Undergraduate Thesis Prospectus

Point-Of-Use Water Treatment Against Pathogens and Mosquito Larvae

(Technical research project in Civil Engineering)

Poison in the Pipes: How U.S. Cities Have Responded to Lead-Contaminated Water

(Sociotechnical research project)

by

Kevin Barnes

October 27, 2022

Technical project collaborators:

Jeffrey Nutt

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Kevin Barnes

Technical advisor: James Smith, Department of Engineering Systems and Environment

STS advisor: Peter Norton, Department of Engineering and Society

General research problem

How may access to safe drinking water be improved?

Water quality is essential to health. According to the World Health Organization (WHO), water-related illnesses are the leading cause of death globally, averaging 3.4 million deaths per year (Berman, 2009).

In developing countries where centralized water supply and sanitation systems are scarce, point-of-use (POU) water treatment methods are necessary. In developed countries, water supply infrastructure must be maintained and improved to protect water quality. Safe drinking water also depends on sound public policy that ensures standards enforcement through regulation, monitoring, and inspection; when such systems fail, communities must respond to ensure their own safety.

Point-of-use water treatment against pathogens and mosquito larvae

How can scientists effectively use chlorine and metal-based disinfectants in point-of-use water treatment against pathogens and mosquito larvae?

My capstone project focuses on testing the effectiveness of copper, silver, and chlorine in disinfecting water against pathogens such as E. Coli. as well as against mosquito larvae. I am working on a team capstone project with Professor Jim Smith, a professor in the Engineering Systems and Environment department, and Jeffrey Nutt, a fellow student. We hope to develop and test methods to compare the relative effectiveness of the various disinfectants against MS2, a bacteriophage, and mosquito larvae.

As previously stated, the WHO declared waterborne diseases to be the top cause of death globally. According to the Centers for Disease Control and Prevention (CDC), "2 billion people lack access to safely managed drinking water at home" (2022). Not surprisingly, this affected group is predominantly located in developing countries. Of those 2 billion people without safe drinking water at home, approximately 640 million live in rural areas (Centers, 2022). While urban settings are more likely to devote funding towards creating centralized infrastructure, rural areas are often left out due to high-cost considerations. With this in mind, POU water treatment has come to the forefront in helping to improve the water quality in affected rural areas.

Copper, chlorine, and silver are all known to be effective disinfectants when used separately (Pinto et al., 1994). Their effectiveness when used together is still not entirely understood, and is the subject of research for PhD students under the supervision of Professor James Smith at UVA. They are conducting research to see whether the combination of the different disinfectants has a synergistic effect, having a stronger disinfection rate than the individual parts, while also testing the effect of these disinfectants against mosquito larvae. With mosquito-related diseases more prevalent in areas with poor water quality, the potential to address both problems at once would be groundbreaking (Okanga, Cumming, & Hocker, 2014).

The capstone goal for my partner and me is twofold. First, we are working with the PhD student researchers to design a lab experiment to test the efficacy of disinfectant combinations versus MS2 and mosquito larvae. At the same time, we are working separately on a unique design to 3D print that houses the ceramic silver block and the copper mesh sheet, which are the forms of the disinfectants that have been found to be most effective.

For the lab experiment portion, the main constraint is trying to work with products that are not compatible for lab use. Namely, the block size of the silver tablet is designed for a ten-liter bucket, much larger of a scale than can be measured in a lab. How to effectively divide the block to maintain characteristics is a major hurdle. Many of the constraints fall on the disinfectant housing side of the project, as scalability of production as well as user friendliness need to be considered. The disinfectant vessels need to be small and easily packageable, readily easy to reproduce, and ideally low cost. They also need to be intuitive enough that someone that is totally unfamiliar with water disinfection could still effectively use it.

The current commercially available options for POU water disinfection include products like the MadiDrop, which is the basis for the silver ceramic block used in the new design. Other products include Aquatabs, which uses chlorine, and PUR packets by Procter and Gamble, which uses coagulation and flocculation along with chlorine similar to a wastewater treatment facility (Estrella-You & Smith, 2022; Lougheed, 2006). While all of these products effectively utilize disinfectants, it is important to note that none of them currently use more than one.

In the design to test the disinfectants against MS2, the first step is cultivation of MS2, which utilized a standard culturing method for MS2 and E. Coli as described by Jackson et al. (2020). The MS2 would then be exposed to water treated with the ceramic silver tablet along with a copper mesh sheet. After exposure, the MS2 would then be measured simply by counting MS2 plaque. The results are then compared to safe drinking water concentration standards to determine the efficacy of the disinfectant combination. To test the disinfectants' lethality versus mosquito larvae, eggs are shipped in and placed in beakers treated with the disinfectant combination with a mesh enclosure. The progress of the eggs is monitored by counting the number of mosquitoes that end up hatching and surviving in the beakers. Without many quantifiable standards, the comparison for effectiveness is mostly against the control and against similar studies.

For the vessel encasing the block and mesh sheet, most of the design process is trial and error utilizing SOLIDWORKS, a CAD modeling software that will be used to create the eventual 3D model. There will be multiple prototypes made, each from a different angle to try and find the right combination of ingenuity and simplicity. In the end, we hope to have a working model of a casing for the silver ceramic tablet and the copper mesh that is backed by our research to show its effectiveness. Ideally, this product would then be able to go out in the field and have the potential to improve water quality and subsequent public health in affected areas.

Poison in the pipes: how U.S. cities have responded to lead-contaminated water

How have U.S. cities responded lead-contaminated water?

Problems of water quality are not limited to developing countries; for example, many U.S. communities have faced lead contamination. Such cases in Flint, Michigan, and Washington, D.C., have attracted wide attention, but many other U.S. cities have had lead-contaminated water too. In 2016, the U.S. Centers for Disease Control and prevention (CDC) estimated that 2.5 percent of young children in the U.S. had elevated lead levels in their bloodstreams (Pell & Schneyer, 2016). As corroding lead pipes in aging infrastructure have caused public health emergencies nationwide, communities have demanded accountability from public authorities.

Flint, Michigan, is the most prominent example of the many U.S. cities devastated by water contamination from lead pipes. From 2014 to 2017, Flint endured three consecutive years of unsafe drinking water. Though the contamination was alleviated, economic and psychological burdens endure (Pauli, 2020; Danagoulian & Jenkins,2021). Though less widely reported, similar public health emergencies have also afflicted Washington, D.C., and Chicago (Guidotti et al., 2007; Heard-Garris et al., 2017).

Citizens have responded to local lead contamination, alone and through advocacies. In Flint, citizens banded together to form Flint Rising, a local advocacy seeking justice for all residents harmed by the water crisis. It demands reparations in the form of refunds for the contaminated water that residents paid for, repair of water infrastructure, and health services for affected families (Flint Rising, 2016). The U.S. Water Alliance, an interest group predominantly representing municipalities, public water utilities, and their private contractors and suppliers, works with local public agencies such as the Philadelphia Water Department and Chicago Public Schools to promote education, strengthen guidelines, and represent communities with lead contamination in ways that protect the interests of it member organizations (USWA, 2018). Unorganized residents are also engaged. Many fear for children's health. Charles Eason of Washington, D.C., noted "It's a particular risk for young people, and I have a 4-year-old grandson in my house regularly" (Nakamura, 2004). The American Civil Liberties Union (ACLU) pursues a litigation strategy. It has filed class-action lawsuits on behalf of Flint residents (ACLU, 2022). Public water utilities have been engaged too. In Flint the utility attempted unsuccessfully to deflect blame, claiming that "the water provided to you today meets all safety standards" (City, 2015). The resounding evidence has since disproved this statement.

Researchers have studied the enduring health legacies of infrastructure policies. For example, Nicholas (2019) examined the public health burdens in Los Angeles of air pollution from motor vehicles. In both cases, infrastructure policy reflected underestimates of the risks (Triantafyllidou, Lambrinidou, & Edwards, 2009). According to Guidotti et al. (2007), authorities typically respond to such underestimates by increasing their monitoring in an effort to improve their forecasts.

References

ACLU of Michigan (2022). Flint Water Crisis. https://www.aclumich.org/en/issues/flint-water-crisis

Berman, J. (2009, Oct. 29). WHO: Waterborne Disease is World's Leading Killer. *VOA News.* https://www.voanews.com/a/a-13-2005-03-17-voa34-67381152/274768.html

CDC (2022). U.S. Centers for Disease Control and Prevention. Global Water, Sanitation, and Hygiene (WASH) Home. https://www.cdc.gov/healthywater/global/wash_statistics.html

City of Flint Water Treatment Plant (2015, July). Water Quality Update. https://www.cityofflint.com/wp-content/uploads/2022/03/July-2015-Letter-to-Water-Customers.pdf

Danagoulian, S. and Jenkins, D. (2021, March). Rolling Back the Gains: Maternal Stress Undermines Pregnancy Health after Flint's Water Switch. *Health Economics 30,* 564-584. EBSCOHost.

Estrella-You, A. and Smith, J. A. (2022, Sept. 23). Synergistic Bacterial Inactivation by Silver Ions and Free Chlorine in Natural Waters. *Journal of Environmental Engineering 148*. Web of Science.

Flint Rising (2016, May 16). Arnett Rison III [Video]. YouTube. https://www.youtube.com/watch?v=Rn0VN42cybo&t=14s

Guidotti, Calhoun, Davies-Cole, Knuckles, Stokes, Glumph, Lum, Moses, Goldsmith, and Ragain. (2007, May). Elevated Lead in Drinking Water in Washington, DC, 2003-2004: The Public Health Response. *Environmental Health Perspectives 115,* 695-701. Web of Science.

Heard-Garris, Roche, Carter, Abir, Walton, Zimmerman, and Cunningham (2017, Dec.). Voices from Flint: Community Perceptions of the Flint Water Crisis. *Journal of Urban Health-Bulletin of the New York Academy of Medicine 96*, 776-779. Web of Science.

Jackson, Kahler, Kucharska, Rekosh, Hammarskjold, and Smith. (2020, Mar. 1). Inactivation of MS2 Bacteriophage and Adenovirus with Silver and Copper in Solution and Embedded in Ceramic Water Filters. *Journal of Environmental Engineering 146.* Web of Science.

Lougheed, T. (2006, July). A Clear Solution for Dirty Water. *Environmental Health Perspectives, 114,* 425-428. GreenFILE.

Nakamura, D. (2004, Jan. 31). Water in D.C Exceeds EPA Lead Limit. *The Washington Post.* https://www.washingtonpost.com/archive/politics/2004/01/31/water-in-dc-exceeds-epa-lead-limit/1e54ff9b-a393-4f0a-a2dd-7e8ceedd1e91/

Nicholas, Vidyanti, Caesar, and Maizlish. (2019, Mar.) Routine Assessment of Health Impacts of Local Transportation Plans: A Case Study from the City of Los Angeles. *American Journal of Public Health 109,* 490-496. EBSCOHost.

Okanga, S., Cumming, G., and Hocker, P. (2014, Jan. 22). Avian malaria prevalence and mosquito abundance in the Western Cape, South Africa. *Malaria Journal, 12.* Web of Science.

Pauli, B.J. (2020, May). The Flint Water Crisis. *Wiley Interdisciplinary Reviews-Water 7.* EBSCOHost.

Pell, M. B. and Schneyer, J. (2016, Dec. 19). Thousands of U.S. Areas Afflicted with Lead Poisoning beyond Flint's. *Scientific American*. https://www.scientificamerican.com/article/thousands-of-u-s-areas-afflicted-with-lead-poisoning-beyond-flints/

Pinto, Diez, Bosch, and Abad. (1994, July). Disinfection of human enteric viruses in water by copper and silver in combination with low levels of chlorine. *Applied & Environmental Microbiology, 60,* 2377-2383. Environment Complete.

Triantafyllidou, S., Lambrinidou, Y., and Edwards, M. (2009, Nov.). Lead (Pb) Exposure through Drinking Water: Lessons to be Learned from Recent US Experience. *Global Nest Journal 11,* 341-348. Web of Science.

USWA (2018). U.S. Water Alliance. Reduce Lead Risks, and Embrace the Mission of Protecting Public Health. U.S. http://uswateralliance.org/sites/uswateralliance.org/files/publications/uswa_listen_big6_032818_a.pdf