Selection of Suitable Water Treatment Technologies for Natural Disaster and Emergency Situation

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Abstract

This review paper emphasises the selection criteria for deployment of water treatment technologies during the immediate emergency phase of 1-2 weeks followed by a disastrous natural event. Selection of the water treatment technologies by assigning a score in the range of 1 to 5 for the selected six evaluation criteria i.e. ease of deployment, ease of use, performance, throughput, energy requirement & public acceptance. Secondly, the deplorability of available treatment technology was assessed with respect to the magnitude of impact of any natural disasters. Based on the performance, treatment capacity & energy requirement, the various available membrane and non-membrane water treatment technologies are reviewed. The treatment technologies are scored based on selected evaluation criteria followed by their suitability during the disaster to bring an idea of deployment of suitable technology.

Keywords: *Natural Disaster, Water Treatment, Membrane, Evaluation Criteria*

1. Introduction

As per the Centre for Research on the Epidemiology of Disasters (CRED) disaster as "a situation or event that overwhelms local capacity, necessitating a request at the national or international level for external assistance; an unforeseen and often sudden

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event that causes great damage, destruction and human suffering". Further, survey was carried out by CRED that in the year 2015 total 376 natural disasters are main cause of death of around 22,765 people, made 110.3 million victims and caused US$ 70.3 billion damages. Natural disasters like flooding, hurricanes, landslide, tornados, earthquakes or a national emergency can happen anywhere, anytime (CRED, 2015). Natural disasters impact magnitude results in power failure, water shortage, infrastructure damage, contamination or pathogenic spread and transportation failure.

Due to compromised water supply & contamination; outbreaks of diseases such as dysentery, typhoid and hepatitis are reported widely. (WHO, 2002). Agencies have to provide a minimum of 7.5-15 liters per day water for drinking, basic hygiene & cooking. (Sphere Project, 2011). In the absence of preparedness-centric approach; disaster management agencies follow relief-centric approach and deploy conventional or advanced water treatment technologies without considering the success criteria like their ease of deployment, through put volume with quality, cost of treatment, maintenance, operator's skill, consumables supply, public acceptability and energy requirement. (Loo et al., 2012). That results in the failure of safe water supply strategy.

1.2 Disaster: Statistical Overview

In the year 2015, globally, approximate 376 natural disasters were the main cause of the death of nearly 22,765 people. Wherein, made 110.3 million victims and caused US$ 70.3 billion in damages.

India has been traditionally vulnerable to natural disasters due to a number of factors as its unique geo-climatic conditions, topographic features, non-scientific development practices population growth etc. Also, earthquakes, floods, cyclones and landslides have been recurrent phenomena. About 60% of the landmass is prone to earthquakes of various intensities. In the decade 1990-2000, an average of about 4344 people lost their lives and nearly 30 million people were affected by disasters every year (DMI, 2009).

1.3 Magnitude of Impacts

Natural disasters like earthquakes, cyclones, floods, tsunamis, volcanic eruptions etc. can cause significant impact on the basic amenities related to their intensity. The impact over water supply infrastructure, transportation, power supply, personnel shortage etc.

significantly disturbs the basic lifeline of a city, town or village. The common levels of impact of natural disasters on environmental health services are represented below in Table 1 (Pan American Health Organization, PAHO, 2000).

Table 1. Common levels of impact of disasters on environmental health services (PAHO, 2000)

Most common effects on enviromental health		Earthquake	Cyclone	Flood	Tsunami	Volcano
Water supply & Wastewater disposal	Damage to civil engineering structures	1	1	1	3	1
	Broken mains	1	2	2	1	1
	Damage to water sources	1	2	2	3	1
	Power outages	1	1	2	2	1
	Contamination (Biological or chemical)	2	1	1	1	1
	Transportation failures	1	1	1	2	1
	Personnel shortages	1	2	2	3	1
	System overload due to population shift	3	1	1	3	1
	Equipment, Parts and supply shortages	1	1	1	2	1
Vector control	Proliferation of vector breeding sites	1	1	1	1	3
	Increase in human/vector contacts	1	1	1	2	1
	Disruption of vector-borne disease control Programmes	1	1	1	1	1
NOTE : 1 - Severe possible effect ; 2 - Less severe possible effect ; 3 - Least or no possible effect						

(Source: PAHO, 2000)

1.4 Water Requirement during Emergency

Insufficient quantity & poor quality of water are the foremost reason for the ill health & water-borne diseases among the disaster affected (WHO, 2002). The minimum requirement of safe drinking water may vary among rural & urban community. Minimum 20 litres of safe water is required during short-term survival for drinking &

cooking (Maslow, 1943). During relief camp or post-disaster management this water requirement increased significantly for carrying out personal sanitation & washing. Sphere guidelines for water supply stipulate that at least 15 litres/day/person should be provided, with water quality at point of delivery with turbidity <5 NTU (nephelometric turbidity units), zero faecal coliforms per 100 ml, and free residual chlorine of 0.5 mg/l (in the case of piped water or diarrheal disease outbreaks) (Sphere, 2011). Furthermore, basic water needs vary based on social and cultural norms, climate and the degree of displacement. It is required to consider leakages and other losses of water in the catchment, treatment or distribution process and spare capacity (Sphere, 2011). The source of water needs to be within 500 meters reach from camp. If no such specific water purification technology available then at least double chlorination shall be carried out.

1.5 Water Treatment Technologies

The most common water treatment method practiced by the affected population is either boiling or chlorination (WHO, 2002). However, the water quality compromised severely after the disaster in respect of turbidity, salinity, microbial contamination & odor. A four weeks pilot survey of 48 households of Aceh, Indonesia by NGO CARE during Tsunami (December, 2014); the water sources like shallow wells, boreholes and streams were all positive for *E. coli*, shallow wells (450 CFU/100ml; high risk), boreholes (15 CFU/100ml; low risk) and streams (>2500 CFU/100ml; very high risk). It was surprising that, 67% of the 43 samples from water stored at the house hold were positive for *E.coli*, with 15% havingcounts>101 CFU/100ml (the WHO "high risk" level) and 22% between 11 and 100 ("intermediate risk") (Albert et al, 2006). While inadequate disinfection of supplied water presents an apparent health risk. Also, over-dosing is also problematic since it encourages people to consume water from untreated sources. Against chlorinated water which may be difficult to reverse (Albert et al, 2006). Considering the failure of boiling and chlorination in providing safe drinking water to the affected population; it is important to explore other available non-membrane and membrane-based water treatment technologies with respect to their performance, energy requirement & through put to accommodate the need of the population as per the prescribed minimum standards. The water treatment technologies are tabulated in Table 2 & 3.

Table 2. Available non-membrane based water treatment technologies (Loo et al, 2012 as modified)

Available Water treatment Technology for Emergency	Particulars	Treatment Capacity (Liters/ hr)	Performance	Energy Requirement	Other treatment required	Reference
Activated Carbon & UV disinfection	Activated carbon-based filter candle followed by UV	160	6 LRV bacteria 3 LRV protozoa 4 LRV virus	3/4 hp centrifugal water pump (60 psi)	-	Abbaszadegn et al., 1997
Biosand filter	sized granite, gravels or sand (for 95 cm x 36 cm filter column)	30-40	0.3-4 LRV Bacteria 3.8-5 LRV Protozoa 0-1.3 LRV Virus 96% turbidity	Gravity filtration	-	Mahmood et al., 2011
Boiling	Rolling boil for at least 1 minute	Varies	86-99% bacterial removal	Fuel	-	Rosa et al., 2010
Chlorination tablets	-	Varies	1-2.8 LRV bacteria	None	Filtration	Jain et al.,2010
Chulli purifier	Chulli & Aluminium coil	30	>5 LRV bacteria	cooking fuel	Sand filtration	Gupta et al., 2008
Combined Flocculation-disinfection	PUR® sachet	10 (per sachet)	4-8 LRV bacteria >2.5LRV protozoa 1-4 LRV virus	none	Cloth filtration	Mclennan et al., 2009
SODIS	PET bottles	varies	3-5.5 LRV bacteria 1-3 LRV protozoa 2-3 LRV virus	Solar radiation	Filtration	Sobsey et al., 2008
Upflow clarifier	Oxfam tank, clarifier cone, non-woven fabric polishing filter, coagulant dose (10-60mg/l)	5000	<5 NTU 2 LRV bacteria	Diesel Generator	Chlorination	Dorea and Clarke, 2006

UVdisinfection portable	UV lamp	500	>2.3 LRV virus	Powered by hand crank, bicycle or electric	Filtration	Berg, 2010
NEERI-ZAR	$KMnO_4$, sand filtration & chlorination	20	1-2 LRV bacteria <3 NTU	Gravity filtration	-	CSIR NEWS 57 (8) 30.4.2007
DIVVY 250 System™	2-step water purification Super Chlorination (3-5ppm) & Micro filtration	250	6LRV Bacteria 3LRV Protozoa 4LRV virus	Hand powered	-	www. espwater products. com

Table 3. Available membrane-based water treatment technologies (Loo et al, 2012 as modified)

Water treatment Technology	Particulars	Treatment Capacity (Liters/hr)	Performance	Energy Requirement	Other treatment required	Reference
Ceramic filter	Varied pore sizes	2.4-18	2-4 LRV bacteria 2-6 LRV protozoa 1-2.3 LRV virus	Gravity filtration	-	Brown and Sobsey, 2010
Bicycle powered Microfiltration	Micro filter ceramic pore size	240	67% Total Coliform 89% Feacal Coliform <1 NTU	Pedal powered pumps	Upflow rapid sand filter	McBean, 2009
FO pouch	0.04 micron pore sized membrane	50	>5 LRV bacteria	Gravity filtration	Mesh sieve	Frechan et al, 2011
Bicycle powered Ultra filtration	UF membrane	800	<1 CFU/100ml <1 bacteria/ml <1 NTU	Pedal powered	Pre-filter	He, 2009

Supremus Aquastandal one water purification system	Low pressure hollow fibre membranes (0.4micron pore size)	500-700	>4LRVBacteria >4LRVprotozoa >3LRV virus <0.1NTU	Hand powered	2 minutes backwash everyday	Ministry of Drinking water & Sanitation, 2015
LifeStraw®	UF hollow fiber membrane 20nm	8.6-12	6-7 LRV bacteria 2-4.7 LRV Virus 3.6 LRV protozoa	Gravity or suction	Prefilter& halogen chamber	www. lifestraw. com
Outback Plus™ (OB-25NF)	4-stage (Pre-filter,0.5 micron filter, Nano filter & multimedia filter)	1-3	4LRV Protozoa 6LRV Bacteria 4LRV Virus	Gravity filtration	-	www. espwater products. com
Bicycle powered Nanofiltration	60cm^2 poly acromatic flatsheet NF	12-18	90% of total Arsenic	Pedal Powered (0.2-0.7MPa)	Pre-oxidation	Oh et al., 2000
Small ScaleRO system	RO module for brackish water desalination at 6 bar pressure	240	<100mg/l TDS	Electric power	Prefilter, GAC, UV dis-infection	Elfil et al., 2007
Photovoltaic RO	Seawater RO membrane module at 65bar pressure	50	<500mg/l TDS	68.5Kwh powered PV & DG set for power backup	-	Tzen et al., 1998
Wind Powered RO System	Brackish water RO at 600- 1100KPa pressure	9	83% salt rejection	150W powered wind pump & DG set for power backup	Activated carbon filter if organics are present in feed	Robinson et al.,1992

(Source: Loo et al, 2012)

2. Methodology:

2.1 Evaluation Criteria for Water Treatment Technologies:

To evaluate the water treatment technologies for emergency, criteria should be its ease of deployment, throughput volume with quality & cost of treatment (Quinn et al, 1997). Whereas (Steele and Clarke, 2008) emphasize on maintenance, operator's skill, simplicity of system, consumables along with the above criteria. Loo et al, 2012 suggested considering the energy required torun the technology along with the acceptability of the treatment by affected population. It also suggests including impact on environment as well as supply-chain requirement. All these technology evaluation criteria are not assessed for their suitability during the immediate response phase of 1 to 2 weeks after a disaster strike.

In this review paper, the most important criteria are considered to give score on the scale of 1 to 5 for the selection of the technology in emergency and their arithmetic total score provide the key of technologies acceptance or rejection. The criteria adopted are ease of deployment, ease of use, performance (Log removal value for bacteria, protozoa & virus and turbidity), potential acceptance, energy requirement & through put (Table 4). The ease of deployment & potential acceptance are two partially subjective criteria i.e. size of technology large, moderate or small & its weight heavy or light; similarly, the objectionable taste & visual improvement are the parameters of subjectivity. As construction of treatment technology at disasters it is not suitable & easy and supply of large power after power failure is not possible during the immediate response phase; it is decided not to give minimal acceptable score of 1 for these two evaluation criteria i.e. ease of deployment & energy requirement. For these two criteria minimum acceptable score set is 2 i.e. no construction required only onsite assembly is enough to deploy the technology & technology that can also run on renewable energy is selected on a minimal acceptable score. The other evaluation criteria i.e., ease of use, performance, potential acceptance & through put minimum score set is 3 respectively. Under ease of use the minimal acceptability is based on the basic operator skill requirement with more than 1 hr treatment time required.

Earlier studies (Loo et al, 2012) defined evaluation criteria i.e. performance as subjective in nature viz. modest or excellent treatment. Effort is made in this paper to avoid subjectivity by allotting specific log removal values. The technology with minimal performance of <3LRV of bacteria & protozoa and 2-3 LRV of virus along with poor turbidity removal is selected. The treatment that gives visual improvement & no objectionable taste are selected as minimal acceptability score. The minimal through put of 50-100 litres/hr selected as it can cater the need of 10 to 20 affected populations hourly i.e. suitable for an immediate response for 100-200 peoples.

The total score was calculated after assigning equal weight to each evaluation criteria as all the parameters selected are equally important. The final score is added arithmetically i.e.

$$\textbf{Totalscore} = \sum_{i=1}^{i=6} (x1, x2\ldots\ldots xn) = 30$$

i - Evaluation criteria

X1, X2…..Xnis assigned score for 6 evaluation criteria respectively

$$\textbf{The minimum acceptablescore} = \sum_{i=1}^{i=6} (2+3+3+3+2+3) = 16$$

The total score for the assessment of water treatment technology for 6 criteria is 30 whereas, for the acceptance of the technology, the minimum score needs to be equivalent or more than 16. Technology selection based on 06 evaluation criteria is represented below in Table 5 (Loo et al, 2012, Jozwiakowski et al, 2015 & Balckwood et al, 2016)

Table 4. Description of scoring scale of Water treatment technology's 06 evaluation criteria (Loo et al, 2012 as modified)

Criteria 1		Description of the score on a scale of 1 to 5				
		2	**3**	**4**	**5**	
Ease of deployment		Large & heavy Require construction & onsite assembly	Large & heavy require onsite assembly	Moderately large & heavy require simple set-up	Light & small require simpleset-up	Light & small require no set-up
Ease of use		Advance operational skill required; complicated process design	Require skilled operator; proper chemical dose	Require basic training to operator; treatment time >1h	Require basic training to operator; treatment time <1h	Essentially no training required; treatment time <1 h
Performance	Bacteria	<1LRV*	<2LRV	<3LRV	<4LRV	>4LRV
	Protozoa	<1LRV	<2LRV	<3LRV	<4LRV	>4LRV
	Virus	1 LRV	2 LRV	2-3 LRV	3-4 LRV	>4 LRV
	Turbidity	Can't remove	Can remove	Can't remove	Can remove	Can remove turbidity & other contaminants
Throughput (Litres/hr)		<10	10-50; meteorological Conditions dependency	50-100	100-500	>500
Energy requirement		Uses a large amount of energy and cannot be powered by renewable energy	Uses a large amount of energy but can be powered by renewable energy	Can be powered by a small hand pump or bicycle	Require energy/fuel for operation but does not involve additional use of energy	No power requirement (gravity fedor mouthsuction)
Potential acceptance		No visual improvement; objectionable taste; harmful byproducts	No visual improvement; No objectionable taste;	Visual improvement; No objectionable taste; Use chemicals	Visual improvement; No objectionable taste; No harmful byproducts	Common practice among users

(Source: Loo et al, 2012)

*LRV – *Log removal value (90% - 1LRV; 99% - 2 LRV, 99.9% - 3 LRV; 99.99% - 4 LRV)*

S.No.	Water treatment technologies	Scoring of Evaluation Criteria									Total Score
		Ease of deployment	Ease of use	Performance in Log Removal Value (LRV)			Average performance	Throughput (Litres hr)	Energy requirement	Potential acceptance	
				Bacteria	Protozoa	Virus					
1	AC & UV disinfection	4	5	5	3	4	4	4	2	4	23
2	Biosand filter	1	4	3	4	1	3	2	5	4	19
3	Boiling	4	5	2	1	1	1	2	2	5	19
4	Chlorination tablets	4	2	2	1	1	1	4	5	1	17
5	Chulli purifier	1	5	5	1	1	2	2	4	4	18
6	PUR® sachet	5	4	5	2	3	3	4	5	3	24
7	SODIS	5	3	5	2	3	3	2	5	2	20
8	Upflow clarifier	1	2	2	1	1	1	5	1	3	13
9	UV disinfection portable	5	5	1	1	1	1	5	1	2	19
10	NEERI-ZAR	1	2	2	3	1	2	2	5	3	15
11	DIVVY 250 System™	3	2	5	3	4	4	4	3	3	19
12	Ceramic filter	1	3	3	4	2	3	1	5	4	17
13	Bicycle powered MF	1	3	3	4	1	3	4	3	4	18
14	Bicycle powered UF	1	3	4	4	2	3	5	3	4	19
15	Supremus Aqua® UF	4	5	4	4	3	4	5	5	3	26
16	LifeStraw®	3	2	5	4	3	4	1	5	3	18
17	Outback Plus™ (OB-25NF)	3	3	5	4	4	4	1	5	4	20
18	Bicycle powered NF	1	3	5	4	4	4	2	3	3	16
19	Small Scale RO	2	3	5	5	5	5	4	1	5	20
20	Photovoltaic RO	1	3	5	5	5	5	2	2	4	17
21	Wind Powered RO	1	3	5	5	5	5	1	2	4	16
22	FO pouch (0.04µ membrane)	5	5	5	1	1	2	1	5	4	22

(Source: Loot et al, 2012& https://sswm.info)

(AC – Activated carbon; UV – Ultraviolet; MF- Microfiltration; UF – Ultrafiltration; NF- Nano-filtration; RO- Reverse Osmosis; FO- Forward Osmosis)

NOTE: - Scoring may vary based on field & meteorological conditions

Scores(colorcoding)

MostSuitable

Least Suitable

Acceptability ore

=>16 ACCEPT

<16 REJECT

3. Discussion:

3.1 Selection of Water Treatment Technology's Deployment Based on Disaster

The geophysical, hydrological, meteorological & climatological disasters occurrence frequency increased significantly due to anthropogenic intervention with nature, increasing needs & climate change. The crude mortality rate i.e. 1 death per day in 10,000 guide administration to call for an emergency. After the strike of disaster, the immediate emergency response phase of 1-2 weeks is crucial in all sort of manner whether it is drinking water, food, sanitation, shelter etc (Smith & Reed, 1991). To have an effective immediate response system helps in reducing the chance of disease outbreak. Due to compromised water supply & contamination; outbreak of diseases such as dysentery, typhoid and hepatitis are reported widely. All water of uncertain source or quality should be treated before using it for drinking, food preparation or hygiene. Agencies have to provide minimum 7.5-15 litres per day of water for drinking, basic hygiene & cooking.

Loo et al, 2012 has reported the technology selection based on road accessibility, utilizable renewable energies and source water quality. This kind of selection criteria is only useful for post-disaster relief as road conditions, source water quality & renewable energy sources can only be assessed on reaching the affected population. This may delay the speedy relief support. This review paper brought a disaster based selection of technology as the magnitude of effects caused by natural disasters vary significantly there is minimal water shortage during landslides, hurricanes & floods whereas it's severely affected during draught. The structural damage to system infrastructure is minimally affected during volcanic eruptions & drought whereas earthquakes, landslides, hurricanes & floods severely affect the infrastructure. (Pan American Health Organization, 2000).

It is pertinent to mention that administration has very less time to respond against these disasters and in that hurry without understanding the common level & magnitude of the impact of disaster similar kind of approach is followed for all kind of disaster by deploying the same water treatment technology. It is to mention that during flood, hurricane & cyclone meteorological condition are humid, speedy wind with minimum solar radiation prevails; deploying solar based water treatment technology are meaningless.

Similarly, deploying high-end RO or NF technology during minimal affected water of pathogenic contamination during draught & landslide is not useful. Considering the common level & magnitude of disaster impact for the selection of treatment technology is tabulated in table 6.

Further, Safe water supply of <5NTU turbidity, 0.5ppm residual protection & zero coliform contamination is on priority of administration and humanitarian communities. Based on the 6 evaluation criteria of water treatment technologies total score, it is suggested that Upflow clarifier and NEERI-ZAR are not suitable for emergency water supply. SODIS, PUR purifier, UV disinfection portable & FO pouch scored highest i.e. 5 for the ease of deployment whereas Bios and, Chulli purifier, Upflow clarifier, NEERI-ZAR, Ceramic filter, Bicycle powered based MF, UF & NF alongwith Photo voltaicRO and wind powered RO scored lowest i.e. 1.

The Chlorination tablets, NEERI-ZAR, & DIVVY 250 system is least suitable on the criteria of ease of use due to the involvement of doses of disinfectant. Whereas, membrane-based water treatment technologies are most suitable on the evaluation criteria of performance; the boiling, chlorination, upflow clarifier, UV disinfection & FO pouch are least suitable for the required quality of treatment (Rikhi et al, 2018).

The most suitable technology on the criteria of throughput is Upflow clarifier, UV disinfection, Supremus aqua & UV disinfection. Due to energy requirement; UV disinfection, Small scale RO & Upflow clarifier are least suitable whereas Chlorination, SODIS & Upflow clarifier are least suitable on the criteria of potential acceptance. However, considering the cost, maintenance and supply of consumables as additional evaluation criteria, this scoring may change & acceptability or rejection of technology mayvary.

Table 6. Selection of water treatment technologies based on the impact of disaster

Natural disaster	Meteorological condition (Humid, Solar radiation)	Common effects of natural disaster on water supply & disease outbreak (Pan American Health Organization (PAHO), 2000)						Suitable treatment technology $
		Damage to water sources	Power outages	Contamination (Biological or chemical)	Transportation failures	Personnel shortages	Proliferation of vector breeding sites	
Earth quake	**	+	+	++	+	+	+	3,4,6,7,10,11,15,16,17,20,21,22
Cyclone	*	++	+	+	+	++	+	4,6,10,11,15,16,17,22
Flood	*	++	++	+	+	++	+	2,6,10,11,15,16,17,19,22
Tsunami	*	+++	++	+	++	+++	+	1,2,6,10,11,12,13,14,15,16,17,18,19,22
Volcano	**	+	+	+	+	+	+++	6,7,10,11,15,16,17,20,21,22

**No rain/less humid, good solar radiation

*Raining/too much humid, very low solar radiation

+++ Least or no possible effect

++Less severe possible effect &

+Severe possible effect

$Water treatment Technologies {1.AC & UV disinfection 2. Biosand filter 3. Boiling 4. Chlorination tablets 5. Chulli purifier 6.PUR® sachet 7.SODIS 8.Upflow clarifier 9.UV disinfection portable 10.NEERI-ZAR 11. DIVVY 250 System™ 12. Ceramic filter 13. Bicycle powered MF 14. Bicycle powered UF 15. Supremus Aqua® UF 16. LifeStraw® 17.Outback Plus™ (OB-25NF) 18. Bicycle powered NF 19. Small Scale RO 20.Photovoltaic RO 21. Wind Powered RO & 22. FO pouch (0.04μ membrane)}.

4. Conclusion

The selection of technology based on common level of disaster impact shows that SODIS, Photovoltaic RO, Solar still & Wind-powered RO is suitable in earthquake due to good solar radiation and proved itself to be simple, robust for long periods as SODIS method can only be evaluated in the context of other household water treatment technologies, and the benefits it offers can vary significantly from one location to another. As a low-cost method that is independent from supply chains for products other than PET bottles, SODIS has comparative advantages particularly among the poorest segments of the population, and in areas where no other household water treatment technologies are marketed as only sunlight and PET bottles are required for the application of the method.

Further, Solar still & Wind-powered RO is economically competitive with other sources. The systems offer realistic solutions to many regions without any grid connection. One of the main objectives of this study was to verify the integration of the several components, which were tested and modeled, and their performance over a wide operational range. Whereas, the same technologies are not suitable during cyclone, flood & tsunami. During tsunami, transportation failure is not too severe & personnel shortage is also not severe; that allows us to select ceramic filter, bicycle-powered MF.

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