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Exploring an Innovative Automatic Disinfection System for Drinking Water Production from Harvested Rainwater

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Abstract

The safe water sources for dwellers in remote and underprivileged locations are limited. Therefore, harvested rainwater becomes one of the critical clean water sources in these isolated locations. However, the lack of facilities for water treatment and electricity supply for small communities compels people to drink harvested rainwater without any formal treatment. Researchers have found microbiological contaminants in this rainwater, which are detrimental to human health. Although chlorination is a popular method to disinfect water in large volumes, it is still not widely applied on small scales. This study presents an innovative disinfection method that can treat harvested rainwater for small communities and run on batteries. The proposed treatment system has two functions: filtration and disinfection. Pool chlorine (sodium hypochlorite) is used as the disinfectant. Both processes are controlled by a programmable logic controller, solenoid valves, and non-contact liquid-level sensors. In addition, the operation is visible through a human-machine interface display. The successful development of such a system could significantly change the water supply of underprivileged rural/regional communities.

Keywords: Harvested rainwater treatment, Disinfection, Automatic disinfection, Drinking water.

1. INTRODUCTION

Rain is the primary source of fresh water. Centralised facilities for preserving water and making it available to the public have been popular for many years (Bond et al., 2013). In remote areas, storing rainwater in a storage tank or container and consuming it is an ancient practice. Growing cities have increased water demand and forced scientists and engineers to develop more sophisticated water treatment systems and distribution networks.

Despite technological achievements, World Health Organisation (WHO) has been concerned about not having universal access to safe drinking water (Lantagne et al., 2006). About 2.1 billion people do not have access to a clean drinking water supply (Alim et al., 2020). Establishing universal water supply systems to make clean water available to regional communities requires a massive investment in infrastructure. Many developing countries cannot afford this. Even in developed countries, remote communities are still deprived of a centralised clean water supply system (Mattos et al., 2019). The water scarcity situation deteriorates further when chemical wastes contaminate surface and groundwater, which are too costly to treat. Therefore, Alim et al. (2020) suggested that rainwater can be one of the safest clean water sources for domestic use in remote locations.

However, many researchers identified contaminants (chemical & microbiological) in the samples of harvested rainwater (HRW) collected from storage tanks in various countries (Latif et al., 2022). Latif et al (2022) identified that the pollutants in collected samples have exceeded WHO drinking water guidelines at many places. The drinking of untreated rainwater from the rainwater tank leads to immediate and long-term health impacts. Therefore, current drinking water regulations strongly recommend HRW treatment before using it for potable purposes.

Regardless of the source, water treatment on a domestic scale is less concerning to the less educated and poor people (Alim et al., 2020). Likewise, HRW treatment in homes is generally uncommon. The main argument for not considering HRW treatment in houses is that the rainwater is clean and safe to drink (Alim et al., 2020). Alim et al. (2022) and Lantagne et al. (2006) also noted the following reasons that discourage dwellers to treat HRW:

i. Proven automatic water treatment systems on a small scale are rarely available.
ii. The capital cost is high for economically disadvantaged people.
iii. No mechanism for the safe storage of chemicals for treatment.
iv. Long-term investment, financial support, and supply chain support are not available.

Lantagne et al. (2006) outlined various ways of domestic water treatment, which can be applied to HRW treatment at homes. An innovative automatic disinfection system (IADS) is proposed here to treat HRW with minimum human intervention.

2. CHLORINATION OF HARVESTED RAINWATER

Lantagne et al. (2006) suggested several options for domestic water treatment, including HRW treatment, which are (i) chlorination, (ii) filtration (bio-sand and ceramic), (iv) solar disinfection, (v) combined filtration & chlorination, (vi) combined flocculation & chlorination, and (vii) combination of granular activated carbon filter & ultraviolet (UV) light (Senevirathna et al., 2019). Among these options, chlorination is appeared to be the most suitable method to address the challenges of domestic HRW treatment due to the following reasons (Latif et al., 2022):

(i) Chlorination can remove a large portion of harmful microorganisms from water.
(ii) It has a residual effect that can protect treated water from recontamination as long as the free chlorine remains in the water greater than a certain level. Intermittent dosing can extend the residual effect of the chlorine and keep the treated water safe in the storage tank (Amy et al., 2000).
(iii) It is reasonably cheaper and widely available (Lantagne et al., 2006).

Pool chlorine (liquid sodium hypochlorite solution) is more convenient and safe than chlorine gas (Naddeo et al., 2013). It should be noted that chlorine tablets can also be applied for disinfection at a smaller scale (Pickering et al., 2015).

When chlorine is injected into water, it produces free chlorine. Free chlorine is the combination of hypochlorite acid (HOCL) and hypochlorite ion (OCL^-) (Amy et al., 2000). Between the two elements, hypochlorite acid (HOCL) performs better disinfection than hypochlorite ion (OCL^-) (dan Eddy, 2000).

$$Cl_2+H_20 \rightarrow HOCl+H^++Cl^- \quad (1)$$
$$HOCl \rightleftarrows H^++OCl^- \quad (2)$$

Likewise when the (NaOCL) and $CaO(Cl)_2$ are injected, they also produce HOCl

$$NaOCL + H_2O \longrightarrow HOCl + NaOH \quad (3)$$
$$CaO(Cl)_2 + H_2O \longrightarrow HOCl + Ca(OH)_2 \quad (4)$$

3. CHALLENGES AND SOLUTIONS

Wei-ling and Jensen (2001) identified free chlorines as highly active elements. They quickly react with the contaminants retained in HRW. Among various contaminants, ammonia, nitrite, nitrate, and natural organic materials (NOM) have been found in the HRW tank. They quickly react with free chlorine elements, as shown in equations 1 and 2. Table 3 indicates that these precursors exist in HRW in various countries. They react with the free chlorine, increase chlorine demand, and reduce the disinfection efficiency (Amy et al., 2000; Wei-Ling & Jensen, 2001).

Table 3. Chemicals that react and consume chlorine in the water

Country	NH_3 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	Reference
Australia	0.35 ± 0.01	0.006 ± 0.001	0.196 ± 0.02	(Alim et al., 2021)
China	0.01			(Zhu et al., 2004)
Jordan	0.06		1.56	(Radaideh et al., 2009)
South Korea	0.02		2.2	(Lee et al., 2010)
Palestine	1.4		4.2	(Al-Salaymeh et al., 2011)

Table 4 shows that the precursors decline after filtration. Otherwise, any remaining precursors in the water can increase chlorine demand and produce disinfection by product (DBP). Table 4 also indicates tap water is much purer than filtered HRW, even though the quality of the filtered HRW complies with Australian Drinking water guidelines.

Table 4. Chemicals' reduction before and after filtration (Alim et al., 2021)

Parameter	Before filtration	After filtration	Contamination reduction	TAP water	Australian standard
NH_3	0.35 ± 0.01	0.332 ± 0.01	1.80%	0.013 ± 0.001	0.2
NO_2	0.006 ± 0.001	0 ± 0.001	0.60%	0 ± 0.001	3
NO_3	0.196±0.02	0.151 ± 0.02	4.50%	0.026 ± 0.05	50
TOC	0.8874±0.05	0.667 ± 0.05	22.00%	0 ± 0.5	

Scientists consider total organic carbon (TOC)and NOM measurement in water as they can react with chlorine, forming chlorine disinfection by-products (CDBP) (Amy et al., 2000). Trihalomethans (THMs), haloacetonitriles (HAAs), and halonitromethanes (HANs) are the most common CDBP (Amy et al., 2000; Bond et al., 2012). Mazhar et al. (2020) mentioned that DBPs could enter into the human body through three pathways (i) inhalation, (ii) ingestion, and (iii) dermal absorption. Mishaqa et al. (2022) identified that various Trihalomethanes (THMs) species could cause cancer. They classified THMs into four categories, TTHMs, Chloroform, bromodichloromethane (BDCM), and chlorodibromomethane (CDBM).THMs could enter the human body at different concentrations in these three pathways. According to their findings (shown in Table 5), THMs enter into human body through inhalation at 68.95 % occasion, chloroform 37.97% through oral ingestion, BDCM 97.86 % and CDBM 97.66% through inhalation.

Table 5. Percentage of THMs exposure route to the human body (Mishaqa et al., 2022)

	Chloroform	BDCM	CDBM	Bromoform	TTHMs
Oral ingestion	37.97	0.78	0.93	16.40	2.21
Inhalation	6.80	97.86	97.66	81.46	68.95
Dermal Absorption	55.23	1.36	1.41	2.14	27.94

A recent study shows that these DBPs exposed to the human body for an extended period can increase the likelihood of cancer (Mazhar et al., 2020). That is why environmental pollution authorities in many countries and the WHO have imposed acceptable limits on some DBPs. Therefore, to efficiently achieve proper disinfection (such as UV, chlorination, or solar disinfection), it is recommended to adopt some pretreatment methods (Alim et al., 2021). Latif et al. (2022) suggested some recommended pretreatment options, such as filtration, coagulation, or a combination of filtration and coagulation.

4. PROPOSED IDEA

This project proposes a novel idea to inject pool chlorine automatically into the filtered HRW. The idea is to utilise a Programmable Logic Controller (PLC), a Human Machine Interface (HMI) display, solenoid valves, and non-contact liquid level sensors. Two 12-volt batteries will provide electric power to the instruments.

Although the project focuses on automatic disinfection, the filtration process will also be brought under automation to achieve disinfection efficiency. Figure 1 shows the treatment concept in a schematic diagram combined with filtration and disinfection. Figure 2 shows the actual location where the proposed idea will be tested.

Figure 1. Schematic diagram of the field setup, A-Rainwater tank, B-Filter, C-Solinoid valves, D-Corrosive graded solenoid valve, E-Pool chlorine tank (15Liter), F-Disinfection Tank, G-Storage tank.

Figure 2 . Project location at Western Sydney University's Werrington Campus (Alim et al., 2021)

5. PROJECT PROGRESS

A detailed design has been completed, and necessary materials have been procured, which are listed below:

(i) PLC
(ii) HMI
(iii) Solenoid valves
(iv) Solenoid valves for corrosive material
(v) Non-contact liquid sensor
(vi) Fifteen liter and tween liter jars
(vii) A manual valve
(viii) Some cables
(ix) Two 12-volt DC batteries
(x) Pool chlorine, Liquid sodium hypochlorite (Waiting for arrival).

In addition, the PLC code and HMI display have been completed. Also, the process has successfully been simulated. Currently, instrument testing and connection are in progress.

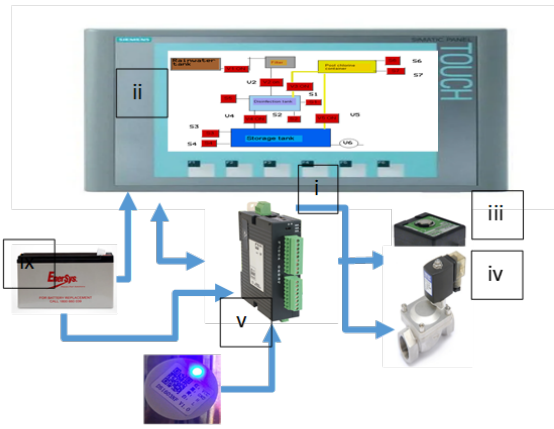

Fig 4. Proposed instrument connections

6. FUTURE STEPS

Once the instrument testing and connection are completed, a test operation will be conducted with the tap water in the laboratory. Also, a shed and a platform will be built at the project site (shown in Figure 2) to place the instruments. After that, the actual treatment operation with disinfectant will be conducted. The treated HRW will be sent to a NATA-accredited lab for quality assurance.

7. CONCLUSION

This study presents an independent HRW treatment system to produce clean water which meets the Australian Drinking Water Guideline. The key advantages of the proposed method are:

(i) Complete treatment as per the drinking water guideline.

(ii) Provide safe storage options and prevent recontamination while storing water in the treated water storage tank.

(iii) The product is independent and automated. Human intervention will be required to refill the pool chlorine and replace the batteries. This system does not require a conventional grid power supply; however, solar support will be beneficial to recharge the battery continuously.

(iv) This product is cost-effective, and instruments are readily available.

(v) This product can be placed in a remote location where a traditional power supply is unavailable or partially available.

Despite having advantages, the primary concern of this product is DBPs production. To minimise the DBPs, a filter has been engaged to reduce the precursors that contribute to forming DBPs after chlorination. In addition, to ensure the water quality, the residual chlorine and pH are recommended to measure with a convenient method.

REFERENCES

Al-Salaymeh, A., Al-Khatib, I. A., & Arafat, H. A. (2011). Towards sustainable water quality: management of rainwater harvesting cisterns in Southern Palestine. *Water resources management, 25*(6), 1721-1736.

Alim, M. A., Ashraf, A. A., Rahman, A., Tao, Z., Roy, R., Khan, M. M., & Shirin, S. (2021). Experimental investigation of an integrated rainwater harvesting unit for drinking water production at the household level. *Journal of Water Process Engineering, 44*, 102318.

Alim, M. A., Rahman, A., Tao, Z., Samali, B., Khan, M. M., & Shirin, S. (2020). Suitability of roof harvested rainwater for potential potable water production: A scoping review. *Journal of Cleaner Production, 248*, 119226.

Amy, G., Bull, R., Craun, G. F., Pegram, R., Siddiqui, M., & Organization, W. H. (2000). *Disinfectants and disinfectant by-products*. World Health Organization.

Bond, T., Templeton, M. R., & Graham, N. (2012). Precursors of nitrogenous disinfection by-products in drinking water—a critical review and analysis. *Journal of hazardous materials, 235*, 1-16.

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Lantagne, D. S., Quick, R., & Mintz, E. D. (2006). Household water treatment and safe: storage options in developing countries. *Navig, 99*, 17-38.

Latif, S., Alim, M. A., & Rahman, A. (2022). Disinfection methods for domestic rainwater harvesting systems: A scoping review. *Journal of Water Process Engineering, 46*, 102542.

Lee, J. Y., Yang, J.-S., Han, M., & Choi, J. (2010, 2010/01/15/). Comparison of the microbiological and chemical characterization of harvested rainwater and reservoir water as alternative water resources. *Science of the Total Environment, 408*(4), 896-905.

Mattos, K., King, E., Lucas, C., Snyder, E. H., Dotson, A., & Linden, K. (2019). Rainwater catchments in rural Alaska have the potential to produce high-quality water and high quantities of water for household use. *Journal of water and health, 17*(5), 788-800.

Mazhar, M. A., Khan, N. A., Ahmed, S., Khan, A. H., Hussain, A., Changani, F., Yousefi, M., Ahmadi, S., & Vambol, V. (2020). Chlorination disinfection by-products in municipal drinking water–a review. *Journal of Cleaner Production, 273*, 123159.

Mishaqa, E.-S. I., Radwan, E. K., Ibrahim, M., Hegazy, T. A., & Ibrahim, M. S. (2022). Multi-exposure human health risks assessment of trihalomethanes in drinking water of Egypt. *Environmental Research, 207*, 112643.

Naddeo, V., Scannapieco, D., & Belgiorno, V. (2013). Enhanced drinking water supply through harvested rainwater treatment. *Journal of hydrology, 498*, 287-291.

Organization, W. H. (2022). Guidelines for drinking-water quality: incorporating the first and second addenda.

Pickering, A. J., Crider, Y., Amin, N., Bauza, V., Unicomb, L., Davis, J., & Luby, S. P. (2015). Differences in field effectiveness and adoption between a novel automated chlorination system and household manual chlorination of drinking water in Dhaka, Bangladesh: a randomized controlled trial. *PloS one, 10*(3), e0118397.

Radaideh, J., Al-Zboon, K., Al-Harahsheh, A., & Al-Adamat, R. (2009). Quality assessment of harvested rainwater for domestic uses. *Jordan Journal of Earth and Environmental Sciences, 2*(1), 26-31.

Senevirathna, S., Ramzan, S., & Morgan, J. (2019). A sustainable and fully automated process to treat stored rainwater to meet drinking water quality guidelines. *Process Safety and Environmental Protection, 130*, 190-196.

Wei-Ling, C., & Jensen, J. N. (2001, Nov/Dec 2013-01-28). Effect of chlorine demand on the ammonia breakpoint curve: Model development, validation with nitrite, and application to municipal wastewater. *Water Environment Research, 73*(6), 721-731.

Zhu, K., Zhang, L., Hart, W., Liu, M., & Chen, H. (2004). Quality issues in harvested rainwater in arid and semi-arid Loess Plateau of northern China. *Journal of arid environments, 57*(4), 487-505.