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EDITORIAL

Crucial need for water quality monitoring of biological contaminants

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Globally, it is estimated that approximately one billion people do not have access to a safe water supply. The affected population is largely concentrated in developing countries; however, developed nations are also susceptible to contaminated public drinking water supplies, during natural disaster emergencies, from human error, or as the results of deliberate contamination. Types of water contaminants fall into four categories: biological, chemical, radiological, and physical. Biological contaminants pose the greatest immediate public health threat to drinking water supplies due to their ability to cause widespread outbreaks of disease. Chemical and radiological contaminants are important but, in most cases, adverse health effects are not acute and occur after prolonged exposure. Physical contaminants affect the public perception and acceptability of the drinking water; however, health effects from physical contaminants, such as sediments, are often caused by associated biological contamination.

Providing safe drinking water in both industrialized and developing countries are one of the greatest challenges of the twenty-first century. The current approach to biological contamination assessment of drinking water is reactive and biological monitoring is only conducted intensively after a waterborne outbreak, in other words after the damage has already occurred. There must be a focus on the development of new monitoring methodologies and devices which allow for a more expeditious and preventive approach, especially during natural disasters. A preventive approach will require technology that can monitor drinking water supplies in real-time and in situ to stop outbreaks from occurring, ensuring the safety of consumers. These devices must also take into account user needs and address the realities of adverse field conditions in developing countries or during natural disasters in order to be sustainable and become widely adopted.

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Biological monitoring strategies

Current monitoring strategies still largely rely on the laboratory incubation of indicator organisms, typically in the presence of chromogenic reagents, a technology originally developed in the nineteenth century. Test kits and portable laboratories have been developed to make these incubation-based techniques field-applicable and more rapid, but test-kit approaches are not real-time and have limitations, including supply costs that may restrict their use in developing countries. Test kits are useful for determining presence or absence of biological contaminants, but do not provide specific information about the pathogens so crucial for effective water quality monitoring and management.

A real-time and continuous monitoring system for biological contaminants is needed if preventive monitoring is to become a reality. Microbial monitoring is difficult because microorganisms are discrete and their concentrations vary over time and space. Another difficulty is that pathogenic microorganisms can be bacteria, protozoa, viruses, and even fungi. These different classes vary greatly in size, shape, and morphology, as well as basic physiology. The current state of microbial monitoring involves the use of indicator organisms which are generally members of the coliform bacteria group. The presence of these organisms within a supply only illustrates the potential for a waterborne pathogen to be present. The greatest disadvantage of utilizing coliform bacteria as indicator organisms is that these bacteria are less persistent than viruses or protozoa meaning that their absence does not ensure the absence of more robust pathogens. New methodologies must be developed which can detect specific harmful microorganisms, including viruses.

It is not feasible to detect all possible waterborne pathogens; therefore, priority target pathogens for detection must be determined. Ideally, the selected targets pathogens should have contaminant indicator function and be able to indicate the presence or absence of viruses and protozoa also. Another possibility is to select the monitoring of specific pathogens based on regions. It is understandable that pathogens that are the priority in developing countries are not the same as those in industrialized nations. In addition, prevalence can also vary by countries and states. By breaking down and categorizing contaminants by region, more effective monitoring strategies can be developed and implemented. Some progress has occurred in these areas, but in situ and real-time monitoring methods are still largely experimental.

In situ biological monitoring devices

At present, there are no devices in the market or in prototype development that have been proven capable of detecting all classes of microorganisms. The most promising devices utilize nucleic acid (large biological molecules essential for all known forms of life; they include RNA and DNA) or protein-based detection due to their high specificity, however, very few of these currently have the capability to detect viruses. The Ruggedized Advanced Pathogen Identification Device (R.A.P.I.D.) and the RAZOR EX BioDetection System are both portable devices that use polymerase chain reaction (PCR) to detect bacteria and protozoans. They do not have the ability to detect viruses and require training for sample preparation, but are effective, specific, and give results quickly. A device that is able to detect viruses as well as bacteria and protozoa is the μChemLabT: Biodetector. Handheld and portable, this device is specifically designed for field work, but requires more validation for accuracy. Currently, these devices are typically supplemented by additional laboratory testing—a practice that is not sustainable in developing countries—and further research must continue to develop technologies capable of rapid, specific, in situ detection as well.

Spectroscopic devices may offer new opportunities for preventative monitoring and rapid response to natural disasters, especially when combined with modern communication technology. For example, an easy to use biodetection device called the Water Canary (Sonaar Luthra, watercanary.com) does not require training, literacy, or complex operations. The easy to use prototype theoretically promotes widespread usage. This device is in early stages of development and appears to have tremendous potential. It can test contaminants in seconds by analyzing light passing through water, rather than using chemicals for analysis. If contaminants are found, a red light appears. The device can then transmit the GPS-tagged data across wired and wireless networks. This assists in identifying spatial and geographical extent of the water source contamination.

A very promising approach is the use of biosensors for rapid, near real-time, in situ monitoring. Biosensors use a transducer to monitor some biorecognition component (such as enzymes) to determine the amount of microbial contamination present. While biosensor technology is sensitive, rapid, and portable, it requires validation of results before it can be used in the field. Developing such biodetection devices that generate real-time information will help determine the normal conditions of the water supply by creating baseline data. By establishing this baseline, areas of high risk and vulnerability can be more easily identified through significant biological changes in the water quality and will allow for a quicker response. Instead of relying on the monitoring of treated water as a measure of safety, multiple points throughout the distribution system can be monitored in order to prevent a widespread contamination event. Implementing such a monitoring system will require research on the most effective locations to place such sensors. Permanent biosensor installations are helpful to create baseline data, they, however, cannot be installed everywhere and are not applicable in every situation.

While the devices mentioned above are becoming more feasible for field applications, no device that is easy to use and has specific detection has been developed. Thus, research objectives for the future are to develop devices and methodologies which allow for the detection of all classes of microorganisms that can potentially be used for routine monitoring, field testing, and devices that can be used during natural disasters.

In summary, examples of field testing devices that include real-time polymerase chain reaction (technique for amplifying DNA sequence in vitro), biosensors, and lab kits all require field validation and further development. Portable devices that can expeditiously monitor water quality and be most effective in natural disasters are still needed. Monitoring devices that have GPS transmission capability, such as the Water Canary, could allow rapid reporting of presence of pathogens by location and allow for a quick and appropriate response. Thus, a crucial need exists for real-time, effective, and pathogen specific water quality monitoring of biological contaminants. These devices will be helpful for routine monitoring of drinking water supply systems and especially useful during natural disasters and emergencies. The challenge then is: should science and engineering community work diligently to generate public support for major investment in research and development to address this significant need!