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PUBLIC HEALTH AND WATER QUALITY ISSUES IN SOUTH-WESTERN THAILAND AFTER THE DECEMBER 2004 TSUNAMI: LESSONS LEARNED AND ACCTED UPON

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ABSTRACT

In December 2004, a major earthquake in the Andaman Sea generated a tsunami radiating across the Andaman Sea and Indian Ocean, including coastal resort communities of Thailand among affected areas. When the tsunami struck, the Thai coast local resort communities were filled with seasonal holiday travellers from Europe and elsewhere combined with the local populations. Devastation in low lying coastal plain was indiscriminate and extensive, resulting in over 5,000 dead and 500,000 displaced.

Water supplies, sewage disposal, and solid waste management facilities were almost uniformly destroyed. Local water supplies and surface waters were immediately contaminated and subject to continuing contamination by human wastes in the absence of functioning collection and treatment systems. Public health efforts were prioritized to avoid epidemic waterborne illness. Water quality monitoring including analysis for waterborne *Cryptosporidium* and *Giardia* along with enteric disease surveillance are described to illustrate this feature of managing of natural disaster.

Keywords: *Tsunami; health effects; water quality; risk management; Cryptosporidium and Guardia; social support*

Graphical Abstract

1. INTRODUCTION

On Sunday, 26^{th} of December 2004, at about 08:00 local time (ICT, UTC + 7), a magnitude 9.0 earthquake occurred off the northwest coast of Sumatra, Indonesia. The epicentre was under the Andaman Sea at 3.32 N 95.85 E, (Figure 1). Worldwide, this was the fourth largest earthquake in the last century. The earthquake generated tsunamis that radiated out across the Indian Ocean striking first Sumatra and the nearby Andaman Sea islands, southwestern Thailand, Sri Lanka, India, and eventually the northeastern coast of Africa. Over 220000 people were killed and a half million were injured. More than 100000 were missing and over 500000 displaced in northwest Indonesia alone. [1]

Areas near the epicentre in Indonesia, e.g., Meulaboh, and Banda Aceh on the northwestern end of Sumatra, were devastated by the earthquake and tsunamis (Figure 2). In Thailand, Phuket and adjacent coastal tourist districts were heavily affected.

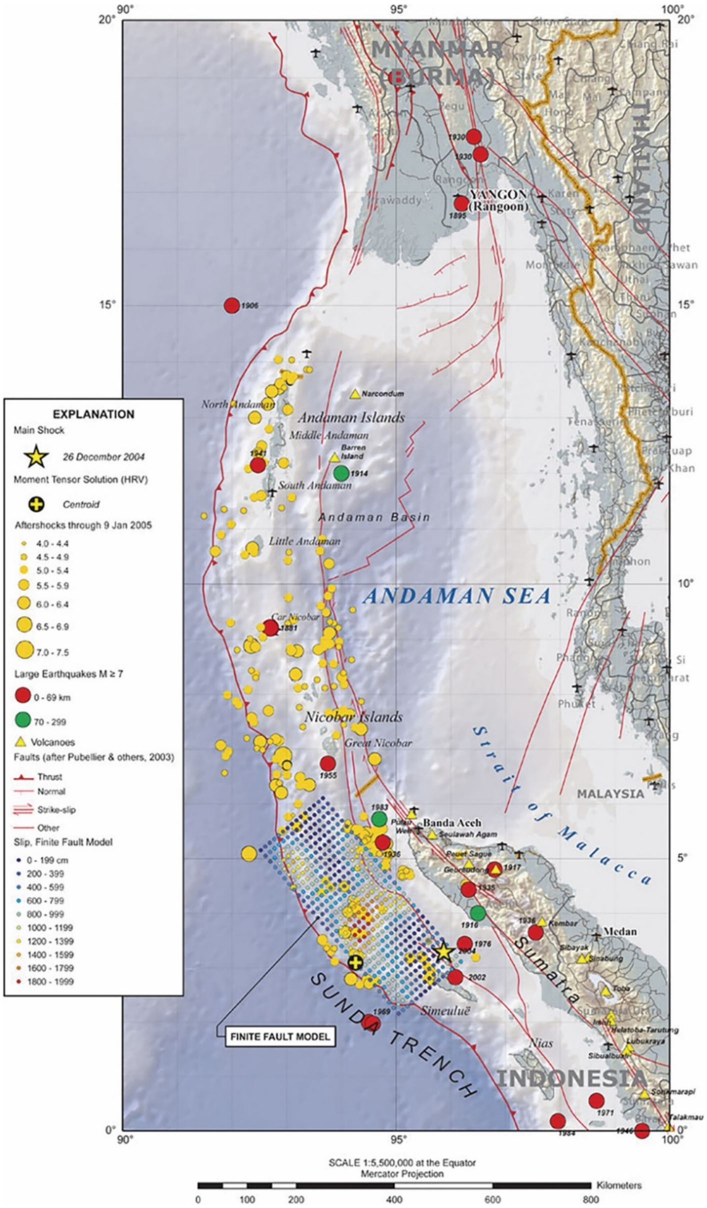

Figure 1 Andaman earthquake epicentre and after shock of > 4.0 Richter, 26 December 2004 [17].

The primary focus of this paper is the impact of the tsunami on public water supply and related public health effects in the southwest coastal tourist areas of Thailand. However, we provide an introductory description of local geography and conditions along with overriding physical effects of the earthquake and tsunami necessary to provide some perspective to those who find themselves responsible for sanitation and health issues under the most strenuous conditions in the aftermath of such a disaster.

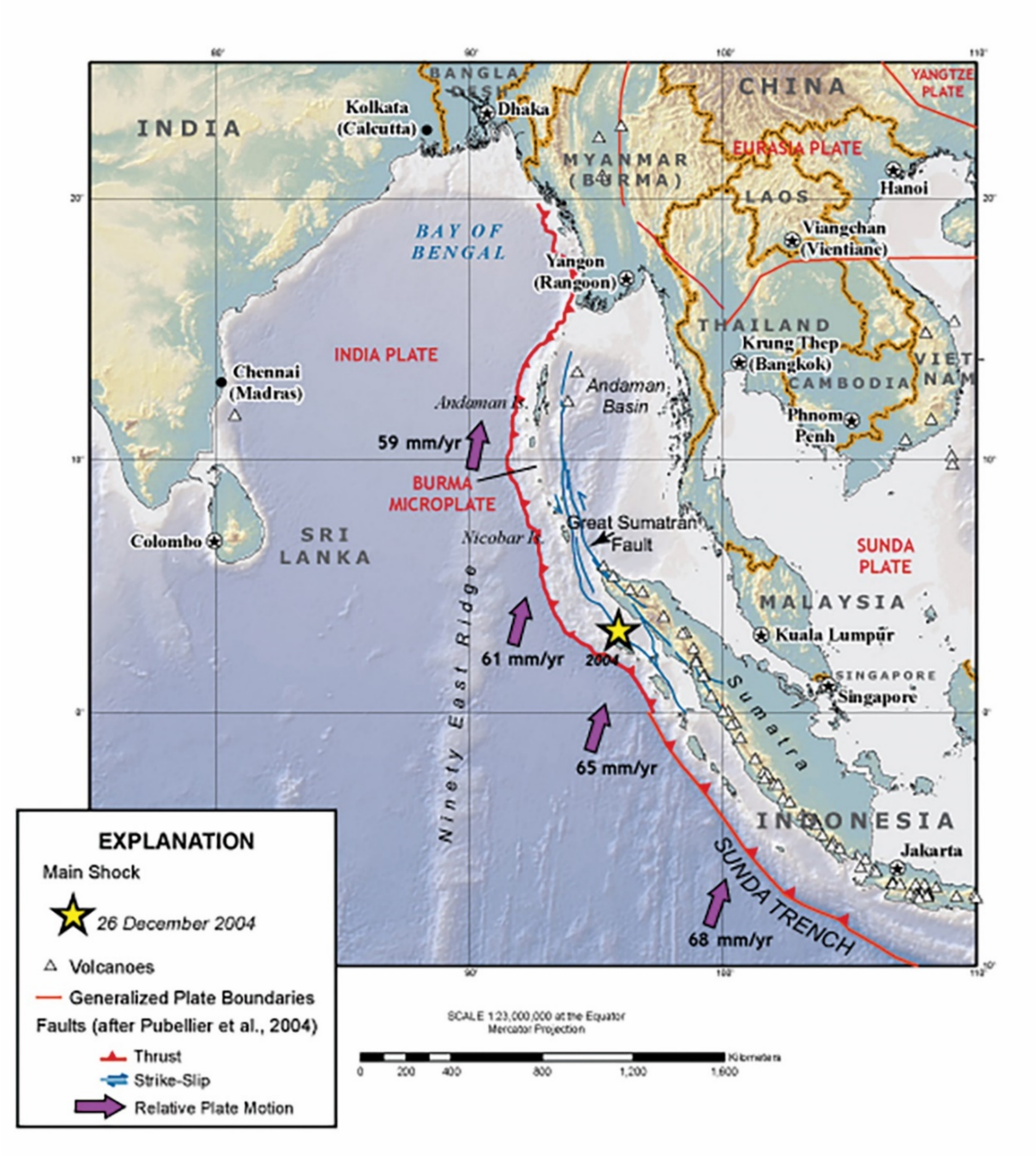

Figure 2. Indian Ocean earthquake and tsunami, 26 December 2004 [17].

Nearly a year after the occurrence of these events, the World Health Organization (WHO) reported on environmental health relief efforts in the regions affected by the earthquake and tsunamis [2]. An estimated five million people were affected by the disaster either directly or indirectly. Physical damage included indiscriminate destruction of structures leaving the population homeless, without access to food, basic sanitation, healthcare facilities, and with means of transportation and communication severely impaired. In the three weeks following the primary earthquake and tsunami more than 200 aftershocks of magnitude greater than four were recorded (Figure 3) contributing to continuing psychological effects on the traumatized local populations.

Figure 3. IKONOS satellite image, Area 2, Khao Lak, Phang Nga, Thailand before (left) and after (right) the tsunami on 29 December 2004 [18].

In Thailand, specifically, effects were spread throughout the six south-west coastal provinces including Phang Nga, Phuket, and Krabi where coastal towns, villages, and resorts were virtually flattened. The WHO estimated that over 650,000 of the local population and tourists were affected (Table 1). Totals compiled more than six months after the occurrence indicated 5300 dead, 3000 missing, and 17000 injured for Thailand alone. Foreign tourists, particularly from Europe enjoying warm holidays away from the European winter comprised over a third of the casualties.

2. PUBLIC HEALTH EFFECTS OF THE TSUNAMI

In assessing conditions and associated relief requirements, WHO listed major public health effects including immediate loss of life and the need to deal with the dead and injured. Bodies had to be located, collected, identified, and final disposition had to be arranged, all tasks for which neither facilities nor precedent existed and had to be created from scratch. Injured had to be cared for. Nearly 1000 children were orphaned and required care. Throughout the affected areas health care facilities were damaged or destroyed. Temporary facilities required independent supply of all equipment and materials including water supply sewage disposal, and management of solid wastes containing significant hazardous and infectious components. In the months following the tsunami the WHO reported on local conditions indicating that as many as 50000 rescue workers including 200 disease surveillance specialists had been deployed in affected areas to monitor and control potential disease outbreaks. In that period, WHO public health protection priorities were focused on supplying safe drinking water to displaced populations, strengthening sanitary and hygiene conditions in relocation camps, and heightening disease surveillance to detect and limit potential disease outbreaks [1].

Table 1. Total and affected areas by the tsunami classified by province [16].

Province	Village			Household			Population		
	Total	Tsunami Affected	Percent Affected	Total	Tsunami Affected	Percent Affected	Total	Tsunami Affected	Percent Affected
Ranong	178	45	0.2528	56471	1126	0.0199	178664	3770	0.0211
Phang Nga	318	68	0.2138	72737	4615	0.0634	236274	19509	0.0826
Phuket	103	61	0.5922	109686	952	0.0087	278480	13065	0.0469
Krabi	383	112	0.2924	79148	2759	0.0349	380367	15812	0.0416
Trang	720	51	0.0708	162177	660	0.0041	611436	12118	0.0198
Satun	276	59	0.2138	67626	81	0.0012	273702	2376	0.0087
Total	**1978**	**396**	**0.2002**	**547845**	**10193**	**0.0186**	**1958923**	**66650**	**0.0340**

Source: *Department of Disease Control, Ministry of Public Health, Nonthaburi, Thailand. Data as of 31 March 2005.*

Threats of infectious disease principally through environmental media including water and food were presumed to be present and broadcast as traveller advisories by foreign tourist agencies (e.g., UK) [3].

Advisories cautioned against potentially water or food borne typhoid, infection potential from injury including tetanus, hepatitis B, and *Vibrio vulnificans* in salt water coastal and inundated areas; leptospirosis characteristic of flood contamination; and increased vector borne (mosquito) endemic diseases; malaria, dengue haemorrhagic fever (dengue or DHF) and Japanese Encephalitis (JE).

Public health response was coordinated by the Thai Government including assessment of water supplies, sewerage systems, and solid waste management facilities to determine the extent of damage and contamination, and to assess the needs for immediate action and eventually, restoration services to local populations. Response activities can be divided into three phases: immediate, the initial 48 hours; interim, 2–10 days; and recovery 10 days to present. Key public health-related activities in these periods, Table 2, began with the process of locating, collecting, and processing the dead, and relocating the surviving population into temporary "migration centres". A critical need for the relocated population was to provide for food, shelter, and sanitation.

Table 2. Key public health and sanitation activities in post-tsunami periods.

Post Tsunami Period	Essential Public Health-Related Activities
Immediate: **0 to 48 Hours**	Locate, collect, and process dead; locate and treat injured; relocate dispossessed; provide for basic needs: water, food, shelter, sanitation. Assess magnitude of needs, locate, and acquire needed personnel, equipment, supplies.
Interim: **2 to 14 Days**	Continue processing dead; provide for continuing basic needs, sanitation, and health care of relocated population; Establish reliable water sources and provide for interim sanitation; Establish controls and routine for maintaining sanitary conditions in relocation centres including food preparation; personal sanitation practices; and waste disposal; Establish disease surveillance system; Begin clean-up of debris concentrating on dead animals, decaying materials, and physical hazards.
Recovery: **After First Two Weeks**	Complete removal of debris. Re-establish essential utilities; electric power; secure water supply, initially to relocation centres then to communities, rebuild water supply and wastewater disposal systems. Begin transfer of population from relocation centres to permanent dwellings. Reassign temporary external resource personnel.

Outside of the migration centres the debris including all manner of contamination from the devastating waves, accompanying flooding, and indiscriminate distribution of crushed and broken building materials, household goods, rubbish, dead animals, and waste materials of every description presented a chaotic blanket of dangerous contamination to the local population and relief workers. Through the first ten days, public health work focused on water supply and sanitation needs of the relocated population, and on assessing the condition of water supply, sewerage, and solid waste management facilities. A survey of water supply facilities in the affected areas showed that very few systems were able to function without significant repair (Table 3).

In devastated areas facilities were heavily damaged. Inundation filled ponds and tanks with sand, seawater, and general debris. Sewerage facilities generally closer to the shoreline were typically more heavily damaged. Normally buried water distribution and sewer pipe systems were also heavily damaged by the force of the tsunami, resulting erosion, and transported debris, in which such tsunami damages were detected with remote sensing [4].

Table 3. Water supplies in tsunami affected areas, 5000 households in six provinces.

Province	Village			Household			Population		
	Total	Tsunami Affected	Percent Affected	Total	Tsunami Affected	Percent Affected	Total	Tsunami Affected	Percent Affected
Ranong	178	45	0.2528	56471	1126	0.0199	178664	3770	0.0211
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Total	**1978**	**396**	**0.2002**	**547845**	**10193**	**0.0186**	**1958923**	**66650**	**0.0340**

Source: Department of Water Resources, Ministry of Natural Resources and Environment, Bangkok, Thailand. Data from 27 December 2004 to 1 March 2005.

Water quality testing was a very difficult task. The water quality team arrived after an eight-hour drive from Bangkok with the sampling equipment. The goal was in a few days to sample key ground water wells, the reservoir, the tap water as well as key impacted pond areas where wastewater was accumulating, and the beach. The team was able to collect 10 samples. Onsite pH, EC, were measured and the bacterial, other chemical and protozoan tests were measured in samples transported back to the lab. As expected, ponds and a ditch used for shower water were contaminated with fecal bacteria, as was the reservoir that has been used as a water supply. Protozoan pathogens were only detected in the shower water and the reservoir. This demonstrated the need for filtration of any surface water for use as potable water. In addition, the contamination of the ditch suggested infection in the population. Wells in low-lying areas were assumed contaminated due to flooding and inundation. However, testing was needed to assess actual conditions (e.g., elevated salinity, conductivity, total dissolved solids (TDS)) and potential contamination (e.g., coliforms, faecal coliforms, enterococci). Surprisingly, some shallow wells in affected areas were not contaminated (Table 4).

Dealing with contaminated water supplies and potential for further contamination due to disrupted sanitation systems was a critical problem in the recovery period. To deal with this a team was formed of local health personnel, external personnel from the National Health Department, and other available trained personnel. Problems were identified and prioritized, then pursued as resources permitted. Tasks included selection and development of temporary water sources with appropriate disinfection and bacteriological confirmation; arrangement for mobile water supply systems; control of flies and other vectors; provision of health education to victims and the temporarily relocated population on topics of personal hygiene, general sanitation, and food sanitation. Other services provided in support of local authorities included: provision for water and food quality surveillance including monitoring conditions and sampling food and water; construction and maintenance of temporary sewage treatment facilities (initially privies and leach pits); provision for routine storage and collection of solid waste; and installation of a treatment system (anaerobic filter onsite treatment system) to serve the body collection area at Phuket and Krabi province. Recognizing the extent of damage and duration of need requiring many months of maintenance for significant populations in major relocation centres, new permanent water systems were developed.

Table 4 Analysis results of physical, chemical, and water-borne pathogen of tested water.

Collected Date	Water Type	Enterococci (cfu/100 ml)	*E. coli* (cfu/100 ml)	Protozoa *Cryptosporidium & Giardia*	pH	EC (s/cm)	TOC (mg C/l)	Turbidity (NTU)	Salinity (g/l)
21 January 2005	Shallow Well, Chlorinated	0	0	Negative	-	-	-	-	-
21 January 2005	Shallow Well, Chlorinated	<0.5	<0.5	Negative	-	-	-	-	-
22 January 2005	Pond	2419	1986	Negative	8.4	27.7	30.5	15.6	18.6
22 January 2005	Pond	2419	2419	Negative	8.0	25.5	34.6	31.5	16.9
22 January 2005	Tap Water	0	0	Negative	-	-	-	-	-
22 January 2005	Beach Area	<0.5	<0.5	Negative	-	-	-	-	-
22 January 2005	Pond	2419	387	Negative	8.1	6.67	33.6	23.3	4
22 January 2005	Ditch, with shower from temporary relocation camp	2419	207480	Positive	-	-	-	-	-
22 January 2005	Pond	1413	>2500	Negative	7.9	8.35	30.8	6.39	5
22 January 2005	Water Reservoir	>2500	456	Positive	7.7		30.5	3.37	8.2
23 January 2005	Pond	>2	>1000	Positive	8.3	28.4	30.2	32.6	6.2

Infectious disease surveillance during the first month from 26 December 2004 to 25 January 2005 found significant occurrence of GI upset (diarrhoea and vomiting), initially as many as 126 cases/day decreasing to 100 cases/day, an incidence rate of 2950/100000 population. This was nearly double the normal rate for the same period of the previous year (IR = 1758/100000). This emphasized the need for improvement of food sanitation, control of water supply, health education, and disease control to avoid serious disease outbreaks. Surveillance for other diseases showed few cases of malaria and DHF cases. However, numbers were not significantly different from normal and did not appear related to the disaster and aftermath.

The support of clinical and environmental laboratories for performing chemical and microbiological tests in the affected areas was essential to meeting public health needs. Testing confirmed the obvious contamination resulting from inundation with heavily contaminated sources and the general distribution of contamination from inundation and the receding water. Testing was essential to assess the condition of groundwater sources and to verify the condition of water from upland sources not affected by flooding, and of water in beach bathing areas. While no previous information was available for the affected area cursory qualitative testing for protozoan parasites *Cryptosporidium* and *Giardia* confirmed their presence as general environmental contaminants, Table 4. This underscored the potential for waterborne transmission as an additional post-tsunami hazard [5, 6]. In comparison to the magnitude of post-tsunami GI upset occurrence in relocation centres, a routine occurrence of cryptosporidiosis at 2–5 per 100000 or giardiasis at 15–20 per 100000 would be undetectable. Previous investigations, largely of selected and impaired populations have demonstrated that cryptosporidiosis and giardiasis occurrence in Thailand is comparable to other similar regions of the world [7-11]. However, since both organisms have been demonstrated to cause both water and food-borne outbreaks vigilance for adherence to sound and effective water and food sanitation practices as well as attention to personal hygiene needs remain important elements of public health protection particularly under crowded and difficult conditions.

3. LESSONS LEARNED AND FUTURE RECOMMENDATIONS FOR DISASTER MANAGEMENT

Coastal zones and small islands are often densely populated areas that increase people's risk and vulnerability. Nearly three billion people or almost half the world’s population live in coastal zones, which are prone to hazards including tropical cyclones, floods, and tsunamis. Governments and local authorities need to consider human habitats in long-term development planning, ensuring that risks are minimized. The most important – and costly – prevention system is a tsunami early warning system monitoring seismic events and corresponding wave patterns, determining the earthquake’s magnitude and epicentre and subsequently detects the tsunami waves.

Such system can detect the propagation of a tsunami wave before it collides with the shoreline, however, efficient means of communication between relevant authorities and local communities are required to ensure a rapid response. Information exchange between scientists, politicians and local authorities is therefore of high importance. Numerous activities should be considered to improve disaster prevention and, if necessary, recovery and rescue actions. Those include safe construction of buildings, escape routes, storage of food, drinking water and medical supplies, robust transportation options (helicopters are almost indispensable for these purposes) and digital communication devices. In addition, regular drills for rescue forces should be carried out at time intervals. Finally, international, regional, and national organizations should improve their coordination and exchange of information to establish pre-emptive instruments of disaster prevention.

Recent studies provided evidence that wastewater represents a potential source of health risks due to the presence of severe acute respiratory syndrome coronavirus (SARS Cov-2) [12-14]. The disease caused by SARS-CoV-2 is now referred to as coronavirus disease 2019 (COVID-19 and was subsequently declared a global pandemic. The presence of SARS-CoV-2 RNA in human feces was reported in studies.[15] In light of these findings, it became clear that knowledge on occurrence, persistence and possible routes of transmission of water-borne pathogens and in particular viral agents is currently essentially limited. It is therefore urgently required to strengthen research efforts such as wastewater-based-epidemiology aimed at the surveillance of wastewater to understand the public health risks created by these organisms. The ultimate goal of these efforts would be to gather information on prevalence, genetic diversity and possible ways for the eradication of viral threats such as COVID-19.

4. SUMMARY AND CONCLUSIONS

The effects of unprecedented earthquake and tsunami destruction on coastal populations can barely be imagined. The figures of 5300 dead, 3000 missing and 17000 injured within 150 km of coastline in a heavily patronized tourist area of south-west Thailand underscore the magnitude and extent of devastation. Immediate and continuing 3333needs for public health protection in affected areas must rely on basic principles and ability to find, organize, and apply available personnel and resources.

Organisation and application of public health protection resources in response to natural disasters whether a typhoon in Myanmar, earthquake in China, or earthquake and tsunami in South Asia or the pacific islands requires both immediate action and application of essential services for extended periods of time. Recognition of the nature of specific local effects and their potential public health consequences is essential to minimising secondary and hopefully preventable health impact on the affected populations. Water quality effects through overt contamination and disruption of normal water supply and wastewater disposal services must be assessed quickly with appropriate response as resources permit.

Experienced professionals can make effective initial assessment of water quality conditions qualitatively. Confirmation of conditions by selective chemical and biological testing should be applied as soon as resources permit. An understanding of expected levels of environmental pathogen levels as well as enteric disease occurrence rates in the local or comparable populations can be an important asset to public health personnel in monitoring the status of affected populations.

While prevention of natural disasters is out of the question, skilful, well organized, and dispassionate application of public health fundamentals can minimise the degree of human suffering following the event. Thoughtful re-examination of recent experiences such as described here in Thailand's southwestern provinces can assist in facilitating actions needed in future occurrences.

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