Deriving a Town-level WATSAN Vulnerability Index for Urban Areas

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Abstract

A WATSAN vulnerability index, which helps identify vulnerable cities/towns for surveillance of water and sanitation, is derived. The index helps compute the vulnerability of a town to health risks associated with poor water supply and sanitation. This composite index has ten sub-indices, viz., 1] water resource availability; 2] water access; 3] infrastructure characteristics; 4] environmental sanitation conditions; 5] public health outcomes; 6] water quality index; 7] institutions and management index; 8] water price index; 9] role of civil society in governance; and 10] climate, population density and flood proneness. The number of "minor" factors which together are considered to have influence on the measure of these sub-indices, the underlying assumptions, the methods for methods and procedure to compute and the data sources are also discussed.

1.0 Water Supply Surveillance

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 Past 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 Why a Town-level WATSAN Vulnerability Index?

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 (see 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 within a town/locality. Most of the socio-economic criteria are not useful when selection has to be made from among a group of towns/cities. The reason is the variations in socio-economic conditions across towns may not be as sharp as that which exists across localities within a city/town. Even some of the richest cities and towns are having significant populations living in slums. At the same time, a review of international literature suggests that factors such as water resource endowment, water access, water price, the condition of water infrastructure, environmental sanitation conditions, water quality, role of civil society in governance, the nature of institutions and management can have significant influence on the city/town's vulnerability (based on HDR, 2006; NEERI, 2005; Sullivan, 2002; UN-HABITAT; WHO and UNICEF, 2000) These factors can vary significantly across cities and towns. As noted in the earlier paper, the other factors that could potentially influence the vulnerability are population density (Woodward *et al.*, 2000), climate and flood proneness (NEERI, 2005; UNDP and DHA, 1994).

Considering these factors in assessing vulnerability is particularly important for countries like India, where variations in several of these attributes across cities/towns are quite visible, as shown by a recent analysis of 301 cities/towns in the country (source: analysis of data provided in the report of NIUA, 1999). Some cities fall in water-rich areas, whereas some others fall in regions of acute water shortages (source: analysis of hydrological regimes and climate by Arghyam/IRAP, 2009). Many fall in relatively water rich and water stressed areas. Differences are seen in prices charged by utilities across cities (source: data from ADB, 2007), due to the remarkable variations in the cost of production and supply (from 0.13 to 10.17 Rs/m^3 of water as per 1999 data). Major variations in water supply conditions exist. Some cities supply water for 10-12 hours, whereas some supply for half an hour a day. Conditions of sanitation infrastructure vary remarkably from open defecation covering large proportions to decentralized sanitation system like septic tanks/pits to modern toilets connected to sewerage system for distant disposal even across cities falling under the same category. Chemical quality of the supplied water varies drastically depending on the nature of the source[1]. Climatic conditions vary drastically from south to north and from east to west. Population density of the urban areas also varies--from 1,700 per sq.km to 30,000 per sq. km. Some cities in India are located in flood-prone areas (source: based on GOI, 1999: Figure).

4.0 Deriving a WATSAN Vulnerability Index at the Town/City Level

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 town/city to poor water and sanitation conditions is determined by ten broad parameters: 1] availability of water resources; 2] water access; 3] water infrastructure characteristics; 4] public health outcomes; 5] water quality index; 6] water price; 7] environmental sanitation at city level; 8] institutions and management; 9] role of civil society in governance; and 10] climate, population density and flood proneness in the city. Each one of these six broad factors constitutes one sub-index. The number of "minor" factors which together are considered to be influencing the measure of these sub-indices, the methods and procedure for their computation, and sources of data are explained in the table below.

Three quantitative variables are used to get a measure of the sub-index, named "availability of water resources". Likewise, nine variables are used to get a measure of the sub-index named, "water access". In the case of the third sub-index, i.e., water infrastructure characteristics, six quantitative variables are used. In the case of the eighth sub-index, i.e., institutions and management, eight variables are used (see the Table for details).

The composite index of "WATSAN vulnerability" will have a maximum value of 10.0, meaning zero vulnerability; lower values of the index meaning higher vulnerability. It is composed of five sub-indices (from A to J: 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.

Sl.	**Parameters**	**Criteria for Measurement**	**Method of Data**

[1] Generally in areas where wells are the main source of water supply, different water quality issues are encountered from high levels of fluoride to high levels of TDS to high levels of nitrite depending on the region under consideration.

No.			collection
A	**Availability of Water Resources**		
	Note: the max. value of the sub-index **A** would be 3.0; it has to be reduced to a scale of 1.0; 1, 1.1 and 1.2 will be a combined sub-index, computed by taking the multiple	1. Surface water and groundwater availability in the area[1] 1.1 Variability in resource condition[2] 1.2 Seasonal variation[3] 2. Vulnerability of the resource to pollution or contamination[4] 3. Annual water demand of the town (x) as an inverse function of supply potential of the source =[**1-x/WSP**]	Macro level hydrological and geo-hydrological data for all sub-indices Do Geo-hydrological map Secondary data on the city's water supply source Analysis of secondary data from utility questionnaire
B	**Accessibility**		
	Note: the maximum value of the sub-index **B** would be 9. It has to be reduced to a scale of "1.0". 1. & 1.1 will be a combined sub-index. Also, 2 & 2.1, and 6 & 6.1 will be combined indices	1. % households having access to piped water supply estimated as a fraction of total households 1.1. % of households with piped water supply having access to treated (tap) water. 2. Average per capita supply as a ratio of the requirement 2.1Distributional equity (Gini coefficient) 3. Frequency of water supply from public system[5] 4. Power supply conditions[6] 5. Access to sanitation as a % of total households 6. % of households depending on public taps/stand post, value of which is estimated as an inverse function 6.1 Time spent in water collection, including waiting; a relative index, computed by taking the inverse value of the time spent in relation to the best performing utility ($[T_{max}-T]/[T_{max}-T_{min}]$) 7. % Population depending on hand	Utility questionnaire Do Do Estimates based on primary data Utility questionnaire State Electricity Board Utility questionnaire Do Do Do

		pumps/bore wells 8. % Volume of water accessed from private tanker suppliers (as fraction) 9. % of population living in slums as fraction	 Estimated from household data Census
C	**Infrastructure Characteristics**		
	The maximum value of the sub-index would be 3. It will have to be reduced to a scale of 6.0	1. % households covered by the water distribution system as fraction 2. Cost of water production & supply of water, a relative index computed by taking the inverse value of the cost over the lowest cost found ($[C_{max}-C]/[C_{max}-C_{min}]$; lower the cost, lesser would be the vulnerability sub-index 3. % households covered by sewerage system as fraction 4. Condition of water supply infrastructure: very good =1.0; good = 0.8; average =0.6; poor =0.4; very poor = 0.20 5. Condition of sewers: very good =1.0; good =0.8; average =0.6; poor =0.4; very poor =0.20 6. Coverage of stormwater collection system (as a ratio of total households/ W.S connections)	Do Do Do Interview of officials Interview of officials Utility questionnaire Do
D	**Public Health Outcomes**		
	The max. value is 2.0; it will have to be reduced to a scale of 1.0	1.Under-five mortality rate (IMR) (out of 1,000 people), a relative index, value of which is computed by taking the inverse of the value in relation to best city $\{IMR_{max}-IMR\}/(IMR_{max}-IMR_{min})$ 2. % households reporting illness due to WRD, again a relative index, computed by taking inverse of the value in relation to the best city $\{WRD_{max}-WRD/[WRD_{max}-WRD_{min}\}$	Household survey questionnaire (mean values) Do
E	**Water Quality Index**		
	The max. value is 3.0; it will have to be reduced to a scale of 1.0	1. Chemical quality of water (pure =1; impure =0.0) 2. Physical quality (turbidity) (pure =1; impure =0.0)	Utility questionnaire Do

		3. Biological quality (pure=1.0; impure=0.0)	Do
F	**Water Price**[7]		
	The max. value is 3.0; it will have to be reduced to a scale of 1.0	1. Price of water for domestic sector, as a relative index 2. Price of water for commercial use, as a relative index 3. Price for industrial use, as a relative index	Utility questionnaire Do Do
G	**Environmental Sanitation at City Level**[8]		
	The max. value of the sub-index G is 6.0; it will have to be reduced to a scale of 1.0	1. Type of sewer (OSD, BSD, ST, Pt, S) 2. Rate of collection of solid waste against total generation 3.Type of solid waste disposal 4. % of wastewater treated as a ratio of total wastewater 5.Whether preliminary; primary or secondary treatment: value to range from 0.33 for primary to 1.0 for tertiary 6. Point of disposal of treated/untreated wastewater[9]	Utility questionnaire Do Do Do Do Do
H	**Institutions & Management**		
	The maximum value of the sub-index **H** will be 8.0. It will have to be reduced to a scale of 1.0	1. **Staff** :Number of staff per 1,000 connection (relative index, value of which is computed on the basis of the highest and lowest numbers found across utilities	Interview with the officials of the utility
		2. Frequency of Complaints: Vulnerability increases with number of complaints about water supply	Interview with the officials of the utility
		3. Time Taken to handle complaints: Vulnerability increases with delay in handling complaints; again is a relative index, computed by taking time taken by the best and worst performing utilities	Utility questionnaire
		4. **Performance Improvement Measures**: a] Leak detection; b] Leakage reduction; c] Computerization of customer care; d] online payment & complaint registration; e] use of GIS in planning & data management; f] performance rewarding; 7] autonomy in	Interview with officials/Utility questionnaire

		hiring & firing staff[10]	
		6. **Financial performance**: Ratio of revenue and expenditure (Cost recovery ratio); the maximum value is 1.0, and also when income is more than expenditure	The utility questionnaire
		7. **System upkeep:** Relative index, value of which is computed by taking the values of the highest and lowest expenditure incurred for O & M per connection across cities/towns	The utility questionnaire
		8. **Frequency of WQM**: vulnerability increases with reducing frequency[11]	The utility questionnaire
I	**Civil Society in Governance**		
	The maximum value of the sub-index **I** will be "3.0". It will have to be reduced to a scale of 1.0; Value of "1" would be computed by taking multiple of values of 1.1 and 1.2; 2 will be multiple of 2.1, 2.2 and 2.3. The WATSAN committee and the Citizen Oversight Committees report to the council.	1. Role of elected representatives in urban water governance 1.1 Provision of funds for external audit (Y=1.0; No=0.0) 1.2 Organizing ward meetings (Y=1.0; No=0.0) 2. Civil society development initiative 2.1 Public hearings as part of budget preparations 2.2 Awareness campaigns (of water & sanitation; conservation) (Y=1.0; No=0.0) 2.3 Transparency in sharing information on budgets, expenditure, projects etc. (Y=1.0; No=0.0) 3. Civil society participation in decisions 3.1 Formation of WATSAN committees (Y=1.0; No=0) 3.2 Citizen oversight committees (Y=1.0; No=0.0)	Discussion with stakeholders (municipal commissioners; councillors & chairperson; NGO representatives; civil society leaders
J	**Climate, Flood-proneness and Population Density**		
	Climate (whether semi arid/arid/hyper-arid or sub-humid/humid	The vulnerability to poor environmental sanitation is a function of climate (see literature). It increases from hot & arid to hot & semi-arid to hot & sub-humid to hot & humid to cold & humid[12].	Secondary data on climate
	Flood proneness (whether flood prone or not)	Vulnerability increases with increase in flood proneness[13]	Map of flood prone areas of India with the map showing location of cities/towns
	Condition of Water	Vulnerability to poor water supply	Do

	Resources[14]	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[15]	

End notes

1. A renewable water availability of 1700 m^3 per capita per annum is considered adequate for a region or town, estimated at the level of river basin in which it is falling. The value of the index is computed by taking the amount of renewable water as a fraction of the desirable level of 1,700m^3

2. Higher the variability, greater will be vulnerability. The index is computed an inverse function of the coefficient of variation in the rainfall variability in that basin/sub-basin (1-x/100); where x is the coefficient of variation in rainfall.

3. For alluvial areas, the value of this index is considered as 1. For hard rocks, the value is considered as 0.3. For sedimentary and alluvial deposits, the value is considered as 0.65.

4. Shallow groundwater in urban areas; river/stream/reservoirs in the vicinity of industries are highly vulnerable with a value of the sub-index equal to 0.0; distant reservoir in the remote virgin catchments and groundwater from deep confined aquifers has a pollution vulnerability index of 1.0; shall groundwater in rural areas to have medium vulnerability with a value of 0.50.

5. 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.

6. Computed as the total number of hours of power supply as a fraction of total number of hours in a day

7. Higher the price, greater the vulnerability. The weighted average of the price with respect to volume would be used for computing the value of the combined price index for all sectors. It maximum value would be reduced to a scale of 0.0-1.0

8. A combined index for 4, 5 and 6 would be computed by multiplying the values of each sub-index

9. Value will be one (1.0) for sea/ocean (considered to be the safest from environmental sanitation); 0.67 for reuse in agriculture; 0.33 for disposal in natural streams or other water bodies. In the case of tertiary treated wastewater, the value of the sub-index would be considered as "1.0".

10. Presence of these management measures reduces the vulnerability of the city to poor water & sanitation. Presence of each one of them in the management would earn the utility a score of 1/7. In the absence of it, the scope would be 0.0

11. This is a relative index, value of which is computed by taking the highest and lowest frequency in WQM by the utilities having similar type of water source.

12. The value ranges from "0.0" for cold & humid to "1.0" for hot & arid with increments of "0.20"

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

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

15. 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

In this paper, we have attempted a town level WATSAN vulnerability index. Computing the household level vulnerability index can assist a utility in targeting WATSAN interventions into those towns and cities where public health gains are likely to be greatest. On the other hand, public health surveillance undertaken across towns can be used to assess the robustness of the WATSAN vulnerability index derived for a town. The derivation of the index is such that higher the value of the index, lower would be the vulnerability of the town to poor water and sanitation conditions. The present tool is more relevant for countries like India where major variations in resource endowment, climate, population density, water quality, water price charged by utilities, institutional capacity and management styles and governance practices are visible across cities.

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