Cross-contamination of distributed drinking water as the cause of waterborne outbreaks in Armenia 1992–2010

Emma Anakhasyan, Christoph Hoeser, Thor Axel Stenström and Thomas Kistemann

ABSTRACT

Investigations and established causal relationship of waterborne outbreaks (WOs) from developing countries and countries in transition are sparse and mainly centered on agents, such as from Vibrio cholera and Shigella dysenteriae. Information, however, prevails in countries like Armenia with an epidemiological system in place. Groundwater is the main drinking water source (96%); water is delivered intermittently 12–14 hours per day. In 2005 about 7% of all infant deaths were attributed to intestinal infectious diseases. Recorded information on WOs and supply systems (1992–2010) was obtained from published official sources, from ‘gray-literature reports’, primary data collection from statistical records and through personal communication. Epidemiological descriptive analysis was made and Geographical Information System (GIS) applied for results visualization. In-depth outbreak analysis was conducted on selected cases. Overall, 104 WOs caused by different etiological agents were revealed. The main drinking water source in areas where outbreaks occurred was the centralized water supplies (69.2%) based on GIS mapping. The major cause of outbreaks was the cross-contamination of drinking-water distribution by wastewater. In Armenia the main areas to be addressed for the future are: service quality, source protection, delivery interruption and subsequent microbial contamination.

Key words | delivery interruptions, microbial water contamination, water and sanitation, waterborne outbreaks, water distribution

ABBREVIATIONS

ADB Asian Development Bank
CDCP Center for the Disease Control and Prevention of Armenia
CDC Centers for Disease Control and Prevention
CISID Centralized Information System for Infectious System
GIS Geographical Information System
HEC Hygiene and Epidemiological Centers
MoH Ministry of Health
NSS National Statistical Service
OECD Organisation for Economic Co-operation and Development
SHAEI State Hygienic and Anti-Epidemic Inspectorate
SHEEC State Hygienic and Epidemiological Expertise Centers
SHESES State Hygienic and Epidemiological Services
AWS ‘The Armenia WSS’
UK United Kingdom
UNECE United Nations Economic Commission for Europe
USA United States of America
WSS Water and Sanitation Services
WOs Waterborne outbreaks
WHO World Health Organization

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INTRODUCTION

Importance of water and sanitation for public health

Water-related diseases and sanitation-related infections are major causes of diarrhea morbidity and mortality worldwide (Hunter 2005). Unsafe drinking water, inadequate availability of water for hygiene and lack of access to sanitation together contribute to the burden of diarrhea.

The World Health Organization (WHO 2008) estimates the global burden of disease for diarrhea to be 4.1% which includes an estimated death of 1.8 million people annually. The main burden of disease falls on the poorest societies and especially on children under 5 years of age (Hunter 2005; WHO 2007) being responsible for 17% of the deaths in this age group (WHO 2008; UNICEF & WHO 2009).

Although, over 90% of the population of the WHO European Region is covered by improved water supplies, such as piped water into dwellings, yards or plots, public taps or standpipes, tubewells or boreholes, protected dug wells, springs and rainwater (WHO & UNICEF 2010), outbreaks of water-related disease do occur in the region due to e.g. contamination of the distribution network or the irregular use of small water supplies (Valent et al. 2004; WHO 2007).

In the countries of the former Soviet Union, the water and sanitation infrastructure has deteriorated and the service has been further disrupted due to poor maintenance during the last two decades (Valent et al. 2004). A true estimate of the burden of disease in these countries has not been made. It has however been realized in Armenia that contaminated water has been an important cause of diarrhea and that about 7% of all infant deaths can be attributed to intestinal infectious diseases (National Statistical Service [NSS] 2006).

Factors that relate to waterborne outbreaks (WOs) in Armenia include deterioration of water and sanitation infrastructure, the access and availability of drinking water, the types of supply, and the sanitation coverage.

The main objective of this study was to present a comprehensive baseline analysis of the WOs (1992–2010) in Armenia after independence from the former Soviet Union by bringing together scattered data from various sources and assessing their causal relationships. This paper is an epidemiological retrospective study of WOs where Geographical Information System (GIS) has been applied for further visualization of the results.

Waterborne outbreaks

The epidemiological relationship between water and disease was well established at the end of the nineteenth century and thereafter. Outbreaks of cholera, shigellosis and typhoid then occurred in Western Europe. For example, in 1897–1898 the Maidstone typhoid outbreak occurred in the United Kingdom (UK) where 2,000 people were affected and 143 people died due to the contaminated water and poor distribution system (Stanwell-Smith 1997). The seventh pandemic of cholera (1961–1989) again highlighted the global perspective of traditional waterborne disease affecting 117 countries (1,713,057 cases) mainly in Asia and Africa. In the beginning of this period (1965–1969) 10,723 cases of cholera were reported in the 11 Soviet Republics, but none in the Baltic Republics or in Armenia (Narkevich et al. 1993).

The list of potential etiological agents has been expanded from the early stages, from mainly shigellosis, typhoid and cholera, to include a range of bacterial, viral, and parasitic agents. The 65 UK WOs in 1991–2000 serve as an example with 4,112 cases reported, mainly due to Cryptosporidium and Campylobacter (Hunter 2005). Similarly, outbreaks in Sweden in recent years were mainly attributed to Campylobacter, Giardia intestinalis and noroviruses (Anderson & Bohan 2001; Carlander 2006). Two recent large Cryptosporidium outbreaks occurred in 2010–2011 affecting in total more than 40,000 people (Stenström personal communication).

The picture is similar in the US with 126 drinking water outbreaks recorded in 1991–1998 (Hunter 2003) related both to public (109) and individual water (17) systems. Thereafter, in 2003–2006, 40 WOs were reported linked to contamination and lack of treatment of drinking water (Liang 2006; Centers for Disease Control and Prevention [CDC] 2008).

WOs, in general, mirror a failure in the supply system and its documentation, which presents an opportunity for
improvements both in the affected system as well as in similar ones.

**Drinking water and sanitation in Armenia**

Groundwater from springs or boreholes is mainly used as the source of drinking water in Armenia (96%) (United Nations Economic Commission for Europe [UNECE] 2000). Water from 296 groundwater sources, of which 176 are artesian wells, and 29 river water intakes provides the main centralized drinking water (Babayan 2006). In addition, 12 surface water sources provide water for about 170,000 people (Babayan 2006 and personal communication 2010). Centralized drinking water is disinfected by chlorine in the distribution network (UNECE 2000). The percentage of people with access to the centralized water supply differs between rural and urban populations: 49 and 93% correspondingly (Manvelyan et al. 2006).

The Water and Sanitation Services (WSS) are provided by five companies, all mainly serving urban settlements as well as part of the rural population (45%) (Manvelyan et al. 2006; Organisation for Economic Co-operation and Development [OECD] 2008). Among the 934 communities, 871 are located in rural areas (World Bank [WB] 2004). About 530 rural communities historically operate their water supply services (with or without piped water) independently through local springs and other sources (Karapetyan 2006). Generally, the duration of water delivery for cities is 12 hours and for villages 14 hours (OECD 2008). Unlike the large companies, the issues related to drinking-water service provision are not regulated in the smaller communities. The infrastructure for rural water supply differs relatively old (the average age is about 35 years) (OECD 2008). According to the World Bank report, only 2% of the rural drinking water infrastructure among the surveyed 871 communities was considered good, 35% fair and 63% poor (WB 2004).

A sewerage system existed in about 96% of urban and 4% of rural areas (Asian Development Bank [ADB] 2008; OECD 2008). In rural settlements sanitation is in the form of a simple pit latrine (81%), collection in septic tanks (3%), open ditches (3%) or unclassified (9%) (OECD 2008).

In the smaller communities, with a high degree of poverty, the lack of investments and collapse of water supply systems have resulted in an inadequate and often unsanitary water supply.

**Structure of surveillance system and data collection**

The sanitation and epidemiological offices inherited from the Soviet system were responsible for surveillance in the early 1990s (Wuhib et al. 2002), but were replaced by local provincial ‘Hygiene and Epidemiological Centers (HEC)’ in 1997 under the State Hygienic and Epidemiological Services (SHES).

A further restructuring was done in 2002 with a division between the State Hygienic and Anti-Epidemic Inspectorate (SHAEI) and the State Hygienic and Epidemiological Expertise Centers (SHEEC). The regional SHEECs assist the regional SHAEI centers ensuring the implementation of necessary investigations, expertise and laboratory analyses. At the national level the National Hygiene and Anti-Epidemiological Surveillance Inspection is supervisory and the Center for the Disease Control and Prevention of Armenia (CDCP) is responsible for collection and analysis of epidemiological data.

The local SHAEI receives notification about each case of communicable disease including waterborne diseases from all health-care facilities, carries out and/or facilitates epidemiological investigation through SHEEC, determines the cause of the outbreak and develops and implements preventive measures and recommendations. The SHAEI also monitors the quality of drinking water. If three or more confirmed or suspected cases of an infectious disease with similar symptoms are registered simultaneously, the country SHAEI should be notified by telephone or personally within 12–24 hours. Data on infectious diseases are provided monthly and annually from the district to the national level.


Armenia is a signatory to ‘The UNECE/WHO Protocol on Water and Health’, which is a legally binding instrument for ensuring access to safe water, provision of sanitation and prevention of waterborne diseases (UNECE 2000).
METHODS

Information collection

Information on WOs was obtained by reviewing the published official sources, ‘gray-literature reports’, SHES and Bulletins of the National Health Analytic center; collection of primary data in statistical records; and through personal communication with the main responsible information providers of SHAEI and CDCP.

The data on morbidity for selected infectious diseases were obtained from the databases of the National Statistical Service (NSS) of Armenia and the WHO Centralized Information System for Infectious System (CISID). In the case of a discrepancy between data of NSS and CISID databases, preference was given to the information of the NSS. If data on diseases were absent in the NSS database then CISID information was used.

The data on 104 WOs during 1992–2010 were compiled, including the details on location, outbreak onset, number of ill and hospitalized persons, mortality and type of outbreaks.

Information on the water supply system was obtained by literature review, collection of statistical records and through personal communication with the main responsible information providers of ‘The Armenia WSS’ (AWSC) and CDCP. More detailed data were collected for the largest WSS, the AWSC, which provides water for 619,000 people (37 urban and 280 rural settlements). The data on water and sanitation coverage were sometimes uncertain especially from the 530 locally operated communities. However, the validity of the collected data was sufficient for the application of the GIS-tools.

The data from different sources were cross-checked to improve the reliability of information.

GIS application

GIS software (ArcMap program (version 9.3) – Environmental Systems Research Institute, Inc., Redlands) was applied for visualization of obtained information. Maps, tables and export files were created. The set of parameters which were transferred to the GIS were: location of the WOs, communities, the main types of drinking water supply, centralized drinking water and sanitation coverage, population of urban areas connected to centralized sanitation system, the availability of centralized drinking water delivery, major rivers and lakes, surface waters and water quality monitoring stations (mainly chemical monitoring), irrigation water canals, irrigated areas, wastewater treatment plants and sewerage canals.

The spatial data on administrative boundaries, settlements, rivers and lakes, infrastructure, water and sanitation canals were obtained from the Acopian Center for the Environment and AWSC. The information on the main sources of potable water for the community, water delivery of the centralized water supply and the percentage of community households with connection to the sewerage main was obtained from the United Nations Development Program in Armenia (Community Data Base for Rural Communities).

According to the law ‘On Territorial Administrative Division’ 134 settlements were united in 61 communities. The co-ordinates representing spatial information on the settlements were used for the creation of maps. The geographical co-ordinates representing spatial information were missing for three communities having WOs. These three communities were excluded, whereas 16 settlements were included in the GIS maps although they represented seven WOs (one outbreak in several settlements).

RESULTS

In 1994, 34% of water distribution networks did not comply with the regulations while in 2006 this percentage had increased to 60.2% (Figure 1). In order to prevent and eliminate the pollution of water used by the communities, the local government councils have determined sanitary protection zones with special protection regimes. The lack of these
protection zones for drinking water sources however had gone up from 20.7% in 1994 to 61.4% in 2006. Data related to protection zones for water sources were not available for 1995 (min in Figure 1 graph). The identified causes were: lack of sanitary protection zones (64%), lack of treatment facilities (45%) and lack of equipment for disinfection (90%) (Vanyan 2008).

Similarly, an increase in water samples with elevated levels of *Escherichia coli* and fecal coliforms occurred: in 2000 (13.4%) and in 2006 (21.8%) mainly due to deterioration of water pipelines resulting in contamination of drinking water by wastewater. The contamination of water (89.7%) was mainly due to the failures in the water distribution network (Vanyan 2008).

**Waterborne outbreaks in Armenia**

The following groups of intestinal infectious diseases are subject to official registration: typhoid/paratyphoid fever; infectious salmonella; hepatitis A; shigellosis (laboratory confirmed; based on the clinical picture in case of negative bacteriological results; and/or the patho-morphological and histological picture in case of lethal outcome); and confirmed cases of enteric/intestinal infections caused by other specified bacterial and viral agents. The cases with negative laboratory results are included in the group called ‘Acute enteric infections of unknown etiology’.

Acute intestinal infections of unknown etiology dominated the etiology of enteric infections in 1993–2008 in Armenia (Figure 2). All diseases showed a decreasing trend starting from 1998–1999. The peak of unknown gastrointestinal cases in 1998–1999 was due to an outbreak in the city Abovian. The number of cases of hepatitis A decreased from 1998 to 2001 whereafter it leveled out (700–800 cases per year). The number of cases of bacterial dysentery was 2,520 in 1993, whereafter it decreased to almost half this number. Cases of typhoid/paratyphoid fevers, known enteritis and infectious salmonella stayed at almost the same level.

The detected 104 WOs (1992–2010) were all of microbial origin. The main waterborne diseases were dominated by cases of unidentified infectious enteritis, bacterial dysentery and typhoid. During the outbreaks only bacteriological analysis were performed. The link to water was confirmed by bacteriological analyses or by the epidemiological pattern in the affected population of the area and coinciding accidents in supply system and sewerage. The numbers of cases sometimes lacked precision.

The yearly frequency of outbreaks with the corresponding registered number of cases is summarized in Table 1. The number of cases is presented in ranges showing a summary of minimal and maximal number of cases stated in different sources. Data on the number of cases related to three outbreaks are missing (marked with + in the table) or unreliable. The largest number of outbreaks (19) and cases occurred in 1999. The outbreak in 1994 is of interest since children (0–14 years old) were the most affected group (66.8% of the cases).

The average annual incidence was 3.25 per 10,000 people. The incidence varied between the provinces, with Kotayk showing the highest incidence (16.08) with 15 outbreaks and Aragatsotn the second highest (6.87) with 16 outbreaks. Yerevan with a population of 1,112,100 was...
below average (2.25). Shirak had 9 small outbreaks but the lowest overall incidence (0.41).

Slightly more than half of the outbreaks occurred in urban areas. The affected sources of drinking water were mainly the centralized ones (in 72 outbreaks, 69.2%), the ones managed by communities (13, 12.5%) and the wells (2, 1.9%). In 17 of the outbreaks the supply information is unclear.

The etiological agents are mixed in 52% of the outbreaks, with more than one pathogen, including dysentery, salmonellas, and known and unknown enteritis (Figure 3). In 14 outbreaks the cases were attributed to one predominant pathogen. One outbreak of tularemia and one outbreak of cholera were reported.

**Exemplification of waterborne outbreaks**

Out of the 104 outbreaks four are further exemplified below: (1) the cholera outbreak in 1998, (2) the largest outbreak occurring in Kotayk in 1999, (3) an outbreak in the capital in 2003 and (4) one in Vanadzor in 2008 (Table 2).

Out of the 104 outbreaks 102 either directly or indirectly were related to the distribution network and only two were due to source contamination. Application of GIS allowed integrating and displaying the spatial, water and sanitation information within a single system. The created maps provide the geographical distribution related to parameters such as centralized water and sanitation coverage, availability of drinking water delivery and WOs.

Through the application of the GIS, it was possible to generate the maps that is not existent in the country and which could serve as a baseline studies for further investigation on public health significant problems such as WOs.

**Table 1** | Number of WOs and cases in 1992–2008 in Armenia

<table>
<thead>
<tr>
<th>Frequency of WOs</th>
<th>Absolute number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>7</td>
</tr>
<tr>
<td>1993</td>
<td>13</td>
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<tr>
<td>1994</td>
<td>1</td>
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<td>1995</td>
<td>1</td>
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<td>1996</td>
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<td>8</td>
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<tr>
<td>2008</td>
<td>2</td>
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<tr>
<td>2009</td>
<td>0</td>
</tr>
<tr>
<td>2010</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
</tr>
</tbody>
</table>

**Figure 3** | Etiologic agents of WOs in Armenia (1992–2008).
<table>
<thead>
<tr>
<th>Case</th>
<th>Date</th>
<th>Location</th>
<th>Etiologic agent</th>
<th>Number of cases (deaths)</th>
<th>Cases in children aged 0–14 years</th>
<th>Causes of WOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sept 1998</td>
<td>Village Zartonk (Armatir)</td>
<td><em>V. cholerae</em> El Tor</td>
<td>229–250 (2)</td>
<td>Not available (NA)</td>
<td>Information was scarce and contradictory. Zartonk (about 2,100 people) was supplied with water from two deep wells. Water was delivered according to a timetable. The outbreak was due to contamination of the distribution network by contaminated irrigation water. The cause was either due to the canal water that flowed from the sewerage network of Metsamor without treatment or through the River Sev Jur (Araks).</td>
</tr>
</tbody>
</table>
| 2    | Dec 1998 | City Abovian, (Kotayk)  | *Salm. enteritidis*, *Sh. sonnei*, *Sh. flexneri*  
*Sh. boydii*, *E. coli* O:114, *Sh. dysenteriae* | 5,516 gastrointestinal  
45 Hep A three additional villages with the same water source reported 34 cases with gastroenteritis | 2,040 gastrointestinal symptoms 39 Hepatitis A | One of the largest WOs in Armenia. *E. coli* count before disinfection was more than 1,100. Due to heavy rain a hydroelectric power station (Hrazdan) closed the locks/sluices to avoid the breakdown of the Akhpara reservoir. The level of the river rose and the waters poured into the drinking water catchment. |
| 3    | Oct 2003 | Yerevan                | *Sh. flexneri*, *Sh. sonnei*  
*Salm. arizona*              | 1,762 bacterial dysentery, (407 cases; SHAEI final data) | 945 (53.6%) | 105 positive bacteriological results (fecal coliforms, *Salm. arizona*, *Klebsiella*, *Proteus*). Typhoid fever phage-prophylactics performed among the people at high risk. This practice was used in the former Soviet Union (Wikipedia). The storm water discharge became clogged and the sewage waters contaminated the reservoir and the drinking water pipelines in the vicinity. The pipelines fed the whole of Arabkir and part of the Kentron communities. At the same time the water sources of Arzni were also affected. |
| 4    | Oct 2008 | Vanadzor               | Various bacteria,  
*Salmonella enterica*  
Viruses (rotaviruses, enteric-viruses) | 211                       |                                   | Vanadzor, the 3rd largest city in Armenia with 172,000 p.e. Water is provided from surface water sources (rivers). Drinking water quality was appropriate after treatment, but 40% of tap water samples were contaminated. The cases were related to building blocks supplied from two different water sources. A cross-connection occurred in the distribution system. Additionally construction works of sewerage pipelines were carried out at the cross point of water-supply and sewerage pipes. Disinfection was inappropriate. 51 water samples out of 115 showed bacteriological contamination. |
The water and sanitation case study of WOs occurred mainly in communities with centralized water supply systems (Map 1). Moreover, Map 2 shows that the WOs occurred in areas where the water was supplied with interruptions.

**DISCUSSION**

**Water supply systems**

Although untreated groundwater might be a safe water source, the distribution systems are vulnerable to contamination in Armenia. Interruptions in water supply lead to accelerated deterioration of the water supply system and increase the risk of microbial contamination (OECD 2004). Additionally, the deterioration of the microbial water quality is due to shortage of chlorine and poor maintenance of water disinfection. The interruptions in water supply and the leaking pipes decrease the water pressure in the distribution system resulting in sewage intrusion (OECD 2004).

**Exemplification of water and sanitation supply system**

Armenia’s WSS faced serious problems (Figure 1), especially in rural communities where drinking water supply is locally managed. In contrast, water supply is improved in communities where operators provide centralized supplies.

The improved services provided by AWSC can serve as an example. Since 2005, AWSC has analyzed water samples from approximately 550 sampling points. Bacterial contamination decreased from 6.2 to 1.8% in 2010 in investigated samples (Table 3). Service delivery time went up from 7.4 to 13.6 hours in 2010. However, the percentage of disinfected water has gone down during recent years partly due to a shortage in chlorine supply.

**Surveillance system**

The definitions of cases varied between the provinces. In some WOs only confirmed cases were reported, while in others all cases of gastrointestinal disorders were given. The epidemiological case report forms were originally...
lengthy and non-disease specific and data were mainly handled descriptively without assessing risk factors. Since 2004 new disease-specific case-report forms have been used. Hepatitis A, typhoid fever and bacillary dysentery remain serious health problems for many countries in the region. In contrast, emerging diseases such as campylobacteriosis, giardiasis, cryptosporidiosis and legionellosis are still beyond the technical capacities of the surveillance systems. In Armenia viral gastroenteritis has not been considered a priority and surveillance is poorly developed.

Mainly the large outbreaks were reported from the local to the national level. Calculation of aggregated case numbers, incidence and prevalence rates were mainly done centrally while limited analysis was made on stratification by person, time, and place and the assessment of trends was done locally. Although infectious disease reporting is mandatory on a monthly basis, information on cases of infectious diseases is sometimes not revealed or even intentionally underreported. One reason for this is that the occurrence of an outbreak could be interpreted as incompetence (Wuhib et al. 2002).

Records were stored as paper files that were often lost due to improper data management. Paper-driven investigations, inaccurate reporting and lack of standardized case definitions may lead to biased interpretation. All these factors affect the resulting figures for information, which may be biased or fragmentary for regions.

The major factors related to outbreaks in Armenia were: (1) leakage of contaminated surface waters into the distribution systems at low- or non-pressure zones, (2) formation of negative pressure in the network due to

<table>
<thead>
<tr>
<th>Indicators/years</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water samples not meeting the quality standards (%)</td>
<td>6.2</td>
<td>6.1</td>
<td>3.8</td>
<td>3.4</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Average daily water service (hours)</td>
<td>7.4</td>
<td>9.6</td>
<td>11.0</td>
<td>12.1</td>
<td>13.0</td>
<td>13.6</td>
</tr>
<tr>
<td>Disinfected water (%)</td>
<td>78.3</td>
<td>80.1</td>
<td>90.3</td>
<td>91.2</td>
<td>82.5</td>
<td>78.8</td>
</tr>
</tbody>
</table>

intermittent distribution, (3) direct intrusion of sewage waters into the damaged pipelines, (4) the back flow of water into the drinking water supply systems from illegal consumer connections. The causes of the WOs mentioned in Table 2 serve as an example of the above.

CONCLUSION

This study is the first systematic data collection and evaluation exercise on water and health issues in Armenia following the collapse of the Soviet Union. The present paper summarizes 104 WOs in Armenia and relates to causative factors during the last 19 years. There is an imminent need for attention to the broad issues of drinking water security and an upgraded sanitation system for health protection. The service quality, in terms of uninterrupted access to and microbial contamination of tap water, remains a serious concern in many communities in Armenia. Water source related factors will add to a high overall risk. Implementation of water protection zones may be part of the solution. Armenia, however, has an advantage in its historically established disease surveillance system which by ‘lessons learned’ from outbreaks may have the possibility for prioritization of remedial measures. The capacity of the current surveillance system needs to be strengthened to undertake systematic and ongoing data collection and to incorporate the emerging diseases in surveillance system. The GIS maps related to types of water supply, water availability and centralized water and sanitation coverage provide an excellent means of visualization in relation to vulnerability factors of WOs and are an effective tool for use as part of the decision-support systems for health policy-makers.

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