlu E, Asmelash T. Antibiotic resistance of prevalent *Salmonella* and *Shigella* strains in northwest Ethiopia. *East Afr Med J* 1997;74:708-13.
4. Babaniyi OA. Oral rehydration of children with diarrhea in Nigeria: 9-12 years review of impact on morbidity and mortality from diarrhea diseases and diarrhea treatment practices. *J Trop Pediatr* 1991;37:57-66.
5. Boomsma LJ. Clinical aspects of typhoid fever in two rural Nigerian hospitals; a prospective study. *Trop Geogr Med* 1988;40:97-102.
6. Bolton FJ, Dawkins HC, Hutchinson DN. Biotypes and serotypes of thermophilic campylobacters isolated from cattle, sheep and pig offal and other red meats. *J Hyg (Lond)* 1985;95:1-6.
7. Brewer WS, Lucas J. Examination of probable causes of individual water supply contamination. *J Environ Health* 1982;44:305-7.
8. Butzler JP, Dekeyser P, Detrain M, Dehaen F. Related vibrio in stools. *J Pediatr* 1973;82:493-5.
9. Chalmers RM, Aird H, Bolton FJ. Waterborne *Escherichia coli* 0157. *J Appl Microbiol* 2000;88(S):124-32.
10. Coker AO, Dosunmu-Ogunbi O. Isolation of *Campylobacter jejuni* in Lagos, Nigeria: a new bacteria agent of diarrhea. *East Afr Med J* 1984;60:50-5.
11. Cowan ST, Steel KJ, editors. *Manual for identification of medical bacteria*. 2nd ed. London: Cambridge University Press; 1974.
12. Edberg SC, Allen MJ, Smith DB. National field evaluation of a defined substrate method for the simultaneous enumeration of total coliforms and *Escherichia coli* from drinking water: comparison with the standard multiple tube fermentation method. *Appl Environ Microbiol* 1988;54:1595-601.
13. Edberg SC, Patterson JE, Smith DB. Differentiation of distribution systems, source water, and clinical coliforms by DNA analysis. *J Clin Microbiol* 1994;32:139-42.
14. Edberg SC, Rice EW, Karlin RJ, Allen MJ. *Escherichia coli*: the best biological drinking water indicator for public health protection. *J Appl Microbiol* 2000;88(S):106-16.
15. Fagbenro-Beyioku FA, Oyerinde JPO. Parasitic intestinal infections of children in Lagos. *Nig J Pediatr* 1987;14(3/4):89-95.

16. Federal Ministry of Health of Nigeria. WHO/UNICEF/USAID/CCCD. *Lagos: Nigerian Control of Diarrhea Diseases Programme, 1991-1995*. Lagos: Federal Ministry of Health; 1991.
17. Isaacson M, Canter PH, Effler P, Arntzen L, Bomans P, Heenan R. Haemorrhagic colitis epidemic in Africa. *Lancet* 1993;341:961.
18. LeChevallier MW, Evans TM, Seidler RJ, Daily OP, Merrell BR, Rollins DM et al. *Aeromonas sobria* in chlorinated drinking water supplies. *Microbial Ecol* 1982;8:325-33.
19. LeChevallier MW, McFeters GA. Microbiology of activated carbon. In: LeChevallier NW, McFeters GA. *Drinking water microbiology*. New York: Springer-Verlag; 1990.
20. LeChevallier MW, Welch NJ, Smith DB. Full-scale studies of factors related to coliform re-growth in drinking water. *Appl Environ Microbiol* 1996;62:2201-11.
21. Legros D, McCormick M, Mugeru C, Skinnider M, Bek'obita DD, Okware SI. Epidemiology of cholera outbreak in Kampala Uganda. *East Afr Med J* 2000;77:347-9.
22. Mutch RD, Scott JJ, Wilson DJ. Cleanup of fractured rock aquifer: implications of matrix diffusion. *Environ Monit Assess* 1992:1-26.
23. National Population Commission. Population census 1991: final figures of Lagos State. *Fed Republ Nigeria Off Gaz* 1997;84(25):285.
24. Nola M, Njine T, Djuikom E, Foko VS. Bacteria indicators dynamics in wells as influenced by well depth and well water column thickness, in Yaounde (Cameroon). *Afr J Sci Tech* 2000;1:82-91.
25. Onile BA, Odugbemi T. *Salmonella* serotypes in Ilorin, Nigeria. *West Afr J Med* 1987;6:7-10.
26. Onuigbo MAC. Typhoid fever epidemic in Nigeria? The abuse of widal test and the antibiotic chloramphenicol. *Nig Med Pract* 1989;18:23-5.
27. Stukel TA, Greenberg ER, Dain BJ, Reed FC, Jacobs NJ. A longitudinal study of rainfall and coliform contamination in small community drinking water supplies. *Environ Sci Technol* 1990;24:571-5.