Practical Paper

Use of geographic information system in the assessment of bacteriological quality and sanitary risk factors of household drinking water sources in Ibadan, Nigeria

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ABSTRACT

This study used a combination of Geographic Information System (GIS), bacteriological analysis and sanitary inspections to assess the risk of contamination of drinking water sources in 62 randomly selected households in Ibadan, Nigeria. Findings revealed that the majority of the households used groundwater sources of poor quality. The raw bacteriological data was classified into five water quality Grades A to E (from no risk to very high risk). Majority (82.3%) of the households were grouped as D and E, implying that a large proportion of the households was exposed to high bacterial load in their water supplies thus exposing these households to the risk of water-borne diseases. Results of sanitary inspection also showed that most (62.9%) households have intermediate/high risks associated with physical defects in the water supply facilities which could lead to quality deterioration. A weak positive correlation (Spearman's $r = 0.379$, $p = 0.02$) was observed between the *E. coli* and sanitary risk score grades. The study proposed urgent remedial action by all stakeholders and an extension of the study to cover the rural and urban local government areas in Ibadan.

Key words | drinking water sources, *E. coli*, GIS, households, Ibadan, risk score

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ABBREVIATIONS

E. coli	*Escherichia coli*
GIS	Geographic Information System
GPS	Geographic Positioning System
TC	Total coliform
UNICEF	United Nations Children's Fund
WHO	World Health Organisation
WSP-AF	Water and Sanitation program-Africa Region
HMSO	Her Majesty's Stationery Office

INTRODUCTION

Geographic Information System (GIS) is an analytical tool which combines integrated management, analysis and performance of spatial and tabular data (Reissman *et al.* 2001). It uses a location reference system such as longitude, latitude and altitude. GIS has been used widely in different studies: land use planning (Tong & Chen 2002; Stout & Lee 2004); watershed management (Lively & Czapar 2002); risk of lead exposure (Reissman *et al.* 2001); and ecological implications of Fulbe pastoralism (Omotayo 2003). However, spatial data to enable linking of water sources and quality to households are presently inadequate in many developing countries.

Safe drinking water is essential for health and socio-economic development of families, communities and nations (Ince & Shaw 1991). In many developing countries, household drinking water sourced from wells, springs and boreholes are always grossly contaminated by human or animal excreta (WHO 1996; Howard 2002). Bacteriological examination of drinking water sources and sanitary inspections are

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complementary; while the first detects and enumerates the number of faecal bacteria, the latter assesses the risk of contamination of the sources. The sanitary inspection data is useful for drawing conclusions about the status of the supply and the potential risks of contamination in the longer-term. It can also identify the type of interventions which may include hygiene education, simple repairs or construction work (Howard 2002). This study employed GIS as a tool for identifying households at risk. The results would be useful for decision makers on how to improve water quality and reduce public health risks associated with drinking water in third world countries.

MATERIALS AND METHODS

Study area

The study was conducted in Ibadan, an emerging mega-city in West Africa with a high concentration of urban slums. The estimated population of Ibadan was 1.5million (NPC 1991) but a recent census puts it at 1.34 million (Federal Republic of Nigeria 2007). The majority of the people are Yorubas while other ethnic groups constitute a smaller proportion of the population. Most of the people are engaged in petty trading and small-scale business, while others are civil/public servants.

Sanitary inspections

Multistage random and probability sampling techniques were used to select 62 household water sources from the urban local government areas in the study area. Sanitary inspection was performed at each household water source with the aid of a sanitary inspection checklist (adapted from Lloyd & Helmer 1991) in order to identify observable faults in the drinking water sources. Each observable fault was listed and each point was considered as a sanitary risk factor. The risk score was developed by giving the risk factors equal weighting. The number of risk points recorded for each household water source was summed up to give the sanitary risk score in the range of zero to ten (Lloyd & Helmer 1991). Hence, the higher the risk score, the greater the possibility of water being polluted.

Bacteriological analysis

Drinking water samples were collected during the rainy season (May–November, 2005) from the selected household water sources. All samples were stored in a cool box kept below 4°C and analysed within six hours. Total coliforms and *Escherichia coli (E. coli)* were used as indicator bacteria and enumeration was done using the MPN technique (HMSO 1994; *Standard Methods* 1995).

GIS mapping of household drinking water sources

Two field workers positioned the distance of the water sources to the households, latrines/septic tanks, with the aid of hand-held GPS. The coordinates (longitude and latitude) with the corresponding altitudes were recorded in a notebook and later transferred onto a Microsoft Excel spreadsheet.

Data analysis

Data was analysed using descriptive statistics such as frequency counts, percentages, standard deviation, range and geometric means. Association between faecal coliform and risk score grades was determined using Spearman's rho rank correlation. Spatial data was imported into ArcGIS 9.0 (ESRI), 2004 and converted to maps.

Since the majority of the water supplies were unchlorinated, it was inevitable that such sources would contain large numbers of coliform bacteria, which may have limited faecal significance. Thus, application of the WHO guideline of 0 *E. coli* $100\,ml^{-1}$ to ascertain quality of the drinking water sources may result in condemnation of the supplies used by a high percentage of the populace. Hence, the classification scheme used in Indonesia was adopted (Llyod & Helmer 1991). The scheme was used to quantify the risk associated with high levels of *E. coli* in the drinking water sources into: Grade A (0 *E. coli* $100\,ml^{-1}$)–no risk; B (1–10 *E. coli* $100\,ml^{-1}$)–low risk; C (11–100 *E. coli* $100\,ml^{-1}$)–intermediate/high risk; D (101–1,000 *E. coli* $100\,ml^{-1}$)–high risk and E (>1000 *E. coli* $100\,ml^{-1}$)–very high risk.

Also, the sanitary inspection risk score for each household drinking water source was classified according to the scheme used in Indonesia (Lloyd & Helmer 1991) into

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different levels of relative risk as follows: no risk (0), low (1–3), intermediate/high (4–6) and very high risk (7–10).

RESULTS AND DISCUSSION

Bacteriological quality and associated risk

The results of the bacteriological analysis expressed as the geometric means, standard deviation and ranges for Total coliform and *E. coli* counts are presented in Table 1. Values ranged from 14 to 2,950 Total coliform 100 ml^{-1}, and 7 to 2,480 *E. coli* 100 ml^{-1}. Most of the drinking water sources showed high level of faecal pollution. Of the 62 household sources analysed, only three (3) were of excellent quality (0 Total coliform 100 ml^{-1}and 0 *E. coli* 100 ml^{-1}).

The majority (77.4%) of the selected households used wells as their source of drinking water; the remaining 22.6% was shared between boreholes, taps and springs. Of all the sources, wells recorded the highest level of contamination with geometric means of 2480 *E. coli* 100 ml^{-1}, while borehole had the least, 7 *E. coli* 100 ml^{-1}. Detection of *E. coli* in the groundwater sources is an indication of recent and potentially dangerous faecal pollution which may be as a result of infiltration of runoff into the sources. These results corroborate those of Enabor *et al.* (1998) which concluded that most of the inhabitants in Ibadan relied on well water containing high coliform counts.

The classification of *E. coli* contamination of drinking water from the various sources and the associated risk is shown in Table 2. The base-map of Ibadan showing the bacterial quality of these sources based on this grading system is also shown in Figure 1. In all, only 6.4% of these sources were classified as Grade A (no risk to consumers), none in group B (low risk), 11.3% as Grade C (intermediate to high risk), while 82.3% were classified as Grades D and E (high to very high risk).

Households using tap (pipe-borne) water sources were equally exposed to risk of *E. coli* contamination. 50% had intermediate to high risk, while the remaining 50% had high risk. 40% of the boreholes used by selected households had no associated risk while 60% had intermediate to high risk. Only 33.3% of the springs used by selected households were potable with no associated risk, while the rest (66.7%) were grossly polluted (Grades D and E). Out of the 48 household wells, 46 (95.8%) were classified as Grades D and E. The

Table 1 | Geometric mean of coliform counts of water sources

Water sources	Total coliform 100 ml^{-1}	*E. coli* 100 ml^{-1}
Tap ($n = 6$)		
GM	110	110
SD	±2.6	±2.6
Min	26	26
Max	350	350
Borehole ($n = 5$)		
GM	14	7
SD	±5.0	±6.8
Min	0	0
Max	70	70
Spring ($n = 3$)		
GM	180	130
SD	±96.8	±67.3
Min	0.00	0
Max	5,400	2,400
Well ($n = 48$)		
GM	2950	2480
SD	±7.4	±7.9
Min	0	0
Max	350,000	350,000

GM: Geometric mean, SD: Standard deviation, MIN: Minimum, MAX: Maximum.

Table 2 | *E. coli* contamination of household drinking water sources

	Grade of *E. coli* contamination				
Source	Grade A	Grade B	Grade C	Grade D	Grade E
Tap	–		3	3	
	–		50.0%	50.0%	
Borehole	2		3		
	40.0%		60.0%		
Spring	1			1	1
	33.3%			33.3%	33.3%
Well	1		1	9	37
	2.1%		2.1%	18.7%	77.1%
Total	4		7	13	38
Percentage	6.4%		11.3%	21.0%	61.3%

Classification of risk associated with high levels of *E. coli* in the drinking water sources Grade A = 0 *E. coli* 100 ml^{-1}—no risk; Grade B = 1–10 *E. coli* 100 ml^{-1}—low risk; Grade C = 11–100 *E. coli* 100 ml^{-1}—intermediate/high; Grade D = 101–1000 *E. coli* 100 ml^{-1}—high risk; Grade E = >1000 *E. coli* 100 ml^{-1}—very high risk.

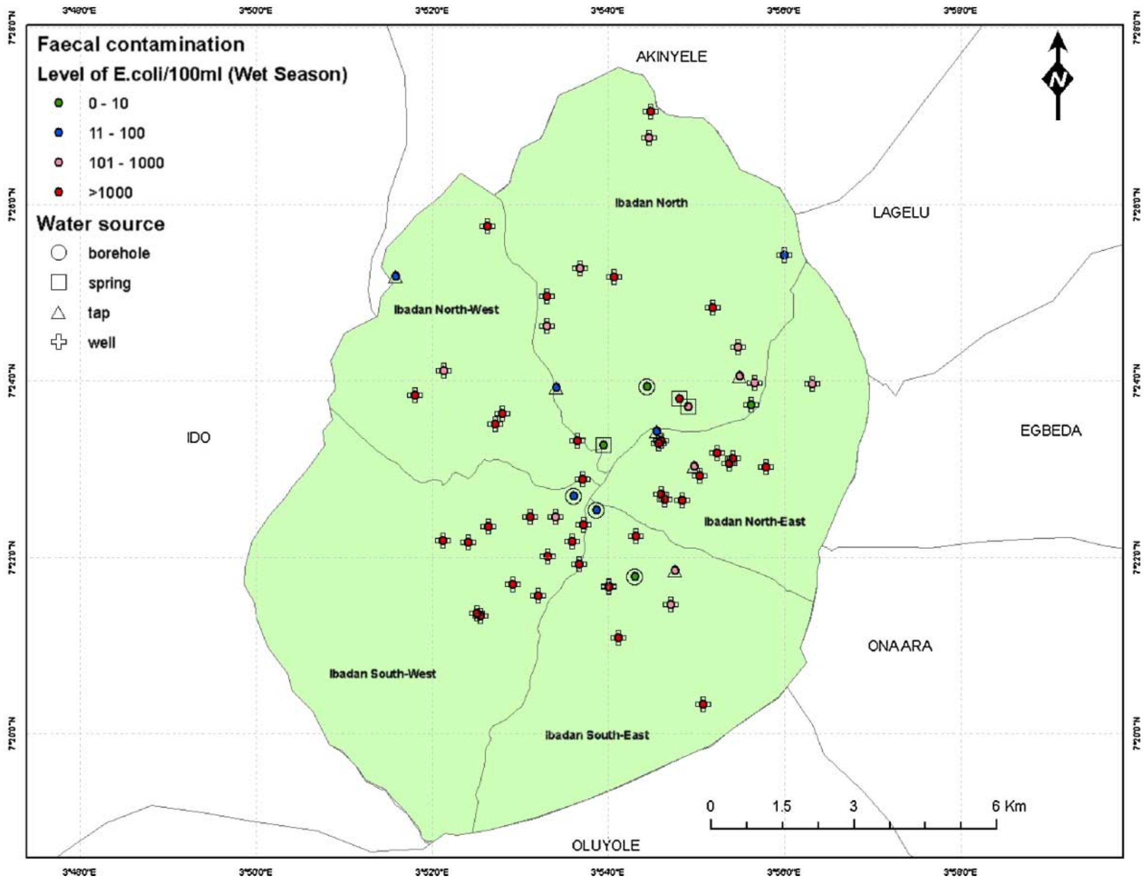

Figure 1 | *E. coli* contamination of drinking water sources in selected households in Ibadan.

implication of these results is that many of these households were exposed to high bacterial load in their water supplies, thus exposing them to high risk of acquiring water-borne diseases. Improvement in quality of these sources is required as this is in line with the revisions of the WHO guidelines for drinking water quality which place great emphasis on water quality protection and control from source to consumer in accordance with Water Safety Plan (WHO 2002).

Sanitary risks associated with physical defects in water supply systems

Most (62.9%) households had intermediate to very high risk associated with physical defects in their water supply facilities, 37.1% had low risk while none of the 62 water sources considered was without associated risk. This could be responsible for the high coliform load in the sources. This implies that the sources require urgent remedial actions such as well upgrading, leak detection and repair, and spring protection and maintenance by all stakeholders. Figure 2 shows the distribution of the sanitary risk scores for the selected household drinking water sources

Table 3 shows the risk factors identified for the different sources. A sizeable proportion of the underground water sources was not only close to pit latrines/septic tanks (wells 35.4%, borehole 20%), but also down–stream from them (wells 20.8%, borehole 20%, spring 66.7%). Many of the wells were not sanitary –inadequate lining (35.4%), cracks on aprons (68.8%) and other sources of contamination such as refuse dumps within two metres of the wells (62.5%). Egwari & Aboaba (2002) in their study of the impact of environmental factors on the bacteriological quality of domestic water supplies in Lagos concluded that poor town planning, overcrowding, aged and faulty pipelines, unhygienic environment, and indiscriminate sitting of wells and boreholes contributed to low bacteriological quality of

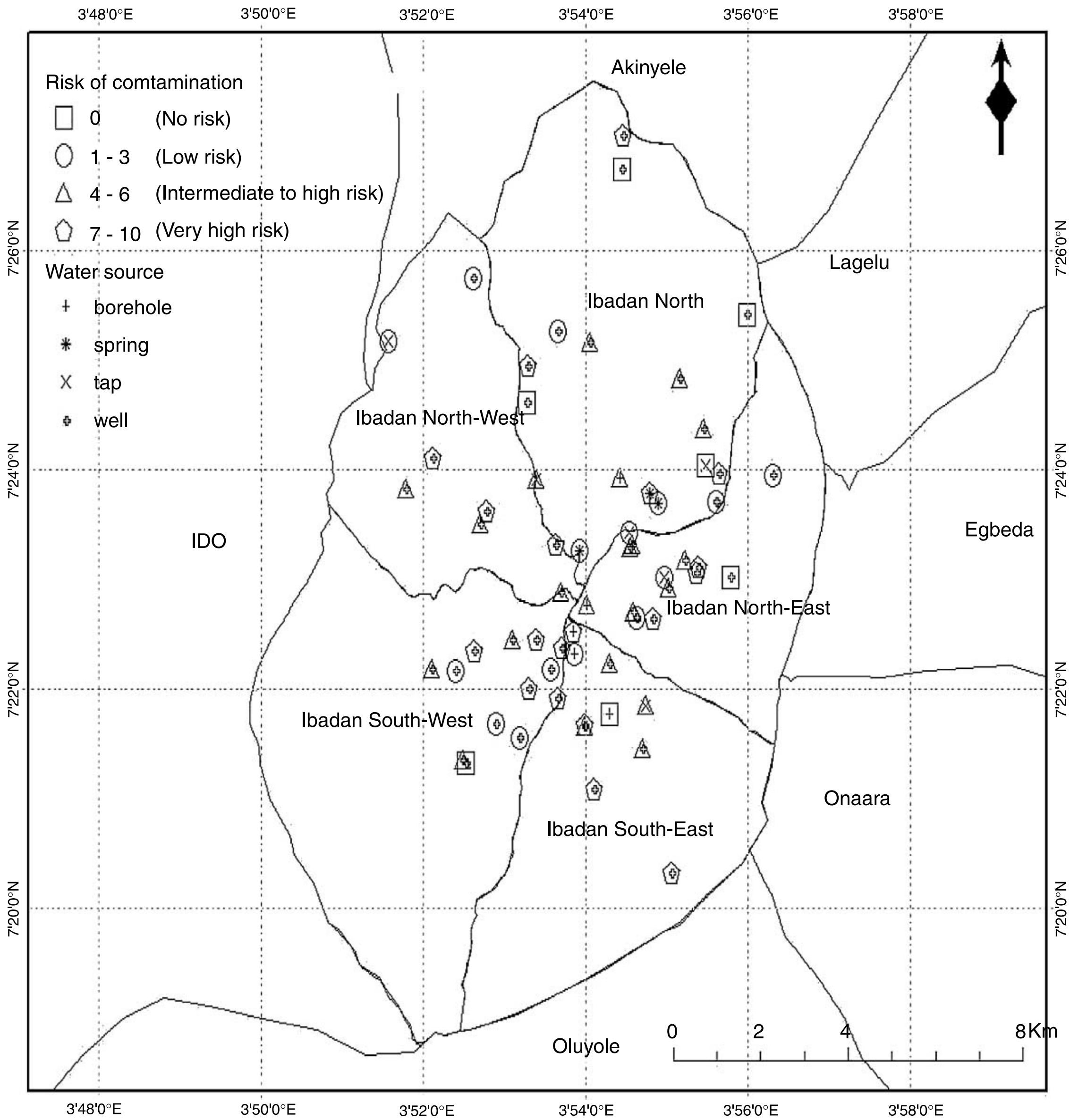

Figure 2 | Distribution of risk of contamination of water sources in selected households in Ibadan.

domestic water supplies. However, intervention studies in Zambia (Nyundu & Sutton 2001) and Zimbabwe (WSP-AF 2002). Showed that upgrading of such facilities improved water quality considerably.

Spatial mapping of *E. coli* and risk score grading of water sources

Figures 1 and 2 show the spatial mapping of *E. coli* contamination and risk score grading of selected household drinking water sources. These maps provide at a glance, households facilities in each local government area requiring the most urgent remedial action. They could also provide a resource base for national strategic planning as shown in studies by Tong & Chen (2002) and Wang *et al.* (2005).

Remedial actions to reduce sanitary-risk factors

Table 4 shows the relationship between risk analysis by sanitary survey and *E. coli* contamination (grading A to E)

Table 3 | Sanitary-risks factors at point source drinking water facilities

Variables	Tap		Borehole		Spring		Well	
Location of water source to latrine/septic tank	No.	%	No.	%	No.	%	No.	%
Adequate	–	–	4	80.0			31	64.6
Not adequate	–	–	1	20.0			17	35.4
Topography of latrine/septic tank								
Upstream	–	–	1	20.0	2	66.7	10	20.8
Down stream	–	–	4	80.0	1	33.3	38	79.2
Vicinity of other sources of pollution								
Within 2/10 m of source	–	–	2	40.0	–	–	30	62.5
None	–	–	3	60.0	–	–	18	37.5
Lining/protection								
Adequate	–	–	–	–	1	33.3	31	64.6
Not adequate	–	–	–	–	2	66.7	17	35.4
Apron/diversion ditch								
With cracks	–	–	3	60.0	1	33.3	33	68.8
Not faulty	–	–	2	40.0	2	66.7	15	31.2
Cleanliness of drawer								
Sanitary	–	–	–	–	–	–	40	83.3
Not sanitary	–	–	–	–	–	–	8	16.7
Fence								
Present	–	–	–	–	1	33.3	–	–
Not present	–	–	–	–	2	66.7	–	–
Layout of pipes								
In drains	3	50.0	–	–	–	–	–	–
Satisfactory	3	50.0	–	–	–	–	–	–
Environmental condition around pipe								
Clean	2	33.3	–	–	1	33.3		
Dirty	4	66.7	–	–	2	66.7		
Drainage around pipe/'pump house								
Adequate	1	16.7	3	60	–	–	–	–
Not adequate	5	83.3	2	40	–	–	–	–

Table 4 | Combined sanitary risk analysis and *E. coli* grading (contamination)

Risk score	*E. coli* grading No risk (A)	Intermediate to high risk (C)	High risk (D)	Very high risk (E)	Total
Low risk	3	4	7	9	23
Intermediate to high risk	1	2	3	14	20
Very high risk	–	1	3	15	19
Total	4	7	13	38	62

of the drinking water sources. The results showed that sanitary risks were identified in the absence of *E. coli* contamination (Grade A). The results also showed that most of the drinking water sources in Ibadan had very high microbial load which may be linked to the physical defects in the water supply systems and lack of hygienic environmental conditions. Compared to the number of wells analysed ($n = 48$), the number of tap, borehole and springs were small ($n < 7$). This makes it statistically difficult to compare the four water sources and conclusions between the water sources are weak. However, a weak significant positive correlation (spearman's rho = 0.379) exists between the *E. coli* grading and risk score ($p = 0.02$). A previous study by Howard *et al.* (2003) discovered a significant association between risk factors and microbial contamination of shallow groundwater in Kampala, Uganda. Also, Haruna *et al.* (2005) showed that the sanitary risk assessment score is a reliable tool for predicting the likely levels of bacterial contamination of protected springs in Katwe and Kisenyi parishes of Kampala city. The results of this study and subsequent grade classification implied that the health risk associated with these water sources is very high and therefore requires urgent remedial action (such as well upgrading, leak detection and repair, and spring protection and maintenance) by all stakeholders.

CONCLUSIONS

This study has indicated that existing practices and technologies may not ensure drinking water safety as most of the sources were not adequately protected. It is important that realistic goals for progressive improvement are agreed upon and implemented. It is practical therefore, to classify water quality results in terms of an overall grading for water safety linked to priority for action. Grading schemes may be of particular use in community supplies where the frequency of testing is low and reliance on analytical results alone is especially inappropriate. Such schemes will typically take account of both analytical findings and results of the sanitary inspection through schemes such as one used in this study. Combined analysis of sanitary inspection and bacteriological quality data can be used to identify the most important causes of contamination. The information provided can be useful for decision makers on how to improve water quality and reduce public health risks of drinking water in third world countries. There is a need to extend the study to cover the rural and urban local government areas in Ibadan.

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