LOW COST EMERGENCY WATER PURIFICATION TECHNOLOGIES

IWA PUBLISHING

INTEGRATED WATER SECURITY SERIES

CHITTARANJAN RAY
RAVI JAIN

BH

LOW COST EMERGENCY WATER PURIFICATION TECHNOLOGIES

Integrated Water Security Series

CHITTARANJAN RAY, PH.D., P.E.
RAVI JAIN, PH.D., P.E.

IWA PUBLISHING

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Butterworth-Heinemann is an imprint of Elsevier

Acquiring Editor: Ken McCombs
Development Editor: Jeff Freeland
Project Manager: Priya Kumaraguruparan
Designer: Russell Purdy

Butterworth-Heinemann is an imprint of Elsevier
225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB UK

Library of Congress Cataloging-in-Publication Data
Ray, Chittaranjan.
Low cost emergency water purification technologies / Chittaranjan Ray, Ph.D., P.E., Ravi Jain, Ph.D., P.E. – 1st edition.
pages cm – (Integrated water security series)
Includes bibliographical references
1. Drinking water–Purification. 2. Water–Purification. 3. Water filters. 4. Emergency water supply. 5. Survival and emergency equipment. I. Jain, Ravi. II. Title.

TD430.R39 2014
628.1′62–dc23
2014001187

British Library Cataloging-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-0-12-411465-4

For information on all Butterworth-Heinemann publications visit our web site at store.elsevier.com

Printed and bound in United States of America
14 15 16 17 10 9 8 7 6 5 4 3 2 1

ABOUT THE AUTHORS

Chittaranjan Ray, Ph.D., P.E. is the Director of Nebraska Water Center and Professor of Civil Engineering at the University of Nebraska. Prior to this appointment, he was a professor in the Department of Civil & Environmental Engineering and Interim Director of the Water Resources Research Center at the University of Hawaii in Honolulu, HI. He received his Ph.D. in Civil Engineering from the University of Illinois at Urbana-Champaign and his M.S. in Civil Engineering from Texas Tech University. He served as a staff engineer with the consulting firm Geraghty & Miller, Inc. (now part of Arcadis Geraghty & Miller) in Hackensack, NJ between his two graduate degrees. Additionally, he was employed as a research associate and associate scientist at the Illinois State Water Survey in Champaign, IL. His research interests are in the areas of riverbank filtration for water supply, transport of contaminants in subsurface, and general water quality. He is a registered Professional Civil Engineer in Illinois and fellow of the American Society of Civil Engineers. He has published six books, over 75 peer-reviewed journal papers, and many technical reports. He has made dozens of presentations in the areas of water quality, contaminant transport, and riverbank filtration.

Ravi K. Jain, Ph.D., P.E. Dean Emeritus, was Dean of the School of Engineering and Computer Science, University of the Pacific, Stockton, California from 2000 to 2013. Prior to this appointment, he has held research, faculty, and administrative positions at the University of Illinois (Urbana-Champaign), Massachusetts Institute of Technology (MIT), and the University of Cincinnati. He has served as Chair of the Environmental Engineering Research Council, American Society of Civil Engineers (ASCE) and is a member of the American Academy of Environmental Engineers, fellow ASCE, and fellow American Association for the Advancement of Science (AAAS). Dr. Jain was the founding Director of the Army Environmental Policy Institute, has directed major research programs for the U.S. Army and has worked in industry and for the California State Department of Water Resources. He has been a Littauer Fellow at Harvard University and a Fellow of Churchill College, Cambridge University. He has published 17 books and more than 150 papers and technical reports.

PREFACE

Access to clean water is of serious concern to the human population. Incredible as it may seem, more than one billion people do not have access to adequate water resources. Access to clean water is, yet again, another hurdle as the available water may not be safe enough for human consumption. Natural disasters such as floods, earthquakes, hurricanes, volcanic eruptions, and tsunamis are known to cause severe human miseries. Additionally, wars and civil conflicts also expose civilians to miseries. Under such circumstances, basic survival requires adequate drinking water resources: a major challenge. Water is also needed for sanitation needs, although that can be achieved with somewhat lower quality water during emergency situations.

Production of potable water and its supply to the affected population is the number one priority in most humanitarian relief missions following disasters. Membrane technology is one of the most common methods of producing potable water. Such treatment systems are typically deployed onboard ships or at water sources (lakes, streams, etc.). The next challenge is to transport the produced potable water to the affected population. In the first phase of disaster response, the military, government agencies, and nongovernmental organizations (NGOs) work jointly to deliver water via helicopters, boats, and trucks (if roads are accessable) to the people for the first few weeks. Subsequently, it is best to set up onsite treatment units until permanent solutions are deployed.

Drinking water security is emerging as a crucial national and international concern due to the vulnerability of the water infrastructure and its importance in protecting human health and the economic wellbeing of the population. In addition to this book, *Low Cost Emergency Water Purification Technologies*, which is meant to serve as a guidance document, another book: *Drinking Water Security for Engineers, Planners, and Managers*, is already in press as a part of the *Integrated Water Security Technologies* book series being published by Elsevier.

In this book, we describe appropriate, yet affordable, technologies for producing potable water for emergency use. This book is meant to be used as a primer by NGOs, government entities, the military, planners, and managers who deal with disaster relief. This book describes low-cost technologies that are available commercially or treatment technologies that can be built with indigenous material for short- and long-term applications.

For short-term applications, energy use is not a big barrier. However, energy use can be a major consideration for systems that are to be deployed for long-term use.

Chapter 1 provides an orientation to current thinking about water treatment for emergency application and guides the reader in the selection of appropriate technologies. Chapter 2 provides a description of systems deployed for short-term applications, primarily for the first few weeks following the disasters. The technologies are further classified as high- and low-energy systems based on their energy need per unit of water produced. Technologies considered for short-term use include reverse osmosis, distillation, and forward osmosis.

Use of solar energy for water pasteurization is the theme of Chapter 3. In situations when chemical oxidants are not available and boiling is not feasible (no power, fuel, or firewood), solar pasteurization may be an effective means of killing microbes present in water. This chapter examines commercial as well as homemade units for their effectiveness.

Disinfection of the produced water is described in Chapter 4. Principles of UV irradiation and commercially available UV units for flow-through and static systems are described. Feasibility of LED-based UV lights for small-scale applications is also discussed. Discussed in this chapter also, is use of silver-impregnated, activated carbon; electro-chlorinators; bleach; and chlorine tablets as disinfectants.

Use of treatment systems over a long period of time at low costs are some of the key objectives for disaster response in developing countries. Chapter 5 examines the effectiveness of slow sand filtration as well as natural (riverbank or lake bank) filtration as means of producing large quintiles of water for community use at low cost. This water may not require significant additional treatment besides disinfection. Various packaged filtration systems are described in this chapter. Other low-cost technologies such as Lifestraw and Chuli are described as well. We also describe various small-scale innovative technologies developed in the last few years. For natural filtration, we show improvements in water quality and provide step-by-step guidance for the design of wells and selection of well screens. Protection of wells from surface contamination is also described.

In Chapter 6, we discuss emerging technologies such as nanotechnology, renewable energy, and iodinated resins for water purification. In the last chapter, Chapter 7, we discuss water infrastructure resilience. Here, we discuss the difference between developed and developing countries and provide guidance on how to improve the resiliency of water infrastructures and provide wholesome and sustainable solutions for crucial potable water supplies.

We would like to express our gratitude to several graduate students and research assistants who worked with the authors in researching and compiling data for this book. They include Natalie Muradian at the School of Engineering & Computer Science, University of the Pacific, and Gabriel El Swaify and Matteo D'Alessio in the Department of Civil and Environmental Engineering, University of Hawaii. Natalie Muradian's hard work and dedication in preparing initial drafts of some of the chapters and reviewing page proofs were invaluable to the completion of this work. We acknowledge and thank Dee Ebbeka of the University of Nebraska for her assistance in preparing illustrations.

Chittaranjan Ray
University of Nebraska, Lincoln, Nebraska, USA
Ravi K. Jain
University of Pacific, Stockton, California, USA

CONTENTS

CHAPTER 1

Introduction

Contents

Keywords: Water quality, Water treatment, Costs, Point of use, Internally displaced person

More than one billion people do not have access to safe drinking water sources (Lantagne et al., 2010). Many of them reside in developing countries with very few resources available to them. Simple and low-cost technologies have been developed to provide ways to treat water, ranging from point-of-use (POU) treatment to small-scale (SS) community treatment. During natural disasters, POU and SS technologies offer ways to provide clean and safe drinking water. This guide to emergency water treatment has been developed based on current research, products, and field studies to create an expeditious and easy process for choosing which technology is most appropriate in each emergency situation.

Natural disasters, such as floods, tsunamis, hurricanes, and earthquakes, affect more than 226 million people every year (UNISDR, 2011). The occurrence of these natural disasters has been increasing each year (see Figure 1.1) due to the synergistic effect of climate change is causing more extremes in weather and growing populations are living in areas vulnerable to natural hazards (Lantagne and Clasen, 2009). Developing a guideline for emergency water treatment will become even more important as the number of natural disasters continues to increase.

During disasters, water sources become contaminated with industrial, human, and animal waste from overwhelmed sewage infrastructures or because of poor hygiene practices. Diseases caused by waterborne pathogens

☆"To view the full reference list for the book, click here"

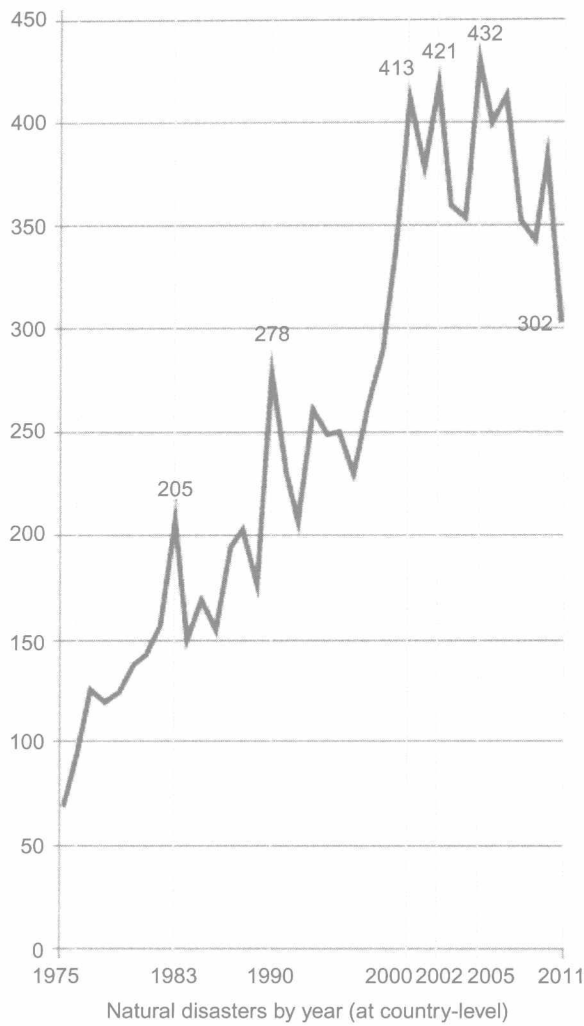

Figure 1.1 The number of natural disasters of per year from 1985 to 2011 (UNISDR, 2012). (For the color version of this figure, the reader is referred to the online version of this chapter.)

can easily be spread by this contamination (Colindres et al., 2007; McLennan et al., 2009), affecting a large number of people, primarily in the developing world. Several billion people use water that is likely contaminated, resulting in approximately 2.5 billion cases of illness per year and about 5 million deaths per year (Burch and Thomas, 1998; Pejack et al., 1996). In the developing world, high rates of morbidity and mortality are caused by common illnesses spread by water contamination, including cholera, typhoid fever, shigellosis, dysentery, and hepatitis A and E (Lantagne and Clasen, 2009). In fact, 40% of deaths in internally displaced person (IDP) camps were due to diarrhea caused by drinking microbiologically unsafe water (Doocy and Burnham, 2006). The communicable diseases present in IDP camps were transmitted through unsafe drinking water. Because of this contamination, water treatment approaches may be valuable in helping to stem a "second wave" of illness and death after a disaster (Colindres et al., 2007).

The poor in developing countries are the most vulnerable to disasters because they do not have the resources to rebuild and fix infrastructures (UNISDR, 2011). After natural disasters, survivors either leave their country and become refugees or stay in the country and migrate to someplace safer, becoming IDPs. Close living quarters, lack of hygiene, and insufficient clean water supplies in IDP camps can exacerbate already poor conditions (Steel et al., 2008). Even if members of an affected community remain at home rather than moving to an IDP camp, there is still a chance that their water will become contaminated.

1.1 STANDARDS FOR WATER QUALITY AND QUANTITY

During a disaster, clean water is necessary for survival. The main health problems associated with drinking water contamination are caused by insufficient water for hygiene purposes and consumption of that contaminated water. There are two standards defined by the Sphere Project (2011) for water supply standards. The first standard involves the quantity of and access to water, while the second standard regulates water quality. The minimum amount of water for safe and healthy consumption is summarized in Table 1.1. Water for hygiene use is considered a basic water need because it is important maintaining proper hygiene during disasters to reduce the risk of disease.

Table 1.1 Basic Survival Water Needs (Sphere Project, 2011)

Water Use	Minimum Requirement (L/day)	Notes
Survival needs: water intake for food and drinking	2.5-3	Depends on the climate and individual physiology
Basic hygiene practices	2-6	Depends on social and cultural norms
Basic cooking needs	3-6	Depends on food type and social and cultural norms
Total	7.5-15 L/day	

Table 1.2 Water Quality Parameters for Disaster Relief (Sphere Project, 2011)

Water Quality Parameter	Minimum Requirement	Notes
Coliforms	0/100 mL of water	Measured at the point of delivery
Turbidity	<5 NTU	For proper disinfection
Chlorine Residual	0.5 mg/L	To reduce risk of posttreatment contamination

Along with the 7.5- to 15-L of water per person per day, other water quantity indicators that can be used to measure the amount of water accessibility include:

- Distance from a household to a water point (~500 m);
- Waiting time at a water source (no longer than 30 min)

These standards should not be followed blindly, as they do not guarantee that water is equally available to all.

Water quality is a secondary standard, according to the Sphere Project (2011). Once water quantity has been assured, water quality should be improved to reduce the risk of dysentery and other diseases. The quality parameters identified in Table 1.2 are specified by the Sphere Project (2011) as the minimum standards that must be met by water treatment technologies.

1.2 TECHNOLOGY REQUIREMENTS

Because the majority of people affected by natural disasters are not knowledgeable about the technologies available for emergency water purification, criteria for technology use should reflect this. There are two types of responses in natural disasters. The first response is a rapid (and potentially short) response to a disaster, designed to keep people alive. During disasters, this response tends to include the transportation of bottled water to the affected population. However, the weight and expense of transporting bottled water has resulted in a lack of sustainability, so alternatives are continually being explored. The second response is a more sustainable and long-term response. This second response needs to last until the IDP camps or community living conditions return to normal. These technologies can even be appropriate for future water treatment during stable times if water treatment was unavailable before the emergency.

Table 1.3 The Flow Rate Needed for a Water Treatment Device Based on How Many People Are Being Served

Persons Per Water Source	Treatment Capacity Needed (L/h)
1	1
5	5
25	24
50	47
100	94
250	235
400	375
500	469

Initial, rapid response for water treatment should have the following characteristics (Ray et al., 2012):

- Provides needed quantity of water, and the water is of drinkable quality
- Portable
- Low cost
- Light weight
- Ease of use or requires minimal training
- Requires minimal or no external power

A solution for a long-term response should have the following characteristics (Ray et al., 2012):

- Ability to support a community or large population by purifying a large volume of water
- Parts require infrequent replacements and minimal supply chains
- Does not require complex training to operate
- Uses easily available power sources

Water treatment technologies available in an emergency must provide the minimum amount of water needed for basic survival; thus, the required capacity of these technologies depends on the amount of people the device serves. Using the minimum amount of water needed for survival from Table 1.1 (7.5 L/day) and assuming that water can be collected for 8 h a day (Sphere Project, 2011), the required capacity of water treatment technologies can be estimated; see Table 1.3.

1.3 CHALLENGES IN PROVIDING WATER TREATMENT FOR DISASTER RELIEF

Water treatment technologies are typically provided to those in need through nongovernment organizations (NGOs), the government, or companies that manufacture water treatment devices. The effectiveness of these organizations in responding with water treatment technologies to these disasters has not been extensively studied in peer-reviewed journals. However, a study by Colindres et al. (2007) did find that NGOs were less efficient then they could be. When delivering water treatment products, NGO representatives were not familiar with the treatment process they were distributing, nor did they have the training or experience needed to promote the water treatment device (Colindres et al., 2007). In order to provide the most help possible, the organization that is offering relief technologies needs to be familiar with the product they are distributing and be trained in using the technology. Emergency responders should include local community leaders in the training, educational, and distribution process to gain community support for the technology. This will also help the local population to understand that licensed technologies provide a way to help them stay healthy and can offer alternatives to drinking dirty water (Colindres et al., 2007).

A difficulty in measuring the effectiveness of emergency water treatment technologies is that metrics are difficult to develop and compare in different emergency situations. For example, the majority of studies that evaluated disaster relief programs were all conducted during a stable time after the emergency, not during the initial, acute response. Thus, the technologies that were found to be effective through field tests and applications may not be as easily implemented in the more chaotic situation of an acute emergency response (Colindres et al., 2007). Another difficulty in assessing the effectiveness of water treatment technologies in an emergency situation is the difference in local conditions. One study found that using chlorinated tablets reduced dysentery in a community while another study found that the same chlorinated tablets did not reduce dysentery in a different population (Clasen et al., 2007; Jain et al., 2010). The numerous factors related to water quality, including the amount of microbiological activity in the water, water storage practices, hygiene, and water treatment technology education, decrease researchers' ability to evaluate and compare results.

Studies that have researched emergency water treatment found that the greatest challenges during implementation were user acceptance and user training (Lantagne and Clasen, 2009). Due to the chaos of acute emergency situations, user training can be difficult to implement. Lantagne and Clasen (2009) found that initial stages of emergency situations had less than a 20% uptake of POU water treatment devices. More stable emergency situations resulted in a higher rate of POU uptake due to the implementation of training. Training is important because effective treatment of water depends on correct use of the device. If the device is not used correctly, users will continue to get sick and assume that the device does not actually work, discontinuing its use. This fosters a lack of trust in water treatment in general. User acceptability is also dependent not only on correct use of the device, but ease of use, proper maintenance, and taste of the treated water.

Implementing emergency devices in a manner that reduces illnesses and is sustainable is difficult because each disaster affects different communities in different ways. Some emergency devices that may work well in some areas may not be accepted in other regions. For example, some regions of developing countries already use a certain type of water treatment during stable times, so implementing the same type of treatment might be more effective than implementing a new technology. Loo et al. (2012) developed a procedure that can be followed during an emergency situation. While this procedure is new and has not yet been tested in an emergency, it provides a guideline to follow that would help implement the most effective technology depending on the scenario. The list of parameters to consider when following the procedure is provided in Figure 1.2. After determining the important parameters, the decision tree in Figure 1.3 can help determine the technologies that are the most appropriate. After selecting several possible technologies, the matrix designed by Loo et al. (2012) in Figure 1.4 can be used to compare the technologies and see which technology is the most appropriate. The matrix in Figure 1.4 can also be tailored to fit the site-specific needs. Equation 1 can be used to determine the nominal and weighted score of each potential water treatment technology listed in Figure 1.4. Than that score can be applied in Step 4 of Figure 1.2.

Score of water treatment device $= \sum_{j-1}^{n} w_j x_{ij}$ (Equation 1, Loo et al., 2012)

Where wj = weighting factor arbitrarily applied to criteria (See top row in Figure 1.4)

Xij = score for each criterion (See columns in Figure 1.4)

When implementing a new water treatment technology, factors to consider include:

- Water source and quality
  - Surface water, types of wells, spring water, pipe network
    - If not piped, how water is collected
  - Turbidity, microbiological activity, arsenic
  - Potential contamination: proximity of nearby industry/agricultural areas and locations of community sewage to water source
- Initial, acute response or long-term application
  - Recipient's culture

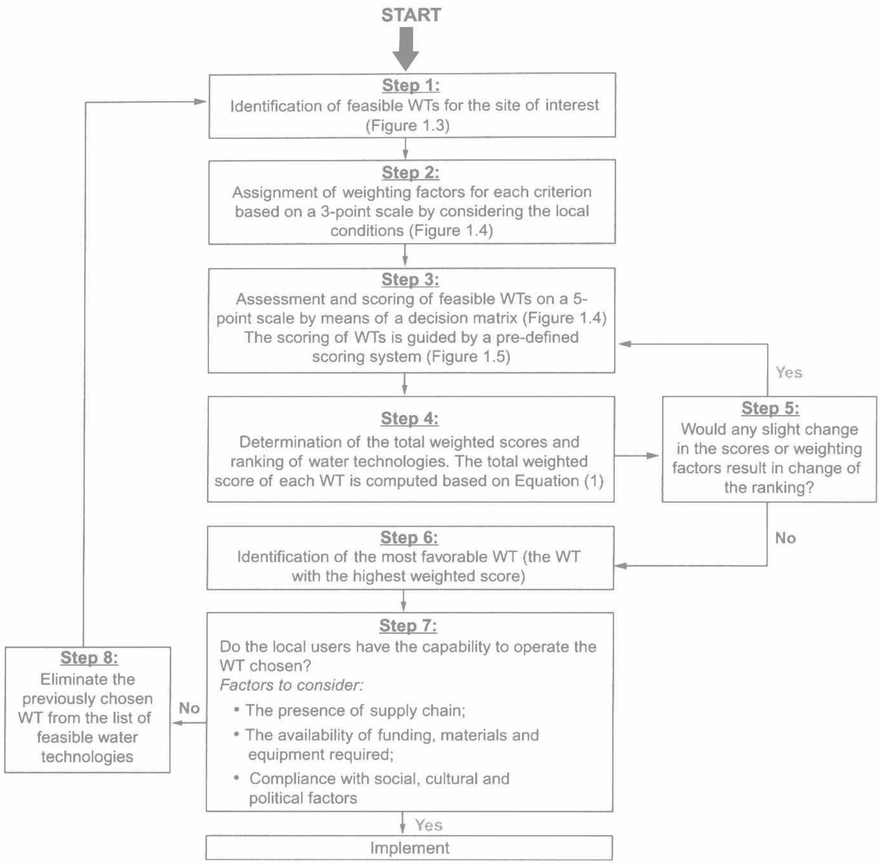

Figure 1.2 Flowchart for the water treatment selection process (Loo et al., 2012). (For the color version of this figure, the reader is referred to the online version of this chapter.)

- Recipient's familiarity with similar technology and/or previous technology use
- Recipient's hygiene practices
- Previous training and adaptability
- How and what water was used for and how it will be used now
- How water is stored and how recontamination of treated water can be prevented

- Cost: Initial investment and maintenance costs
  - Lifecycle costs; see Section 1.4
- Operation and maintenance
  - Labor required to operate and clean device on daily basis
  - Availability of replacement parts