

Effective water supply surveillance in urban areas of developing countries

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ABSTRACT

Water supply surveillance generates data on the safety and adequacy of drinking water supply in order to contribute to the protection of human health. Most current models of water supply surveillance for urban areas come from developed countries and have significant shortcomings if directly applied elsewhere. There are differences not only in socio-economic conditions but also in the nature of water supply services, which often comprise a complex mixture of formal and informal services for both the 'served' and 'unserved'. The development of approaches to water supply surveillance that allow targeting of activities on priority groups is assessed based on case studies from Peru and Uganda. The development of a zoning approach that incorporates indices for vulnerability is shown to be a useful tool to assist surveillance in targeting data collection. Zoning also assists in targeting subsequent interventions into communities and strategies where public health gains are likely to be greatest. Two approaches to urban zoning are presented from Peru and Uganda, both of which are effective.

Key words | drinking water, health, poverty, surveillance, urban, water quality

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INTRODUCTION

The adverse impacts on public health from poor water supply have long been recognised in both developing and developed countries and take the form of outbreaks and contribution to background rates of disease (Esrey *et al.* 1991; Ford 1999; Payment & Hunter 2001). Nevertheless, reliable estimates of the global burden of disease related to water, sanitation and hygiene are only now becoming available (Prüss *et al.* 2002). Waterborne disease contributes a significant proportion of the total disease burden associated with diarrhoea and other gastro-intestinal diseases, estimated at 2.2 million deaths and over 72 million disability adjusted life years (DALYs) (WHO 2002). Children in developing countries bear the great majority of the burden of water-related and diarrhoeal disease (Prüss *et al.* 2002).

Many millions of people, in particular throughout the developing world, use unreliable water supplies of poor quality, which are costly and are distant from their home (WHO & UNICEF 2000). Diarrhoeal disease may be caused by consumption of contaminated drinking water or through poor personal, domestic or community hygiene; which may

in turn be driven by inadequate availability of water. Factors such as poor reliability (continuity of supply), costs (affordability) and distance between a water source and the home may all lead households to depend on less safe sources, to reduce the volume of water used for hygiene purposes and to reduce spending on other essential goods, such as food (Lloyd & Bartram 1991; Cairncross & Kinnear 1992; Howard 2002).

The burden of waterborne disease is unequally spread within and between countries and is often closely linked to poverty (Fass 1993; Stephens *et al.* 1997). The poor tend to be more vulnerable to disease and have least access to basic services (WHO & UNICEF 2000). The evidence suggests that interventions targeted at poor populations provide significant health benefits and contribute to poverty alleviation (DFID 2001; WHO 2002). Information about the adequacy of water supplies and the health risks faced by urban populations at national or sub-national levels remains scarce in many countries. This is despite significant advocacy of 'people

centred' and 'demand responsive' approaches in recent years. Such information can be acquired through water supply surveillance, which is defined as: 'the continuous and vigilant public health assessment and oversight of the safety and acceptability of water supplies' (WHO 1976, 1993, 2004).

Urbanisation is occurring throughout the developing world and projections suggest that by 2025 over 50% of the world's population will be urban dwellers (UNCHS 2001). Much of this 'new' urban population (which arises from both migration and natural growth) is or will be poor, lacking access to basic services of a reasonable quality and living in environments that seriously compromise health (Andreasen 1996; McMichael 2000; Karn & Harada 2002).

Water supply arrangements in developing countries

Based on the Global Water Supply and Sanitation Assessment 2000, Table 1 shows the gross categories of access to water supply for the global population.

Water supply access in most developing countries is complex. Some sections of society enjoy water supply and other services of a quality comparable to those in developed countries, frequently at lower cost. However, many households do not have access to water piped to the home and as a result there is widespread use of a wide variety of communal water sources. These include public taps (where water may or may not have to be purchased), water sold by households with a connection and purchase from vendors (Whittington *et al.* 1991; Cairncross & Kinnear 1992; Howard 2001; Tatietsse & Rodriguez 2001). They also include a variety of small point water supplies such as boreholes with handpumps, protected springs and dug wells (Gelinas *et al.* 1996; Rahman *et al.* 1997; Howard *et al.* 1999).

Significant health gains accrue by ensuring access to an improved water source within 1 kilometre of the user's house

(Esrey *et al.* 1985; Howard & Bartram 2003). Reducing the proportion on the global population that does not enjoy such access remains a global goal for the water sector (UNGA 2000). Further significant health gains are accrued once water supply is delivered 'on-plot' through at least one tap (Howard & Bartram 2003). Experience suggests that improvements in water supply and water-handling hygiene are typically incremental and may be most significant for those that have least access to basic water supply services (Kalbermatten & Middleton 1999).

Water supply surveillance programmes should identify those interventions that will result in improvements in water supply that will be protective of public health (Lloyd & Bartram 1991; WHO 1997; Howard 2002). An important further objective for water supply surveillance is to identify those communities where water supply improvements will deliver the greatest health gain (Lloyd *et al.* 1991). Given the link between vulnerability to disease and poverty (Payment & Hunter 2001) this indicates the value of including assessment of poverty within surveillance programmes (Howard 2002).

Water supply surveillance programmes that comprehensively cover whole cities and towns can provide the evidence base for designing incremental improvements. A range of indicators of water supply will be taken into account, including the quality of water, sanitary integrity of the supply, the costs of water at the point of purchase, reliability of supply and service level, as defined by distance/time criteria. The first two indicators relate to the likely quality of water consumed and therefore are direct influences on health. The remaining three indicators have equally important indirect influence in terms of encouraging alternative source use, decreasing quantities of water used and increasing vulnerability to contamination in some supplies (Lloyd & Bartram 1991; WHO 1997; Howard 2002).

Experiences of urban drinking water supply surveillance in developing countries

In preparing this review, a search for published studies was undertaken to identify experiences with drinking water supply surveillance (as defined above) in urban areas of developing countries. Key word searches in Cambridge Scientific Abstracts (including Aqualine, Water Resource Abstracts and Bacteriology Abstracts) as well as Medline

Table 1 | Global access to water supply (data taken from WHO & UNICEF 2000)

Year	No access (millions)	Access to improved sources within 1 kilometre (millions)	Access through household connections (millions)
1990	22% (1,129)	78% (4,086)	43% (2,255)
2000	18% (1,069)	82% (4,988)	52% (3,169)

were employed. Cases studies were screened to see whether they met the following criteria:

1. Adopted a population-wide approach, for example:
 - went beyond testing of water in piped distribution and incorporated alternative sources and household water;
 - attempted to develop surveillance programmes covering whole cities rather than individual communities;
2. Were sustained for a significant period to enable meaningful review (a minimum of three years);
3. Contained documented methodologies;
4. Were primarily implemented through domestic organisations in developing nations.

Few published studies exist that address the development of water supply surveillance programmes in urban areas of developing countries. A review conducted for the IWA indicated that, while most countries have some form of guidelines on water quality, these are not routinely enforced (Steynberg 2002). This review suggested that the health sector often performs more monitoring than the water supply sector, but provided no evidence that systematic monitoring of water supply extended beyond utility piped systems in urban areas.

A recent assessment of drinking water supply surveillance in the WHO South-East Asia Region noted that none of the countries had a comprehensive national programme of surveillance (Howard & Pond 2002). Surveillance of piped water supplies in urban areas was carried out more extensively than of rural water supplies, although alternative sources and household water in urban areas were not typically included. Even in middle-income countries, sources other than the piped utility system are often not included in monitoring programmes despite the fact that they serve a significant proportion of the population (Parr & Rogers 2002).

There are very few reported examples of surveillance programmes where there is a mix of water source type and service level, or which have addressed the targeting of vulnerable populations. Some projects tried to focus on alternative sources and household water, but were typically focused on single communities or were time-limited assessments of water (Howard 1997; Karte 2001). None of the literature reviewed indicated that poverty or the targeting of vulnerable populations had been a significant factor in the surveillance programme design.

Two principal case studies were identified, each involving one or other of the authors of the present paper. One was implemented in Peru in the 1980s and 1990s (Lloyd & Bartram 1991; Lloyd & Helmer 1991; Lloyd *et al.* 1991); the other was implemented in Uganda in the 1990s (Howard & Luyima 1999a, b; Howard 2002). These case studies are presented here for comparison and as models that have proved to be effective.

CASE STUDIES

Objectives and scope

Both case studies (Peru and Uganda) set out to investigate how water supply surveillance in urban areas could better contribute to information needs to ensure public health gain from improved water supplies. In both case studies the surveillance data assessed service adequacy as experienced at the household level. The findings of these projects and the ways in which the data were used to promote improvements have been reported elsewhere for both Peru (Lloyd & Bartram 1991; Lloyd *et al.* 1991) and Uganda (Howard & Luyima 1999b; Howard 2002).

In both studies, attempts were made to incorporate some assessment of poverty within the surveillance design as a mechanism by which to identify groups or communities believed to be most vulnerable to health consequences of inadequate water supply. This took the form of 'zoning' of urban areas as a first step in programme design using population categories and use of water to provide information to focus resources for subsequent data collection. This was in addition to the zoning of piped water supply, which was also carried out in both countries and which is recommended practice for monitoring of microbial quality in such systems (Geldreich 1996; WHO 1997).

A key factor in the zoning was to introduce a stratified random sampling of communities in the design of water supply surveillance programmes. Stratified sampling was selected as both programmes had the explicit aim of attempting to cover all communities within the surveillance of water supply, using a 'rolling' programme of visits. Stratified random sampling is a commonly applied approach within monitoring programmes that attempt to

cover a representative sample of the total population (Bartram & Ballance 1996).

Alternative approaches, such as cluster sampling, were considered and such approaches are currently being tested for rapid assessments of water quality within overall sector monitoring as part of global initiatives (Howard *et al.* 2003). Cluster sampling within the context of ongoing surveillance programmes, however, remains less well applied. Cluster sampling may be justified for surveillance in rural areas of developing countries, where the numbers of very small supplies inhibit regular visits to an individual community (Bartram 1999). In contrast, in urban areas it would generally be considered that more regular visits to individual communities should be practical given the more concentrated nature of the population and the greater potential for increased numbers of communities to be visited within one sampling period.

The two case studies have clearly defined links – the Uganda study building on the experience obtained in Peru – both in terms of the indicators used and the approach to identifying vulnerable communities.

Indicators

Both projects collected data on a range of indicators of water supply adequacy, although using somewhat different methods for some parameters, as summarised in Table 2. In addition to the indicators common to the Peru case study, the Uganda case study included qualitative estimates of leakage as a key indicator of water supply adequacy.

In both case studies, initial inventories of water supplies were prepared based on desk and field studies. In the Peru case study, the inventory included a review of connections to the piped water supply. In the Uganda case study, the inventory collected data solely on communal water sources (including taps owned by individuals who sold water to their neighbours). This data was supplemented by a review of household connection data from the water utility and a water usage study (Howard *et al.* 2002).

Implementation of surveillance programmes

Surveillance procedures in the Peru programme were developed and refined through application and improvement

in a series of areas including both the dry coastal capital (Lima) and a highland city (Huancayo). The programme developed a phased approach to enable incorporation of lessons learnt.

The Peru programme was institutionally located in the national authority for environmental health in Lima and was implemented by local health authorities (the names of the central and local authorities changed during the project). The programme was also sustained for a significant period (published reports cover the period 1985 to 1990). The programme benefited from external financial support and technical assistance throughout this period although a progressively declining role for external assistance compared with domestic expertise during the period was documented.

The case study from Uganda covered ten towns and cities between 1997 and 2000, with populations ranging from 30,000 to over 1 million people and project reports covering the period 1997 to 2001. The results reported here relate to the activities undertaken in the capital city, Kampala, with a population over 1 million people, complex water supply provisions and where data was available throughout the reporting period. The project was co-ordinated at a national level by the Ministry of Health (Environmental Health Division), but was implemented through environmental health staff working with local governments. This reflected the institutional and policy environment in Uganda. Meetings with all stakeholders were held on a regular basis to encourage inter-sectoral collaboration. The programme benefited from external financial support and technical assistance throughout this period and a progressively declining role for external assistance compared with domestic expertise during the period was documented.

Zoning in Peru

The Peru case study attempted to incorporate measures of vulnerability into the surveillance programme design through a process of zoning that was based on water service characteristics. Experience from its application in Lima was reported as showing that a rapid process of ‘zoning’ of urban areas could be achieved by work on the ground. This typically involved technical staff ‘walking’ an area, verifying the street arrangement and housing against whatever maps were available. One house was selected on

Table 2 | Indicators used in the case studies

Indicator	Data collection method	
	Peru	Uganda
Access to water supply by service level	Visiting a sample of households systematically throughout the urban area	Field assessment through inventories and connection reviews
Use of water sources	Visiting a sample of households systematically throughout the urban area	Water usage study defined use of source type, multiple source use, purpose water collected for and reasons for source selection
Selection of water sources and households for testing	Based on zoning (see below)	Based on zoning (see below) and levels of use of supplies
Quality: analytical	All sources and household water: thermotolerant coliforms (membrane filtration on site, transported to laboratory for incubation), turbidity Piped water: additional tests for chlorine residual and pH (on-site)	All sources and household water: thermotolerant coliforms (membrane filtration on site, transported to office for incubation), turbidity Piped supplies: additional tests for chlorine residuals and pH Longitudinal assessments of quality in point sources using faecal streptococci and thermotolerant coliforms
Quality: Sanitary condition	Sanitary inspection at time of sampling using standardised, semi-quantitative approaches	Sanitary inspection at time of sampling using standardised, semi-quantitative approaches
Quantity	According to source type: for example, by interview to determine number of barrels/drums purchased from tanker trucks each week	According to source type in low-income communities (containers collected per day/family members) Data collected through water usage studies
Continuity	By household interview, distinguishing daily, seasonal and breakdown continuity	All sources: interview during inventories and water usage studies (distinguishing daily, weekly, monthly, seasonal or occasional interruption) Piped water: households interviewed as part of sanitary inspection Boreholes: functional status and downtimes
Cost (affordability)	By interview verified with source (supply agency) where appropriate	Price at the point of purchase (inventories and water usage study); tariff applied by supply agency
Leakage	Investigated as part of sanitary inspection, but not considered a core parameter of water supply adequacy	Qualitative assessment of evidence of leaks and bursts through sanitary inspection

each side of each block by the fieldwork team and the means of provision of drinking water determined.

On the basis of the results obtained the urban area was divided with respect to dominant means of water supply provision. These were of very variable size and typically bore little relationship to administrative boundaries. In areas of piped supply efforts were made to identify supply zones related to the areas of influence of different sources (wells, treated surface water) and to take account of this and the layout of supply mains and different piped networks in order to sub-divide the piped supply into meaningful areas.

One effect of this zoning was to bring into the ambit of the surveillance programme small, often 'informal' urban settlements of very high density and low service provision. It also provided evidence with which to highlight the frequency of the different means of provision, particularly tanker truck delivery, and therefore to argue for their explicit inclusion in subsequent surveillance and improvement activities. The experience in Peru suggested that a qualitative approach could be effective as an initial assessment tool for targeting resources within a surveillance programme.

Zoning in Uganda

The Uganda case study attempted to build on the process of zoning developed and applied in Peru through the development of a semi-quantitative measure of community vulnerability to water-related disease. This was used to zone the urban areas and in planning surveillance activities.

The zoning used a categorisation matrix, which was developed incorporating a quantitative measure of socio-economic status, population density and a composite measure of water availability and use. The rationale for including each factor is described below. Kampala was administratively divided into a number of parishes and each parish assigned to a zone category.

The evaluation of socio-economic status was based on a range of variables reflecting housing conditions, employment status and education, and an index was developed of relative poverty for each town. Socio-economic indices have been shown to be effective in defining socio-economic status and have been used in measuring health differentials in developing countries (Stephens *et al.* 1997). Such measures provide a better indication of relative wealth than wage income, which

constituted a relatively small proportion of total income in Uganda (Bigsten & Kayizzi-Mugerwa 1992). Furthermore, access to services is often more a function of mode of employment (e.g. government) than wage income (Hardoy & Satterthwaite 1989).

Using the approach recommended by Stephens (1995), a series of discussions with expert groups was held to define which of the available variables were sensitive to changes in wealth. An index was then developed based on the following variables:

- Roof material type
- Floor material type
- Persons per room
- Educational attainment
- Main source of household livelihood
- Household size

Data for these variables were taken from household characteristics from the 1991 census. Discussions with the expert groups also led to the definition of low, medium or high income depending on their socio-economic score. This data was then used to prepare a map of socio-economic status for Kampala with the zone category of each parish shown.

Population density was included because more densely populated areas have greater faecal loadings within the environment and the literature indicates that these are associated with greater vulnerability to infectious disease (Woodward *et al.* 2000). 'Vulnerability' in this context includes both the effects arising from the greater pathogen exposure and the increase in the number of people likely to be affected by the introduction of a pathogen.

Population density of each parish was derived by dividing the estimated parish population (calculated from the 1991 populations and applying a 4.76% annual growth rate) by the area recorded in the 1991 census. No attempt was made to correct for intra-urban differences in growth rate. The parishes were then ranked in order of population density: those with populations below the 33rd percentile were classified as low density, those with populations above the 66th percentile were classified as high density and those between the 33rd and 66th percentiles classified as medium density.

Water availability and use incorporated three sets of data as shown in Table 3. These data were the proportion of

Table 3 | Categories of water availability and use, Uganda

Category	Inventory	Water usage study	Review of utility connection data
Mainly using piped water	No point sources	Over 50% of households use taps	Over 30% of households connected
Mixed use of piped water and point sources	Point sources and taps recorded	Less than 50% of households use taps	Less than 30% of households connected
Mainly using point sources	Less than two taps recorded	Less than 20% of households use taps	Less than 10% of households connected

households with a domestic connection, available communal water source types obtained from an inventory and estimated levels of use of different source types obtained from a water usage study. The water usage studies were undertaken because availability of water supplies does not directly equate to level of use for drinking purposes by households (Madanat & Humplinck 1993; Howard *et al.* 2002).

The data on socio-economic status, population density and water availability and use were combined and each parish placed in a zone category as shown in Table 4. The zoning process essentially worked on three levels of stratification with socio-economic status defining the first level of stratification, population density the second level and water economy the third level. Lower socio-economic status represents greater vulnerability to most health problems, including water-related diseases (Stephens *et al.* 1997). Higher population densities indicate increasing likelihood of exposure to pathogens. Parishes with greater use of non-piped sources were considered likely to be at greatest risk from consuming contaminated water. The zone categories therefore were used to prioritise communities based on perceived vulnerability to water-related health risks as shown in Table 4.

Testing of validity in Uganda

The Uganda study further built on the work in the Peru study by trying to validate the process of zoning through the use of health data. This represented certain problems in that the selection of appropriate outcome variables is somewhat difficult. Reliable data on diarrhoeal disease incidence, for instance, remains scarce in many developing countries. Public health surveillance systems are often weak and health facilities

at local levels are often scarce with limited capacity to record data. Furthermore, people suffering from diarrhoea do not necessarily immediately seek health advice or where they do so may not visit 'formal' health care systems in the first instance.

The well known multiplicity of transmission routes for diarrhoeal disease and the importance of sanitation as

Table 4 | Urban surveillance zones, Kampala, Uganda

Description	Number of parishes	Priority
Low income, high density, mixed water source use	22	1
Low income, medium density, mixed water source use	10	2
Low income, high density, principally piped water use	5	3
Low income, low density, mixed water source use	7	4
Low income, low density, principally piped water use	3	5
Low-medium income, medium density, mixed water source use	2	6
Low-medium income, low density, mixed water source use	5	7
Low-medium income, principally piped water use	2	8
Medium income, direct connections and communal piped water	16	9
High income, direct connection rate high	17	10

a protective measure, as well as widespread predisposing factors such as suppressed nutrition and repeated infection, make direct use of health data problematic (WELL 1998). As a result, the validation in Uganda used data from a cholera epidemic in 1997–1998. This provided particularly useful data, as cholera had been absent from Kampala for well over 30 years. Therefore problems with differentiating background and outbreak conditions and the likely mode of transmission did not arise. In many developing countries, the route of transmission of the same disease may vary significantly between outbreaks (when contaminated water supply may be important) and background disease, where transmission derived from poor hygiene or sanitation may predominate.

In order to test the effectiveness of the zoning approach in predicting vulnerability to disease, a retrospective analysis of the zone categories in comparison with the number of cholera cases recorded in the 1997/98 epidemic was carried out using the Spearman's rank correlation statistic.

In Kampala different parishes may share the same name and are differentiated through the use of a numerical suffix: for example Kamwokya I and Kamwokya II. In some cases, up to four parishes share the same name, with a numerical suffix ranging from I to IV (for example, Nakasero I – Nakasero IV). The data on cholera incidence identified the name of the parish, but failed to identify the numerical suffix and therefore could potentially include data from several different parishes under one parish name. This was a particular problem where two parishes sharing the same name were in different zone categories. Therefore all parishes with the same name but different numerical suffix were excluded from the analysis of the cholera data and zone priority. The null hypothesis was that no significant relationship would be found between the priority accorded to zones and number of cholera cases. The analysis gave a correlation significant above the 99% confidence level ($R_s = -0.49$, $p = 0.001$).

As the socio-economic status and connection rate to the water supply were considered likely to be particularly confounding variables, these were tested individually against the cholera cases with the same null hypothesis. The test for socio-economic status gave a result that was not significant ($R_s = -0.16$, $p = 0.294$), while the test for connection rate gave a result that was significant to the 95%

confidence level ($R_s = -0.35$, $p = 0.018$). Analysis of the population density also showed a result significant to the 95% level ($R_s = 0.31$, $p = 0.038$).

These analyses show that correlation between cholera cases is strongest with the use of a multi-criteria zoning approach. This improves the reliability of the zoning methodology to predict which areas are likely to suffer most from an epidemic and provides a mechanism to capture the multi-faceted nature of vulnerability and exposure. The significance of the correlations with connection data and population density also support the need to address water supply adequacy rather than simply water quality. Both suggest that limited access to water supply at higher service levels and increased potential for person-to-person transmission were important in determining the spread of the epidemic. The parishes with low rates of connection and high population density were also those where use of protected springs was more common, which previous research suggests was a significant factor in diarrhoeal disease transmission in the city (Nasinyama *et al.* 2000).

USE OF ZONING IN SURVEILLANCE

Organisation of surveillance and collection of data on indicators, Peru

In Lima, on completion of zoning, the quality of water supply service within each zone was determined through a second round of visits to a smaller number of households. In these visits water supply service was characterised according to water quality, quantity, continuity and cost (affordability).

For reasons of public health priority greatest attention was paid to areas where the greatest populations depended on un piped supplies. For instance a dedicated study was undertaken on tanker truck provision in slum areas. At the time of the study, the piped water supply in Lima was 'rotated' around supply zones as a form of rationing. This affected hydrants used to fill tankers that supplied slum areas, as well as individual households and other users. One result of this rotation was that it severely limited the supply of water via tanker trucks into slum communities and had significant adverse effects on the users. The study into the impact on water

supply in slum areas led to remedial action to ensure that there was no rationing of water at hydrants used by tankers.

In the Peru case study, there were a number of other studies and 'vertical' targeted activities that were outside the simple flow of organised surveillance. The data were also used to influence local and national policy towards water supply provision.

Organisation of surveillance and collection of data on indicators, Uganda

In Kampala, following zoning, data were collected monthly on the quality of different water sources and water stored within households, the continuity of the supply and evidence of leakage. Less frequent data were also collected on the cost of water (as purchased by the household) and quantity of water used.

The zoning was a rapid assessment tool for directing the resources of the surveillance programme. It allowed identification of areas of interest because they contained populations at increased risk of water-related disease. Surveillance data acquisition was focused on those parishes falling into categories ranked 1–7 in Table 4, where more extensive data collection was required to characterise vulnerability to water-related health risks and water supply arrangements. Far less attention was paid to those parishes in categories ranked 8–10, as characterisation in relation to water supply arrangements and water-related health risks was relatively simple. The data collected in the parishes in categories 8–10 primarily focused on piped water supply and was designed to support overall water quality management in the piped supply when water quality problems were found.

The use of zoning significantly reduced the number of parishes to be covered for detailed data acquisition. Overall, five times as many sanitary inspections were performed on water sources and 4.6 times as many samples analysed in parishes in zones 1–7 compared with zones 8–10. All household water quality testing was carried out in zones 1–7. By identifying the numbers of households using different source types, the number of samples required from each source type was calculated.

At a micro-level, the data collected on water supply in priority zones allowed a range of remedial actions to be undertaken including improvement of alternative supplies

and hygiene education (Howard *et al.* 2001, 2002). In addition, the data were used to inform water supply policy at local and national levels.

DISCUSSION

The development of surveillance programmes in urban areas of developing countries has been limited and hampered by a lack of appropriate models. Much reliance is placed on models used in developed countries with an emphasis on the control of quality in piped water supplies. This is reasonable where the norm is for households to have access to piped water supplies, but is less appropriate where the norm is for the use of communal supplies (including non-piped sources) and where other measures of supply adequacy may be as important as water quality. A focus on control of water quality in piped water supply in these situations is likely to direct attention to areas of already improved water supply, rather than to areas where the water supply is less well developed and the potential for public health gain is greatest.

The experience of using zoning in both case studies suggests that assessment of community vulnerability is a useful means of prioritising data collection for surveillance programmes. It also allows surveillance programmes to concentrate on those communities and areas where the greatest potential health gain is available from improved water supply.

The zoning approaches adopted in the case studies were very different. In Peru, the zoning relied on primary data collection through surveys and did not formally introduce poverty. In Uganda, a more formal approach to include poverty was implemented and drew on data from the census, initial comprehensive inventory and systematically designed water usage studies. There are benefits and drawbacks in each approach that should be considered when developing zoning methodology.

The approach adopted in Uganda provided a quantitative and reproducible set of results because a national census is repeated on a regular schedule (the most recent in Uganda was 2001) and the socio-economic index can be revised in light of new data. Acquiring this data does not directly imply additional costs, as the Bureau of Statistics keeps this data and will provide details on request, but does imply the need for

expertise in developing a socio-economic index and in particular selection and weighting of variables and conditions.

There are drawbacks in using this data as it may be considered that the usual interval between censuses (typically ten years) would not capture inter-census changes. However, as the approach is designed to capture relative socio-economic status, the impact in Uganda was not significant because, despite changes in conditions, relative status was less responsive. There was little evidence that 'gentrification' of low-income areas occurred on a wide scale in Kampala. In a review in 2002 of possible changes in socio-economic conditions within the city, it was concluded that there were limited changes in relative socio-economic status (Howard *et al.* 2002). Although the index proved useful, it is important to note that in other countries different variables may be included, for instance nutritional status, where this is available and used in poverty assessments.

As population is recorded within censuses, the population density component can be readily updated, but use of this data may well not be sensitive to inter-census changes. The approach is also not sensitive to intra-urban variation in growth rates that may be significant. The use of this approach would certainly not account for very rapidly developed squatter settlements; however, these were not a common feature in Kampala. Such drawbacks would, however, represent problems in applying this approach in cities where land invasion is common, such as in Latin America (Hardoy and Satterthwaite 1989). Although such drawbacks exist because the population density component is essentially a relative measure, changes in actual population density in Kampala appear to have had relatively limited impact on the use of the zoning methodology.

As a comprehensive inventory would be expected as the first activity in developing a water supply surveillance programme (Lloyd & Bartram 1991; WHO 1997), no additional costs are accrued by using this as part of a zoning methodology. The Uganda methodology used data from water usage studies to refine the component dealing with water availability and use. Although this incurred additional costs, in situations with complex water supply availability, such studies are essential to ensure that only those sources used for consumption are included within programmes to test water quality. Therefore, these studies provide useful data beyond that used in the zoning methodology.

The zoning employed in Peru relied more heavily on surveys. The lack of an explicit measure of poverty is a limitation, as the approach assumes the major influence of poverty can be captured through service level of water supply and estimates of population density. The approach used in Peru did standardise data collection and therefore can be seen as providing reliable data, although perhaps not as rich as the semi-quantitative approach used in Uganda. In repeating the survey approach adopted in Peru, there would be a benefit in collecting data on household characteristics that would allow a wider definition of socio-economic status to be derived.

A follow-up exercise in Uganda, for instance, used sample surveys where data were collected in the field on roof material and wall material, which provides an indication of relative wealth (Howard *et al.* 2002). However, the use of limited surveys was not found to be wholly satisfactory, as it became clear that in defining socio-economic status other data originally included within the quantitative index used, notably employment type, must have exerted a significant influence on overall socio-economic score. Whilst it would be possible to collect such data through community interview, doing so would be likely to increase costs and it may be more cost-effective to use secondary data from a census or other surveys where this was available and considered reasonably reliable.

Both case studies allowed surveillance programmes to prioritise activities and therefore both have legitimacy. In general, the approach used in Uganda may provide greater reliability and reproducibility of results. However, in countries where recent census data is not available, is considered unreliable or cannot be disaggregated to sufficiently small areas, the use of the survey approach in Peru provides useful data for the surveillance programme. In repeating such exercises, the development and field-testing of a range of tools and means of collecting data on socio-economic conditions would be of value.

The testing of validity of such approaches is of importance in assessing whether they provide reliable information regarding likely impact on public health in different communities. In Uganda, the outbreak of cholera provided an opportunity to use health outcome data as a means of validating the approach. This was not without problems given the imprecise reporting of some parishes

within the health statistics. There would be value in developing approaches to validity testing through the use of routinely collected data on diarrhoeal disease. However, the weakness in health surveillance systems in most developing countries suggests that it may be difficult to rely on data from clinics and there may be a need to develop routine prospective data collection in carefully selected sentinel communities (WHO 2004).

In the case studies presented here, the surveillance programme moved beyond simply addressing measures of water quality and took a more comprehensive view of water supply adequacy. These indicators were continuity of supply, cost (affordability) of water at a household level, water quantity (as determined by service level) and the quality of water. The rationale for each of these criteria was outlined based on the work in Peru (Lloyd & Bartram 1991) and is now accepted, along with estimates of coverage, as providing the core set of indicators of value for surveillance bodies in developing countries (WHO 1997). In Uganda, qualitative estimates of leakage from piped water supplies, collected through sanitary inspection, also provided a useful measure of the quality of the water supply, primarily related to overall assessment of performance by the utility. As noted in the results, the evidence from the validation in Uganda suggests that assessment of overall adequacy in supply is important in predicting risks to public health.

The value of the set of core indicators is that it takes a more comprehensive and integrated view of the adequacy of water supply in relation to public health. Given the evidence of the multiple ways in which water supply influences health this is desirable. These influences include direct impact on transmission routes of infectious disease and indirect effects where supply inadequacy results in use of contaminated sources of water and restricts hygiene practices. If surveillance programmes are to be used as a mechanism to inform improvement strategies, it is essential that they collect data that permit an understanding of the interactions between water supply and public health and are able to direct investment into those interventions yielding greatest public health gain.

Work carried out in both case studies moved beyond assessments of the piped water system and addressed issues relating to alternative sources and water stored within the home. This directed intervention strategies to improve the water

sources most commonly used by poor families and supported improvements that delivered significant public health gains.

In both case studies, surveillance staff were also directly involved in the delivery of improvements to water supply. In Peru, this included changing the 'rotation' of water supply to exempt hydrants used by vendors who served slum settlements, where extension of piped water supply was not likely to occur in the short to medium term. In Uganda, surveillance staff were involved in the re-protection of protected springs and hygiene education (Howard *et al.* 2001). Although at an organisation level institutional separation of the surveillance and remedial action roles remains desirable, in practice at a community level such differentiation may not be possible or desirable.

CONCLUSION

The development of surveillance programmes in urban areas of developing countries can generate information about the adequacy of water supplies to protect health. This information is of relevance to public health professionals in helping to set priorities for water supply improvements. The inclusion of all water sources used and of household water is important and has been shown to be possible.

Surveillance programmes are most effective when they target groups that are most vulnerable to public health risks from poor water supply, as it is within these groups that greatest public health gain can be achieved often through relatively low-cost interventions. Simple techniques can provide direction in identifying priority areas as shown by the example from Peru. Targeting of the urban poor can be most effectively achieved when poverty and vulnerability are used in determining the water supply surveillance data collection process. This has been shown in Uganda to be an effective tool in assessing vulnerability of communities to outbreaks of disease.

The data generated through well-designed and implemented surveillance programmes can be used to provide public health input into water supply improvements. Therefore, the development of targeted surveillance programmes has the potential to do much to help reduce the infectious disease burden faced by the poor in urban areas of developing countries.

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