21

Groundwater quality assessments in the John Laing and Misisi areas of Lusaka

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ABSTRACT: Groundwater is becoming a more accessible and comparatively cheap source of water for drinking, agriculture and industry in Zambia than surface water. However, in Lusaka, the country's capital city, increased rates of urbanisation have caused large numbers of people who cannot readily obtain water supply services by self-provision to exploit any other available sources of groundwater supply, thereby exerting enormous pressure on the Lusaka aquifer through construction of private boreholes or hand-dug wells. Consequently, contamination in the city aquifer appears to be increasing and waterborne diseases have increased to endemic levels as well.

Keywords: health, lusaka, pollution, urbanisation, vulnerability.

1 INTRODUCTION

Groundwater use in Lusaka has been increasing rapidly in recent years. Groundwater is relied on for drinking water and as an essential prerequisite for many socio-economic activities, development and growth. In Lusaka alternative sources of water supply are becoming increasingly scarce. The major advantages in the exploitation of this resource are:

(i) In many cases, particularly for drinking purposes and in areas that are remote from intense human activities, treatment is usually simpler and less costly than for surface water.
(ii) Competition and conflict over the use of groundwater resources are typically less than for surface water.
(iii) It usually does not need to be transported over long distances to points of use. As such, it generally provides reliable supplies at comparatively low capital investment.

However, the rapid growth of population in the city initiated by the rural-urban migration has increased rates of urbanisation. Currently, of the estimated two million inhabitants of the city, about 75% live in high-density and poor/low-income settlements. Of these, only about 55% have access to a safe water supply, while more than 80% have no access to satisfactory sanitation facilities. Since these mushrooming low-income settlements are located over the aquifer recharge areas, the use of pit latrines or septic tanks to dispose of excreta threatens to contaminate the groundwater.

2 LOCATION

The city of Lusaka is the capital of the Republic of Zambia. Zambia lies in southern Africa between latitudes 22°–34° E and longitudes 9°–18° S.

3 POPULATION

The settlement and development patterns in Lusaka have been greatly influenced by the growth of the population. With a population of only 195,753 at independence in 1964, the city has experienced a progressive increase in population over the years, rising to 535,850 in 1980 and 769,353 in 1990 (Central Statistics Office, CSO, 1990). According to the 2000 census, the population of Lusaka reached one million two hundred thousand (although the author feels this is understated).

4 CLIMATE

The city experiences a sub-tropical climate that is strongly seasonal. It has three distinct seasons, namely:

a) A cool, dry season from mid-April to mid-August with mean day temperatures varying between 15°C and 23°C. Minimum temperatures may sometimes fall below 10°C in June and July.
b) A hot, dry season lasting from mid-August to mid-November. During this period, day temperatures may vary between 27°C and 38°C.
c) A warm, wet season from mid-November to mid-April, during which 95 per cent of the annual rainfall takes place. The annual rainfall averages about 800 mm/a.

5 TOPOGRAPHY AND GEOLOGY

The topography of Lusaka is characterised by a plateau of the mid-Tertiary (Miocene) peneplain, which stands at an elevation of 1200 m. There are flat-topped hills to the north and east of the city, which stand at an elevation of about 1300 m above sea level, and are assumed to be remnants of an earlier peneplain of Cretaceous age (Dixey, 1960).

The drainage pattern of the Lusaka area is in an essentially radial pattern (Fig. 21.1), which appears consistent with the domical-type relief that conforms with the basin-and-swell concept applied by Holmes (1965) to explain the relief of Africa in which the Lusaka plateau forms a minor swell.

Rocks underlying the city of Lusaka consist of schists interbedded with quartzites and dominated by thick and extensive sequences of marbles (Fig. 21.1), with the latter generally referred to as the Lusaka Dolomites/Lusaka Limestones. The underlying marble has suffered extreme differential dissolution, resulting in the development of a system of subterranean conduits and solution channels.

Available borehole drilling data indicate that carbonate rocks extend to depths in excess of 100 metres, but showing variations in the fracturing intensities (Nkhuwa, 1996). Some of the solution features have been intersected at depths in excess of 60 m below ground surface, and form what are usually referred to as underground rivers (as depicted in Fig. 21.2). From the borehole logs shown in Figure 21.2, no borehole in Lusaka has completely intersected the whole thickness of the aquifer. So it can safely be concluded that the Lusaka aquifer is more than 100 m, which is the deepest drilling that has so far been done.

As a result of the karstification in the Lusaka marbles, one of the most prominent features of the Lusaka plateau is the scarcity and/or complete lack of surface drainage, particularly in its central part, because rainwater drains into the fissures and/or infiltrates through the overburden to enter the groundwater. Only surface water in excess of the infiltration capacity is drained into minor seasonal streams.

Therefore, solution (karstic) features in the marbles are the major factors controlling groundwater flow in the Lusaka aquifer and have transformed the underlying rocks into a favourable and comparatively cheap source of water supply to the residents.

6 SOCIO-ENVIRONMENTAL PROBLEMS

The development of infrastructure for the provision of basic needs and essential social services, including water supply and adequate and safe methods of liquid and solid waste disposal in

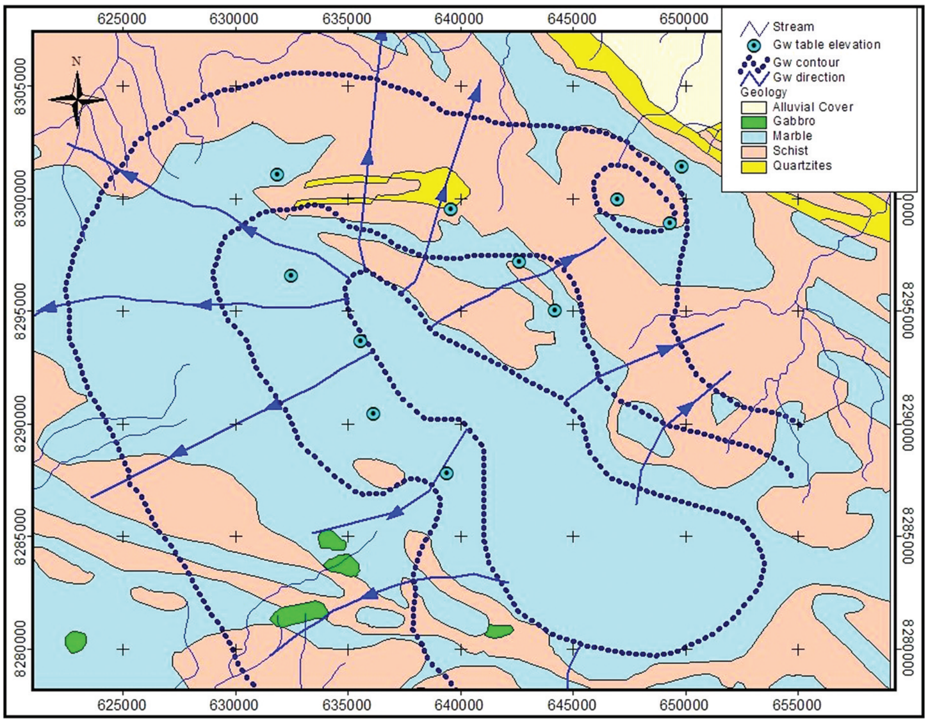

Figure 21.1. Map of the Lusaka plateau showing the geology and surface as well as underground drainage *(Modified from von Hoyer et al., 1978)*.

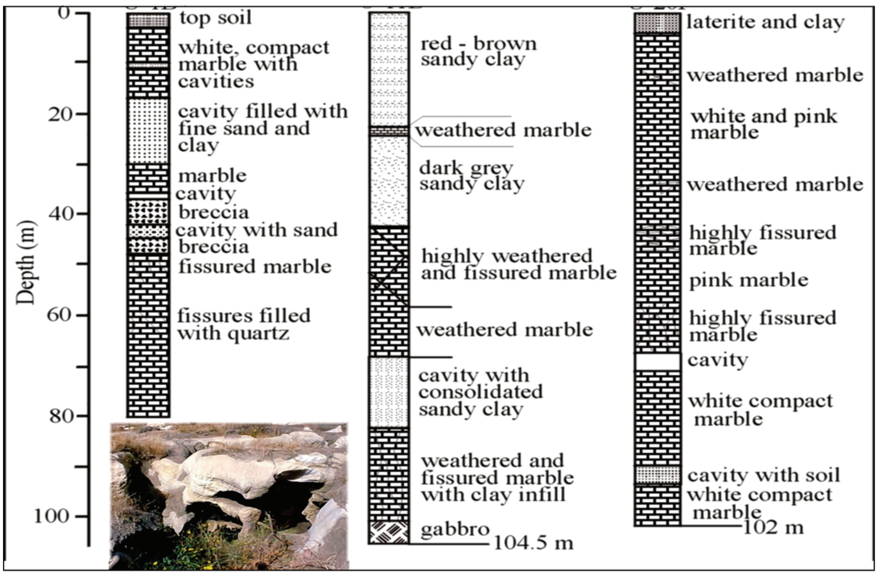

Figure 21.2. Solution features in the Lusaka marbles in John Laing.

Lusaka, has not kept pace with the rate of the population growth. As a result, increasing amounts of waste are being disposed indiscriminately.

Currently, of the estimated 1.2 million inhabitants of Lusaka, about 25% are serviced by a sewer system, about 20% by septic tanks, while 55% rely on pit latrines to dispose of their sewage and waste water. Areas using pit latrines are high-density residential townships that have generally developed in close proximity to areas of natural groundwater discharge or springs, where the groundwater table is very shallow. However, karstic aquifers, such as the one underlying Lusaka, are known to be notorious for being easily contaminated by surface activities, including faecal contamination.

This article discusses the water quality results of the UNEP – UNESCO – UN-Habitat sponsored research carried out in two high-density settlements – John Laing and Misisi Compounds – in Lusaka to examine what impact current methods of excreta disposal have on groundwater quality. The paper also examines public health issues associated with the consumption of water drawn from the aquifer underlying these settlements.

7 JOHN LAING AND MISISI AREAS – A CASE STUDY

The John Laing and Misisi areas are located south of the Central Business District (CBD) of Lusaka and bounded by Eastings $^{6}35500$ to $^{6}38000$ and Northings $^{82}92000$ to $^{82}93500$. The two areas lie in close proximity to one of the major discharge surface excavations, but may also be a recharge facility for some water points that lie downstream as indicated by the general ground water flow direction (Fig. 21.3).

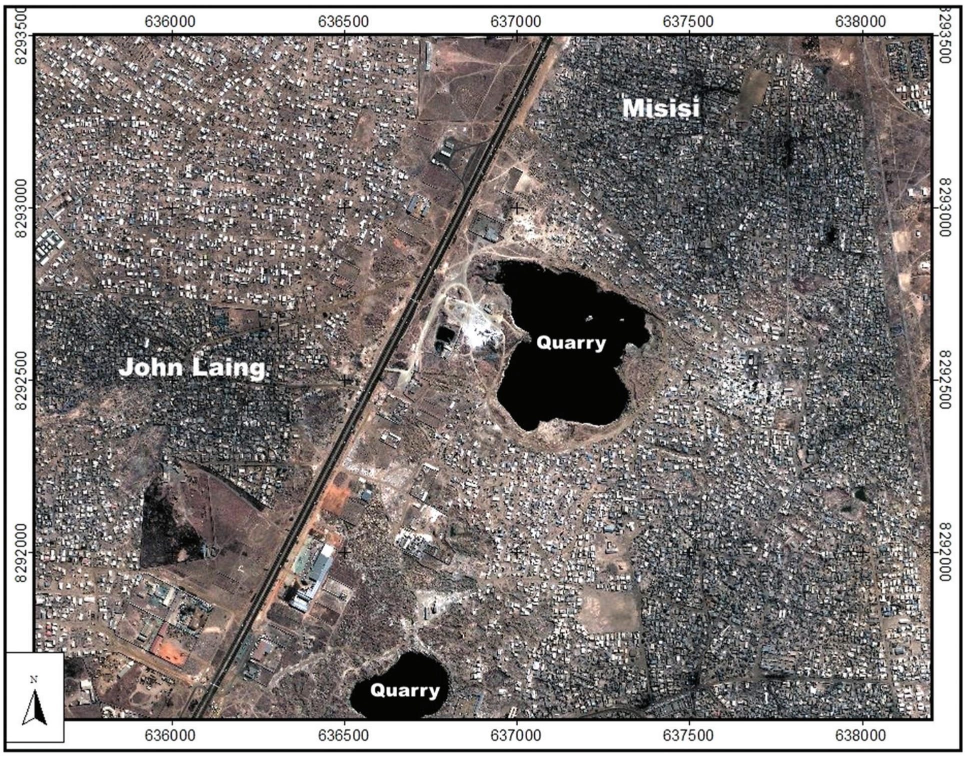

Figure 21.3. Location of John Laing and Misisi townships south of the Central Business District (CBD) and the quarries, which probably act as recharge and discharge points for the aquifer.

The selection of these project areas was based on five major criteria, of which the settlements of John Laing and Misisi satisfied most. The areas needed to:

a) Have a self-contained aquifer, where it would be possible to study source(s) of contamination.
b) Have a predominance of on-site sanitation for the disposal of its excreta.
c) Be in a location where contamination was identified to be a problem (area lying directly over the aquifer).
d) Be where the quality of the aquifer water could be correlated with health status, and where health data could be monitored.
e) Preferably be in a location where there were some water projects of one kind or another taking place or had taken place so that there were some data on which to build.

8 METHODS OF EXCRETA DISPOSAL

Disposal of excreta in the John Laing and Misisi compounds is mainly through pit latrines with minor systems of open defecation, pour flush latrines and limited use of flushing toilets or septic tanks. A number of families that are unable to afford their own latrine share with other families.

Two types of pit latrines are found in these compounds, namely ground-level and raised latrines. The ground-level pit latrines are often constructed in sinkholes over which residents build some form of structure made of sacks, plastics, grass or any other available materials (Fig. 21.4). These pit latrines are not built for structural strength, but only for privacy.

The superstructures for raised pit latrines (Fig. 21.4) are usually made of blocks, and when they are filled, they are either abandoned or the excreta removed and the pit re-worked for re-use. The excreta removed from these pit latrines is sometimes drained into primary discharge points, which may also act as recharge points in the dry season, bringing the excreta into direct contact with the water table.

An increasingly common practice has been noted in these compounds, where dried-up shallow wells are converted into pit latrines during the dry season. Unfortunately, these points have the potential for flooding during the wet season. Probably because of the danger of falling into pits, children in these townships are usually not encouraged to use pit latrines until about five years of age. Before that, the most common method noted is open defecation.

Most of these practices have greatly increased the potential for groundwater contamination. As many of these (low- and high-income) settlements that rely either on pit latrines or septic tanks to

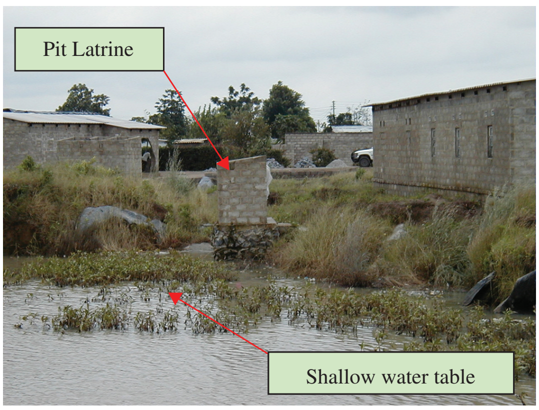

Figure 21.4. Raised pit latrines in the project areas.

dispose of their sewage also depend heavily on groundwater obtained from their private sources, consumption of such water, which is usually of unfavourable quality, has undoubtedly heightened outbreaks of water-borne diseases such as cholera and dysentery experienced in many areas of the city. In most parts of the city, these outbreaks are turning into almost perennial problems. Outbreaks have led to:

(i) An increase in costs for health-care services, posing a special burden, particularly for those members of society that are poor.
(ii) Loss of productive time due to illnesses that could otherwise have been avoided.

While this has been a recurrent problem in the city, there has been no detailed study attempting to link the outbreaks to groundwater quality. Although morbidity and mortality figures highlight the magnitude of the problem, a perspective of annual expenditures to treat these diseases will undoubtedly show the problem from another viewpoint.

Given this scenario, a critical element in the assessment, protection and management of groundwater resources in these areas involves the identification of contamination sources.

9 MAPPING OF WATER POINTS AND EXCRETA DISPOSAL FACILITIES

Most of the residents in the John Laing and Misisi compounds rely exclusively on groundwater from shallow hand-dug wells, which have different levels of protection (Fig. 21.5). Mapping of excreta disposal facilities, water points and dry wells, the latter representing the major sites for solid waste disposal, was done using a Garmin E-Trex hand-held GPS. Results of the mapping campaign were entered in spreadsheets and imported into the ArcView GIS programme (Fig. 21.5).

10 SAMPLING

Since the water table is very shallow in the project areas (up to 0.5 m below ground surface during the rainy season), human activities in these areas pose great risks of pollution to groundwater, which is envisaged to be the primary vector by which epidemic faecal-oral diseases (cholera, typhoid, hepatitis A and many diarrhoeal diseases) are passed from excreta into the water supply system and transmitted to large numbers of people very rapidly.

(a) (b)

Figure 21.5. Typical arrangement of water points (and excreta disposal systems) in the John Laing and Misisi compounds.

Three sampling campaigns were undertaken in mid-November 2003 (just before the onset of the rainy season) March 2004 (during the rainy season), and October 2004 (at the peak of the dry season). This arrangement was meant to compare the variability of pollutant loading with the varying levels of the water table. The second and third sampling campaigns targeted those points that proved qualitatively problematic during the first sampling campaign.

The following parameters were analysed – *pH, conductivity, chloride, sulphate, nitrite and nitrate, total coliforms and faecal coliforms.* These parameters were selected to determine the potability of the water. The values of the parameters in domestic water must conform to the WHO Guidelines for Drinking Water.

11 RESULTS

A summary of the results for the locations sampled during all three campaigns are given in Table 21.1. The most important water quality problem in the project areas of John Laing and Misisi is faecal pollution together with the associated disease-causing organisms.

Water quality problems are particularly serious during the rainy season, when faecal contamination appears to be flushed into the groundwater system. A plot of faecal coliform counts at different sampling points (Fig. 21.7) shows increasing contamination with rising water table levels. Minor spikes during the dry season are probably a result of local through-flow, since these locations are in an abandoned quarry, which places them at a lower elevation than the surrounding area. Thus, they are probably recipients of recharge from most of the (contaminated) surrounding area.

Chemical loading to the aquifer appears to behave inversely with regard to bacteriological contamination and groundwater levels. For example, conductivity (a proxy for TDS), chloride, and

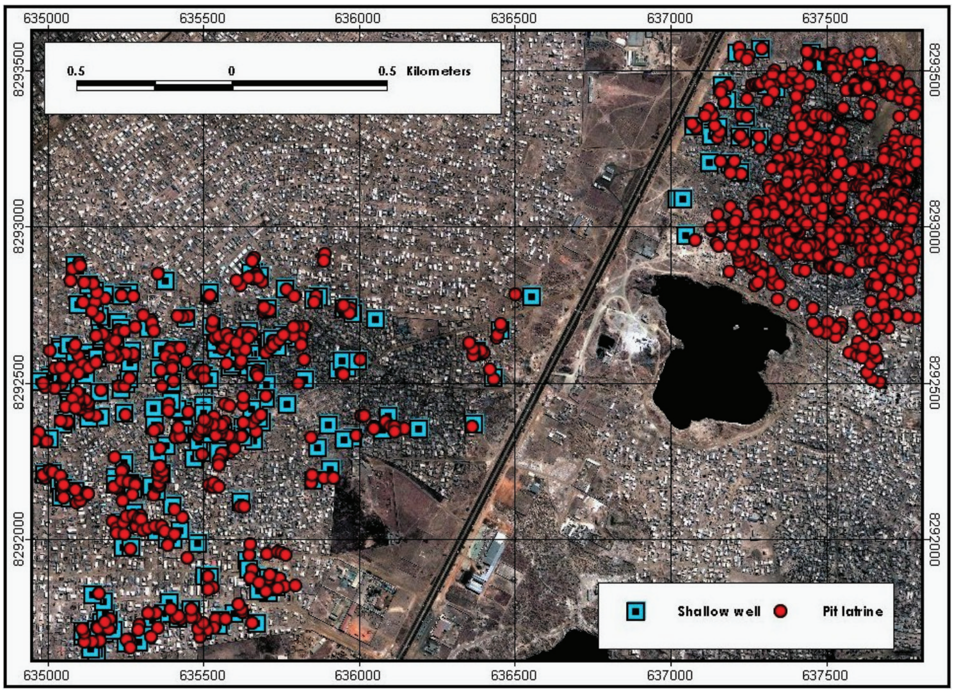

Figure 21.6. The distribution of excreta disposal points (pit latrines in red) and shallow wells in the John Laing and Misisi Compounds *(Image courtesy of the Surveyor General's Office).*

Table 21.1. A summary of results for all the locations that were subjected to at least two sampling campaigns in the John Laing and Misisi project areas.

	Conductivity (μS/cm)			pH			Nitrate (as N, mg/l)			Chloride (mg/l)			TC (counts/100 ml)			FC (counts/100 ml)		
Location	Nov '03	Mar '04	Oct '04	Nov '03	Mar '04	Oct '04	Nov '03	Mar '04	Oct '04	Nov '03	Mar '04	Oct '04	Nov '03	Mar '04	Oct '04	Nov '03	Mar '04	Oct '04
Loc-1	1228	468	1278	8	8.4	6.9	17	28.7	21.4	84	55	95	1,500	285	400	500	240	275
Loc-2	1446	478	1345	7	8.3	8	12	7	19.1	6	75	110	500	35	460	650	20	300
Loc-3	1177	387	ND	8	8.2	ND	19	2.9	ND	81	33	ND	66	100	ND	66	60	ND
Loc-4	1063	442	1079	8	9.1	7	16	2.1	23.9	80	61	85	800	150	21,600	4200	90	11,400
Loc-5	1413	392	1585	7	8.3	7.1	39	7.5	23	157	21	121	550	88	450	500	30	420
Loc-6	1044	754	1038	8	7.6	7.4	19	6.2	27.9	70	80	72	500	120	355	510	95	290
Loc-7	765	447	823	8	7.5	7.6	12	6.8	24.7	39	37	45	560	50	310	550	25	100
Loc-8	652	547	ND	8	8.2	ND	11	11.6	ND	44	55	ND	160	65	ND	160	30	ND
Loc-9	1371	460	1342	8	7.6	7.3	18	10.3	18.3	110	42	108	900	92	13,300	4500	40	9900
Loc-10	1408	724	1375	7	8.1	7.4	25	4.51	23.1	100	119	93	700	18,000	625	500	12,000	500
Loc-11	1056	656	1369	7	8	7.1	40	6.2	19.7	103	115	105	890	14,000	500	500	11,000	385
Loc-12	610	659	786	6	7.3	7.1	16	20	22	28	52	31	5,000	5300	9000	500	3000	3200
Loc-13	1043	ND	1242	7	ND	7.2	39	ND	20	92	ND	85	ND	ND	300	ND	ND	210
Loc-14	1340	1233	ND	7	7.3	ND	15	2.92	ND	107	83	ND	ND	8000	ND	ND	6000	ND

ND – Not Determined.

[1] Sampling campaigns in November 2003 and October 2004 were during the dry season, while the March 2004 campaign was done during the rainy season.

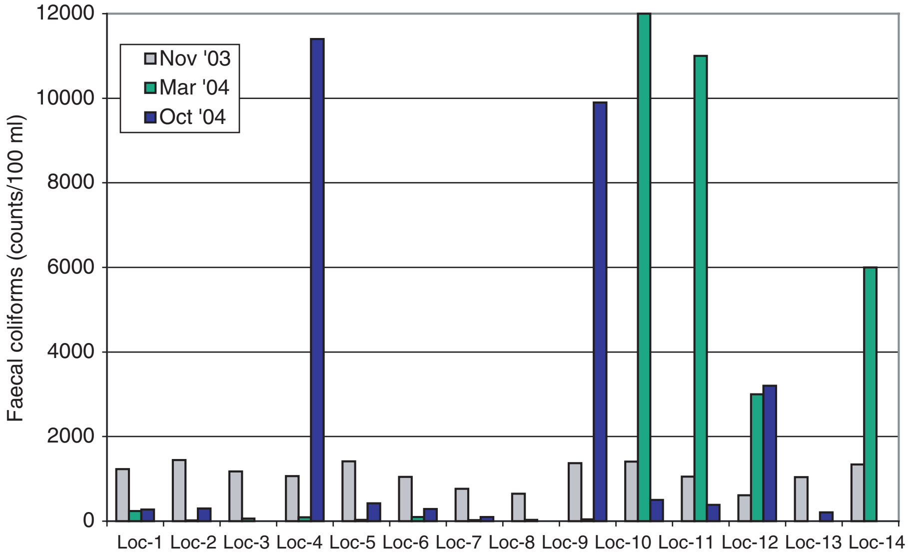

Figure 21.7. Variability of coliform contamination with varying levels of the water table in the aquifer.

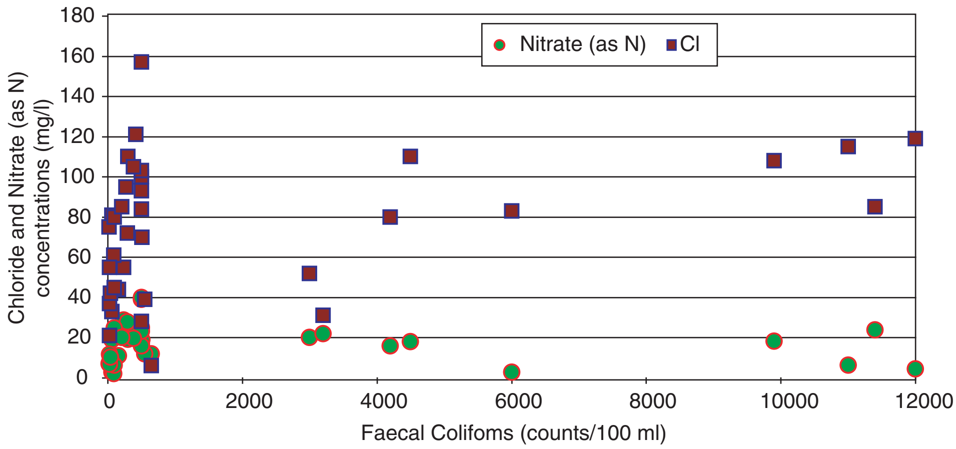

Figure 21.8. Regression plots to show the relationships between chloride and nitrate with faecal coliforms as influenced by varying levels of the water table in the aquifer in the John Laing and Misisi compounds.

nitrate were generally elevated during the dry season (Fig. 21.8). Almost all chemical elements appear to conform to this trend, which can be explained as resulting from lower recharge rates (due to reduced flows) and thus less dilution and greater dissolution of aquifer material.

During the rainy season, the water appears to become more alkaline, probably indicating the predominance of the HCO_3^- (and some CO_3^{2-}) radicals in solution. In other words, the alkalinisation process may result from the exposure of carbonate rocks to a lot of water, thereby raising the pH-levels during this period. Conductivity (arising from high concentrations of chloride, nitrate and sulphate), on the other hand, appears to decrease during the rainy season – also probably as a result of high flows that keep the system flushed and deprived of mineralisation.

Water with high conductivity (high TDS) also tends to have high chloride (and sulphate) concentrations. Sulphate removal is expensive (desalination or ion exchange) and normally not considered viable.

12 SAFETY OF WATER FOR DOMESTIC USE

Decision making on the suitability of water for domestic use is largely determined by the health problems related to drinking the water. One way to determine the safety of the water for domestic use is based on faecal coliform counts. On the basis of the South African Standards, most of the water points in the project areas pose serious effects on all user groups. Based on the WHO Guidelines most of the water sources may be classified as needing very urgent action. This information has not been available previously, and as a result there has been no prioritisation of water supplies to ensure that those sources presenting the greatest risk to public health were improved first.

13 THE RELATIONSHIP BETWEEN WATER QUALITY AND WATERBORNE DISEASES

Annual figures for Lusaka in general and the project areas in particular for the period 1996 to March 2004 are given in Table 21.2. The reason for the lack of and very low cases between 1998 and 2002 could be attributed a heightened campaign for home chlorination, which excited many residents quite regarding this new remedy for cholera outbreaks. In addition, this period does not appear to have been particularly wet. This trend appears to have made the authorities relax their campaign for chlorine use.

However, the outbreak of cholera cases even before the onset of the rainy season in November 2003 took the authorities by surprise. On 3 March 2004, a cumulative total of 4734 cholera cases were reported for the entire city of Lusaka, with 157 deaths and 55 brought-in-dead (BID). For the project areas, John Laing shows a higher disease outbreak than Misisi. This is likely, because there are more shallow wells in use in John Laing.

14 POSSIBLE IMPLICATIONS OF HIGH LEVELS OF FAECAL COLIFORMS ON PUBLIC HEALTH

The presence of faecal coliforms in the groundwater shows the presence of disease-causing microorganisms – *faecal coliforms* – which may be responsible for gastro-intestinal diseases, such

Table 21.2. Annual cholera figures for Misisi and John Laing (1966–2004).

	Cases of Cholera		
Year	Misisi	John Laing	Total ases in the city of Lusaka
1996	109	28	2469
1997	140	26	2492
1998	0	0	0
1999	–	–	6485
2000	0	0	0
2001	46	30	887
2002	–	–	2
2003/2004	96	250	4734*

* Figure for the period 28/11/03–03/03/04; Source: LDHMB cholera reports.

as cholera, typhoid, dysentery, and sometimes including fever and other secondary complications. In this regard, the dependence of residents in the John Laing and Misisi compounds on groundwater resources obtained from private boreholes and shallow had-dug wells is undoubtedly the cause for heightened outbreaks of water-borne diseases, which have also been experienced in other areas of the city with similar sanitary and water-source arrangements.

15 METHODS OF WATER TREATMENT AT HOUSEHOLD LEVEL

Decision making on the suitability of water for domestic use must be determined through the health problems related to drinking the water. Since most of the water sources, particularly in the densely settlement areas are of unsatisfactory quality, a number of methods may need to be employed to purify the water and make it safe for household use. Some of these have been and are still being used by some communities. However, some of the methods have serious drawbacks.

15.1 *Boiling*

This is the simplest way to kill pathogens. Some of its major disadvantages include:

a) Uses a lot of fuel-wood – about 1 kg of wood is needed to boil one litre of water. Because wood is scarce in Lusaka, its use may be limited by its availability and cost.
b) It sometimes gives an unpleasant taste to water.
c) Water may be contaminated again when it cools down.
d) Hot water may cause serious accidents in homes.

15.2 *Chlorination*

This process inactivates all types of microorganisms – protozoa, bacteria and viruses. However, its efficiency to inactivate microbes is affected by pH, contact time and its reactions with water. Microbes may be protected from chlorine if they are attached to or within particles in the water.

There are two types of reactions that can occur when chlorine is added to water that may affect its availability and efficiency as a disinfectant:

(i) Iron (Fe), Manganese (Mn) and hydrogen sulphide (H_2S) react irreversibly with chlorine. As a result, chlorine is removed from the water without contributing to the disinfection process.
(ii) Chlorine may react reversibly with organic matter and ammonia to form weak disinfectants. It has also been recognised that chlorine may react with organic substances in some waters to form trihalomethanes (THMs). There is some evidence that THMs may be carcinogenic.

16 POSSIBLE MEASURES FOR RESOURCE PROTECTION

Aquifer protection in Lusaka is very difficult, because the aquifer is generally characterised by shallow water tables, a thin soil cover, coarse soils with low clay contents, unconfined conditions, a flat topography that generally facilitates increased recharge, and numerous pollution sources located in aquifer recharge areas. Aquifer protection in Lusaka has generally been reactive, usually only in response to aquifer contamination resulting from human activities already established in areas that would, under normal circumstances, have been candidate zones for aquifer protection.

All efforts to protect the aquifer should have started with prohibiting any potentially contaminating development within each borehole's capture zone. Any future groundwater protection measures adopted in Lusaka must accept the fact that existing infrastructure and anthropomorphic activities cannot be moved, but must not be ignored.

Two options for aquifer protection in Lusaka are available – proactive/preventive and retroactive. Clearly, it would be preferable and to the benefit of public health to adopt the former, since a source that can be maintained contaminant-free would obviously be cheaper to use because of low treatment costs.

Retroactive measures in Lusaka, on the other hand, will generally consist of reducing and/or preventing further contaminant entry into the aquifer, the prevention of deleterious land uses in sensitive areas and an element of emergency clean-up.

However, high-density settlements like John Laing and Misisi may render certain forms of protection ineffective. Further, due to reasons of economics and inadequate public awareness, it might be very difficult, if not impossible, to force changes in land use practices in pursuit of aquifer-wide protection strategies.

In order to assess the options and effectiveness of the protection measures, it is strongly recommended that a monitoring system established under this pilot project be up-scaled to cover the rest of the aquifer. Water samples from supply points must be taken on a regular basis for a range of physico-chemical and microbial parameters that will give an early warning system for any contaminant event likely to occur.

17 CONCLUDING REMARKS

- The presence of a well-developed system of conduits, solution channels and subterranean cavities in the Lusaka aquifer(s) reduces and/or completely eliminates the natural attenuation of pollutants through natural filtration.
- Most physico-chemical parameters show a general increase in concentration from the wet season to the dry season, which is caused by the less recharge, dilution and an increase in dissolution of aquifer material. On the other hand, bacteriological loading appears to be greatest during the rainy season, when faecal contamination appears to be flushed into the groundwater system. Regular water quality monitoring from supply points for physico-chemical and microbial parameters will give an early warning of any contaminant event likely to occur.
- There is a need to formulate adequate community-based sensitisation and educational awareness campaign programmes on, for instance, pathways of pathogens into water supply sources and what methods, at household level, may be used to treat and safeguard the water.

The long-term deterioration of water quality, leading to progressively more costly water treatment, is the inevitable result of the current ad-hoc development in a thriving city such as Lusaka, especially as it is located largely on a karstic aquifer. In the long term, groundwater beneath Lusaka may become unfit for human consumption even with expensive treatment. The result is that new sources of water supply away from the current sources will need to be identified, or at least a consideration of whether or not a new site should be sought for the city.

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