A Household Level Water Supply and Sanitation Vulnerability Index for Urban Areas of Developing Countries

M. Dinesh Kumar
Executive Director
Institute for Resource Analysis and Policy
Hyderaba-82
India
Phone: +91 40 4261 7392
Email: dinesh@irapindia.org/dineshcgiar@gmail.com

K. Nagasreenivas
Manager-Urban Programme
Arghyam, Bangalore
Email: nagasreenivas@arghyam.org

&

B. K Harish Kumara
Ph. D Scholar
Mysore University
Email: harish.bk9@gmail.com

Corresponding Author: M. Dinesh Kumar, Ph. D
Email: dinesh@irapindia.org/dineshcgiar@gmail.com

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Abstract

There was very little progress in the past on the development of comprehensive approaches for surveillance of water and sanitation in urban areas of developing countries. A water supply and sanitation (WATSAN) vulnerability index, which helps identify vulnerable areas and communities for surveillance of water and sanitation, is derived. The index helps compute the vulnerability of a household to health risks associated with poor water supply and sanitation in urban areas of developing countries. This composite index has six sub-indices, viz., water availability and use index; personal hygiene and sanitation index; social institutions index; water resource endowment index; climate and flood proneness index; and population density index. The number of sub-variables, which together are considered to have influence on the measure of these sub-indices, the theoretical basis for considering these variables, the quantitative criteria for measuring these variables and the procedure to collect the data for computation are also discussed.

1.0 Introduction

Water supply surveillance is defined as 'the continuous and vigilant public health assessment and oversight of the safety and acceptability of water supplies' (WHO, 1976; 1993; 2004). 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 and UNICEF, 2000). 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 'un-served' (Howard, 2005).

Some sections of society in the developing world enjoy water supply and other services of a quality comparable to those in developed countries, frequently at lower cost (HDR, 2006; Howard, 2005). However, many households do not have access to tap connections at home. As a result, there is widespread use of a wide variety of communal water sources. These include public taps, water sold by households with a connection and purchase from vendors (Whittington *et al.*, 1991; Cairncross and Kinnear, 1992; Howard, 2001; Tatietse and Rodriguez, 2001). They also include a variety of small point water supplies such as bore wells with hand pumps, protected springs and dug wells (Gelinas *et al.*, 1996; Rahman *et al.*, 1997; Howard *et al.*, 1999). In India, urban dwellers depend extensively on private bore wells even when individual tap connections for treated water are provided by the utilities.

The data generated through well-designed and implemented surveillance programmes can be used to provide public health input into water supply improvements. The key to designing such a programme is information about the adequacy of water supplies and the health risks faced by urban populations at national or sub-national levels to identify areas that are vulnerable. But, this is scarce in many countries (Howard, 2005). Far more scarce are the information about status of environmental sanitation conditions. This is despite significant advocacy of 'people centred' and 'demand responsive' approaches in recent years.

2.0 Approaches to Water Supply Surveillance

Few published studies that address the development of water supply surveillance programmes in urban areas of developing countries exist. According to a review, while most countries have some form of guidelines on water quality, these are not routinely enforced (Steynberg, 2002). It suggested that often the health sector 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 by the WHO in South-East Asia Region noted that none of the countries had a comprehensive national programme of surveillance (Howard and Pond, 2002). Though surveillance of piped water supplies in urban areas was carried out, alternative sources and household water in urban areas were not typically included.

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). Poverty or vulnerable populations had not been a significant factor in the surveillance programme design.

3.0 The Need for a Water Supply and Sanitation Vulnerability Assessment

The foregoing discussion suggests that comprehensive approaches to water supply surveillance were by and large lacking for quite some time. The approaches to water supply surveillance that allow targeting of surveillance activities on vulnerable groups were assessed by G. Howard using case studies from Peru and Uganda. The Peru case study attempted to incorporate some measures of vulnerability into the surveillance programme design through a process of "zoning" that was based on water service characteristics. Whereas the Uganda case study involved development of a semi-quantitative measure of community vulnerability to water-related diseases, to zone the urban areas and plan surveillance activities. The zoning used a categorization matrix, which was developed incorporating a quantitative measure of socioeconomic status (education, sources of livelihood, family size and type of housing), population density and a composite measure of water availability and use (Howard, 2005).

But, the main limitation of the approach is that socio-economic conditions, population density, and water availability and use are broad indicators for locating priority areas vis-a-vis water supply, there are many more factors, such as personal hygiene (Cairncross, 1993) and environmental sanitation condition (WHO/UNICEF, 2000) which would determine the actual condition vis-a-vis prevalence of water related diseases and community's health. Again, their effects in terms of degree of access to water supplies and sanitation facilities, and the health outcomes could be influenced by several external environmental factors besides population density.

Essentially, the investments and actions need to be targeted at the areas, pockets and communities that are most vulnerable. Surveillance programmes are most effective when they target groups that are most vulnerable to public health risks, as it is within these groups that greatest public health gain can be achieved often through relatively low cost interventions.

Identifying the most vulnerable groups is not an easy task due to the complex interplay of a wide range of factors. Diarrhoeal disease may be caused by consumption of contaminated drinking water or inadequacy of available water that results in poor personal, domestic or community hygiene (Esrey *et al*., 1985; Howard, 2005). 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 and Bartram, 1991; Cairncross and Kinnear, 1992; Howard, 2002). The burden of waterborne disease 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 and UNICEF, 2000). The evidence suggests that interventions targeted at poor populations provide significant health benefits and contribute to poverty alleviation (DFID, 2001; WHO, 2002). Though it appears that poverty is a major factor deciding vulnerability, it is just one of the many complex factors which would eventually determine the outcomes of family's high vulnerability to poor WATSAAN conditions.

The factors that can influence vulnerability of a family/household to poor water and sanitation conditions are: 1] degree of access to water supplies for human consumption (Howard, 2005) and personal hygiene (in terms of quantity and desired quality); 2] sanitation facilities available; 3] the appropriateness of hygiene practices followed by the communities; 4] environmental sanitation conditions; 5] condition (stock and quality) of water supply sources; and, 6] population density. Population density would be a key variable as 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). Here again, the degree of access depends on the presence/absence of social institutions and local custom and traditions, which are quite characteristic of poor and developing countries.

Climate has a major bearing on the adverse impact of lack of water for hygiene and environmental sanitation on health. In arid and semi arid climates, breeding of water-related insect vectors would be less during hot weather conditions. In flood prone areas and areas receiving high rainfall, the occurrence of water-based diseases are likely to be more, and therefore more caution needs to be exercised in the disposal of human and animal excreta (Hunter, 2003: 37). Thus, in addition to the five key factors we mentioned, climate and flood proneness also would be the macro environmental factors. There is a need to develop a composite index which takes into account these complex factors in assessing the vulnerability of urban households in developing countries to problems associated with poor water supply and sanitation conditions. This will make surveillance programmes more targeted.

4.0 Deriving a Household Level Water Supply and Sanitation Vulnerability Index

We begin with the premise built on the knowledge from extensive review of past research studies dealing with related topics that the vulnerability of a household to poor water and sanitation conditions is determined by six broad parameters: 1] water availability and use; 2] personal hygiene and sanitation; 3] presence of social institutions and ingenuity; 4] water resource endowment; 5] climate and flood proneness; and, 6] population density (based on NEERI, 2005; HDR, 2006; Howard, 2005; WHO and

UNICEF, 2000; Sullivan, 2002; UNDP and DHA, 1994). Each one of these six broad factors constitutes one sub-index of the HH WATSAN vulnerability index.

The number of sub-variables, which together are considered to be influencing the measure of these sub-indices, the quantitative criteria for their measurement, and method of collection of the data required for computing their values, are explained in Table 1. The theoretical basis for considering these sub-variables is built on the insights gained from a wide range of international literature on water supply and sanitation.

For instance, G. Howard and J. Bartram (2003) illustrate how physical distance to the source determine the level of access and how that influences the domestic water consumption by households in volumetric terms, thereby the health outcomes, based on WELL (1998), Esrey *et al.* (1985) and (1991) and WHO/UNICEF (2000). Esrey *et al.*, (1991) shows the needs for supplying good quality water to achieve the desired outcomes of water supply at the household level.

Several studies suggest that hand washing with soap is the critical component of this behaviour and that hand washing only with water provides little or no benefit (Cairncross, 1993; Ghosh *et al.*, 1997; Oo *et al.*, 2000). Similarly, van der Hoek *et al.* (2002) argues that bulk water storage is a major coping strategy for households to the negative impacts of infrequent water supply.

As poor frequency of water supply means greater need for storage and increase in total distance travelled and time spent in fetching water at a time---which were proven to have influence the quantity of water consumed by households (source: based on WELL, 1998; van der Hoek *et al.*, 2002), it is quite likely to have significant impact on domestic water consumption, the health outcomes and therefore the vulnerability.

Cairncross and Kinnear (1992) suggested that in poorer communities, where an increasing proportion of household income must be spent on acquiring water, the only major item of expenditure available for sacrifice was the food budget and therefore it was probable that high cost of water contribute to under-nutrition.

The composite index of "WATSAN vulnerability" will have a maximum value of 6.0, meaning zero vulnerability; lower values of the index meaning higher vulnerability. It is composed of five sub-indices (from A to F: Table), each one will have equal weightage in deciding the value of the index. The maximum value of each sub-index would therefore be 1.0. The sub-sub index also will have equal weightage (measured on a scale of 0 to 1.0). The sum of the values of all sub-indices under sub-index A would be divided by 10 (ten) to obtain the value to be imputed into the mathematical formulation for estimating the composite index. The sum of the values of all sub-indices under sub-index "B" would be divided by four (4) to obtain the value to be imputed into the mathematical formulation for estimating the composite index. The effect of attributes 8 & 10 of sub-index A will be captured by a combined index (m + n*0.33).

Table 1: Deriving a Household Level WATSAN Vulnerability Index

Sr. No	Parameters	Quantitative criterion for measurement	Method of data collection
A	**Water Availability and Use**		
1	Access to water supply by the type of source[1]	Vulnerability increases with deteriorating access. Access is an inverse function of the distance. The index is a function of the distance to the source from '0" within the dwelling to a maximum of 1km and above in gradations of 0.20[2]	Interviews of sample households

2	Access to alternative sources	Vulnerability increases when there are no alternative sources. The value of sub-index for attribute 2 would be "1" if there are four alternate sources & above, and the value would decrease proportionately with decrease in number of alternative sources	Do
3	Frequency of water supplies	Vulnerability increases with decrease in frequency of water delivery. Frequency can be indexed as total hours of water supply in a week as a fraction of no. of hours.	Do
4	Capacity of domestic storage systems	Vulnerability to lack of regular water supplies increases with decrease in volume of storage systems in place[3]	Interview of sample households
5	Sufficiency of water supplies	More than adequate (1); just adequate (0.7); less than inadequate (0.50); inadequate (0.3)	Do (community perception)
6	Quantity of water used	Quantity of water consumed is an important determinant of the health outcome of water supply, and therefore vulnerability Lower the quantity, higher the vulnerability. This sub-index is measured by vol. of water used as a fraction of the min. required (x/n); where "n" is water supply req. as per norms.	Do
7	Quality (chemical, physical and bacteriological) of domestic water supplies	Poor quality of drinking water increases vulnerability; Bacteriologically, physically & chemically pure is the best water[4]	Lab test results/ perceptions
8	% volume of water accessed from vendors	Vulnerability increases with increase in % contribution from vendors; the value of index would be (1-v/x); v is volume purchased from ventor	Interview
9	Total monthly water bill as a percentage of monthly income	Vulnerability increases with increasing percentage of total family income spent on water. An expenditure level of 10% of monthly income is treated as highest and most vulnerable	
10	Hygiene practices in drinking water consumption[6]	The actual quality of drinking water consumed would be the combined effect of attributes 8 and 10. Level of treatment applies to contaminated water only[7].	Primary survey data on treatments after collection

B	**Personal Hygiene & Sanitation**		
1	Access to toilet	The vulnerability is lowest when the families have access to private toilets, and will be highest when there is no toilet access[8]	Primary survey data
2	Sanitation practices followed[9]	Flush toilet is the safest; open defecation is the poorest method[10]	Do
3	Quality of disposal of black water[11]	Unsafe disposal is the most harmful (0.0); the values of the sub-index ranges from 0.33 for leaching pit type to 0.66 for septic tank to 1.0 for sewerage line	Interviews and physical observation of sanitation facilities
4	Hygiene practices followed after use of toilets[12]	Hand-washing with soap is safest from hygiene point of view; hand-washing without soap is second best and no hand-washing is dangerous[13].	Primary data from interviews
C	**Presence of Social institutions**; social ingenuity in the use of services; sanitation practices	Community's vulnerability to poor water supply conditions increases in the absence of social/community institutions; social ingenuity[14]	Primary survey (but qualitative to be obtained from discussions)
D	**Climate and Flood Proneness**		
1	Climate	The vulnerability to poor environmental sanitation is a function of climate. It increases from hot & arid to hot & semi-arid to hot & sub-humid to hot & humid to cold & humid[15].	Secondary data on climate
2	Flood proneness	Vulnerability increases with increase in flood proneness[16]	Map of flood prone areas of India with the map showing location of cities/towns
E	**Condition of Water Resources**[17]	Vulnerability to poor water supply increase with decreased water availability; increases with increase in hydrological variability; the vulnerability increases from regions with abundant water resources having low vulnerability to regions with poor water resources having high variability[18]	Do
F	**Population Density**	Population density in a locality increases vulnerability (see literature). This index is an inverse function of the population density of the city/town. It is a relative index, estimated on the basis of the highest and lowest population	Do

		densities prevailing ($1-d/d_{max}$).	

Explanatory Notes

1. Whether municipal water supplies through pipes, or individual well water or hand pump or local water sources.

2. Within the dwelling is "1.0"; within the premise and up to 100m distance is 0.80; between 100m-1.0 km distance is "0.50"; above 1km is "0.20". Once the time taken to collect water source exceeds 100m or so, the quantities of water collected decrease significantly. Thereafter, it plateaus between a distance of 100m and 1.0km and there is little change in quantity of water collected within these boundaries (Cairncross and Feachem, 1993).

3. It would decrease with increase in the ratio of the actual storage capacity available" to the "storage capacity required"; and the value of the index would be higher. The storage capacity required would be an inverse function of the frequency of water supply. If supply comes once daily but during odd hours, then it can be assumed that the volume of water for the entire day's use would be required to be stored. So, the storage capacity would be "n*f". If it comes during day time for less than an hour, then half the daily water use would be the storage requirement. For more than one hour, the storage requirement would be minimal (around 20 litres per capita). With alternate day water supply, it could be the 2*n*f. For once in three days, it would be 3*n*f and likewise. For round the clock water supply, the storage requirement would be zero, and here the ratio can be assumed as 1.

4. The value of the sub-index "m" would be 0.33 if the water is pure either bacteriologically or physically or chemically. The value would be 1.0 if pure on all counts.

5. The value of the sub-index will be assumed to be "0" if the family spends 10% or more of its monthly income on obtaining domestic water supplies, and would keep on increasing with reducing amount of money spent in water bill. The mathematical formulation for computing the index therefore is [$1-W_C/MI$]; where W_C is the monthly expenditure on securing water supplies, and MI is the monthly family income.

6. Direct consumption; clothe filtration, filters, UV treatment, RO, boiling of water. The value for level of treatment 'n' varies from zero for direct consumption; 1 for clothe filter; 2 for filter and UV to 3 for RO system

7. The combined index would be (m+ n*0.33); clothe treatment would increase its value by 0.33; filter would increase by 0.66; and RO would ensure ultimate treatment with a value of 1.0.

8. The options are private toilet; (1.0) common toilet (0.66), public toilet (0.33) and "no toilet access (0.0).

9. Open defecation; use of pit type toilet; use of flush toilets.

10. The value ranges from 0.0 for open defecation to 0.50 for pit type to 1.0 for flush toilet.

11. No safe disposal; leaching, septic tank; and sewerage system.

12. Does hand-washing with soap; does hand-washing without soap; does not do hand-washing after toilet use; does not use hands but pipes for washing.

13. The value of the index ranges from "0" for no hand-washing to "0.50" for hand-washing without soap to "1.0" for hand-washing with soap.

14. The value can range from "0" for the absence of social institutions or ingenuity to 0.50 for presence of either of these to 1.0 for the presence of both. Social institutions would include: WATSAN committees (Y=0.25; No=0); and Citizen Oversight committees (Y=0.25; No=0.0). Social ingenuity would include: existence of water sharing traditions between households during crisis (Y=0.25; No =0.0) and practice of re-using water in households--using bathing/washing water for toilet flushing, use of sand & ash for cleaning utensils etc. (Y=0.25; No-0.0).

15. The value ranges from "0.0" for cold & humid' to "1.0" for hot & arid with increments of "0.20". The five categories of climate are provided in Table 1.

16. The value can be "0.0" for flood prone area and "1" for the rest.

17. Renewable resource, variability in resource availability over time and stock

18. It takes into account the average annual water availability, and its variability. The value of water resource sub-index for a total water resource availability of 1,700m^3/capita per annum and above is taken as "1.0". For lower values, the value of the sub-index is derived by dividing the figure by 1700. This is multiplied by (1-CV fraction) to obtain the effective water resource index. This is based on the physical water scarcity index developed by M. Falkenmark.

5.0 Conclusions

The development of an approach that incorporates vulnerability indices is a useful tool to identify vulnerable cities/towns and pockets within to target data collection in water supply surveillance (Howard, 2005). In this paper, we have attempted a household level WATSAN vulnerability index for urban areas in order to see how vulnerable they are to problems associated with poor water supply and sanitation conditions. Computing the household level vulnerability index can assist a utility in targeting WATSAN interventions into communities and strategies where public health gains are likely to be greatest. On the other hand, public health surveillance can be used to assess the robustness of the WATSAN vulnerability index derived for a town or household. Ultimately, for a given level of water supply and sanitation, the vulnerability can also vary depending on the age profile of the family members (Hubert, 1985)[1]. We have not considered this aspect, while developing the vulnerability index.

[1] For instance, studies in India showed that smaller children are more vulnerable to the health consequence of poor quality of water supplied in terms of nutritional status, while children

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