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EVALUATION OF ADULTICIDAL CHLORINE WITH BLACK SAND, WHITE SAND AND SILICA SAND FOR DECLINE COLIFORM BACTERIA

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Abstract

Introduction: *The World Health Organization estimates that approximately 2.2 billion individuals globally lack access to safely managed drinking water supplies. The development of chlorine diffusers represents a promising intervention to address bacterial contamination, particularly coliform bacteria in water sources. To optimise their efficacy, rigorous analysis of chlorine diffusers' performance and optimal material combinations is required to ensure a maximum reduction in coliform populations.* ***Methods:*** *The study population comprised all water sources in the Pabelan Kartasura Sukoharjo Village area, with a total sample volume of 720 litres. Subsequently, 100 mL aliquots were collected from each water reservoir using sterilised sampling bottles. Parameters assessed included temperature, pH, total dissolved solids (TDS), and coliform counts. Instrumentation for physicochemical analysis included thermometers, TDS meters, and digital pH meters, while coliform detection was conducted using the Compact Dry EC method. Each sample was evaluated at four time intervals: 0, 30, 45, and 60 minutes.* ***Results and Discussion:*** *Analysis revealed statistically significant differences in coliform bacterial counts among chlorine diffuser types incorporating silica sand, white sand, and black sand. Conversely, no statistically significant variations were observed for temperature, pH, or TDS across the experimental groups. These findings point out the importance of sand composition in enhancing chlorine diffusers' antimicrobial efficacy.* ***Conclusion:*** *Chlorine diffusers incorporating diverse sand media demonstrated varying efficacy in reducing coliform bacteria, with black sand exhibiting the most pronounced reduction. This finding suggests that material selection significantly influences the functional performance of chlorine-based water disinfection systems.*

INTRODUCTION

The World Health Organization estimates that approximately 2.2 billion individuals globally lack access to safely managed drinking water supplies (1-2). Empirical evidence demonstrates that advancements in hygiene, sanitation, and water supply infrastructure significantly mitigate the burden of waterborne diseases. Urban centres worldwide are facing escalating demands for potable water, yet challenges persist in meeting this critical need (3). For water to be classified as potable under Indonesia's Minister of Health Regulation No. 2 of 2023, it must adhere to stringent microbiological standards, including the absence of Coliform bacteria (0 colony-forming units [cfu]/100 ml) and Escherichia coli (0 cfu/100 ml) (4). In Central Java province, 75.88% of households use improved sources for drinking water; however, 24.2% of the population remains underserved, lacking access to adequately treated and distributed water supplies (5).

Escherichia coli (E. coli) originates from faecal contamination pathways that compromise microbial water quality in domestic settings (6). Waterborne

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pathogens, originating in human and animal faeces, may enter drinking water supplies through surface water or groundwater contamination. This microbial pollution poses significant public health risks, including acute gastrointestinal and respiratory disorders, viral hepatitis, dermatological infections, adverse pregnancy outcomes, and, in severe cases, mortality (1,7).

One widely adopted intervention to mitigate microbial contamination involves chemical disinfection using chlorine. Chlorine remains a cornerstone of water treatment in low- and middle-income countries due to its cost-effectiveness and proven efficacy (8). As a WHO-approved disinfectant, chlorine effectively neutralises biological contaminants in potable water systems (9). The chlorination process specifically targets *Coliform* bacteria and *E. coli*, ensuring pathogen inactivation prior to water distribution. While municipal water suppliers, such as Indonesia's Perusahaan Daerah Air Minum (PDAM), routinely implement centralised chlorination, approximately 40% of the country's population relies on untreated well water. This necessitates innovative, decentralised chlorination strategies that are adaptable to household-level water treatment. Decentralised water treatment represents a cost-effective intervention to reduce pathogenic load in drinking water, thereby mitigating diarrhoeal disease incidence and potentially preventing associated fatalities (10).

The technical design drawing of chlorine diffusers requires careful consideration of critical parameters including residual chlorine concentrations, piping material specifications, and optimal pipe diameters (11). Concurrently, complementary materials capable of neutralising residual chlorine in treated water must be integrated to maximise disinfection efficacy while minimising environmental and health impacts (12). Key factors influencing chlorine decay kinetics include hydraulic retention time, downstream transport distance, and water temperature, which collectively accelerate microbial activity and promote the volatilisation of free chlorine species (12-13). Previous research related to the use of chlorine as a disinfectant has been widely conducted in several developing countries and in Indonesia, particularly in drinking water supply companies (PDAM) and other parties. Similarly, the use of chlorine diffusers has been employed in shallow wells. However, currently, many people are storing water using tanks as containers after pumping, necessitating a solution for addressing bacterial contamination in clean water. The novelty of this research lies in creating a chlorine diffuser with several combinations that can be used in household-scale water storage, especially in residential areas with limited land where bacterial contamination of clean water occurs. A limitation of this research is that it was only conducted on one source of clean water.

Commonly employed materials for chlorine residue decomposition include granular media such as silica sand (SiO_2), white sand, and black sand. The choice of sand-based media is informed by its natural abundance of reactive mineral constituents, including amorphous silica and iron oxides, which facilitate redox reactions to neutralise residual oxidants (14). Prior studies have demonstrated variable efficacy in coliform reduction across different sand types, necessitating systematic comparative analysis to quantify temporal differences in microbial inactivation rates under controlled experimental conditions.

METHODS

Research Design and Setting

This study employed a *quasi-experimental* research design. The target population comprised groundwater sources within Pabelan Village, Kartasura Subdistrict, Sukoharjo Regency. A composite sample volume of 720 litres was collected, with subsamples of 100 ml extracted from each water reservoir using sterile sampling bottles. Specimens were stored in an insulated cooling container and transported to the Microbiology Laboratory, Faculty of Health Sciences, Universitas Muhammadiyah Surakarta (UMS), for analysis. Ethical clearance was obtained from the Research Ethics Committee of the Faculty of Health Sciences, UMS, under reference number 667/KEPK-FIK/XI/2024.

The experimental parameters included temperature, pH, total dissolved solids (TDS), and Coliform concentration. We conducted sampling at four post-treatment intervals: baseline (0 minutes), 30 minutes, 45 minutes, and 60 minutes. Instrumentation comprised calibrated thermometers for temperature measurement, TDS meters (Hach DR3900 spectrophotometer) for quantifying dissolved solids, and digital pH meters (Thermo Scientific Orion Star A329) for acidity assessment. Coliform enumeration was performed using the Compact Dry EC method, a standardised microbiological assay for rapid detection of Coliform bacteria.

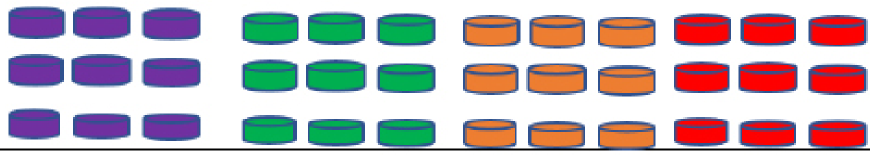
The Technical Design Drawing of Chlorine Diffuser

The fabrication of chlorine diffusers utilises the following materials: 2-inch (15 cm) PVC pipes, ¾-inch (10 cm) PVC pipes, 2-inch pipe end caps, 2-inch pipe couplings, 2-inch threaded screw caps, 50–60 g of granular media (silica sand, white sand, or black sand), and 0.2 g of powdered chlorine tablets.

Initially, the 2-inch PVC pipe is sectioned into 15 cm segments, while the ¾-inch PVC pipe is cut into 10 cm lengths. One terminus of the 2-inch pipe is sealed with an end cap and adhesive, while the ¾-inch pipe remains unsealed for subsequent assembly. Powdered chlorine tablets are homogeneously blended with the selected granular media to form a reactive mixture. This chlorine-sand composite is densely packed into the ¾-inch pipe segment, which is then inserted coaxially into the central cavity of the larger 2-inch pipe. The annular space between the two pipes is backfilled with additional granular media until the inner pipe is fully encapsulated, creating a permeable barrier. The open end of the 2-inch pipe is secured with a threaded screw cap to ensure structural integrity. Finally, the completed diffuser unit undergoes quality assurance checks before field application for controlled chlorine release in water treatment systems.

Table 1. The Types of the Treatment

Type of Treatment	0 Minutes	30 Minutes	45 Minutes	60 Minutes
Chlorine - Black Sand				
Chlorine - Silica Sand				
Chlorine - White Sand				



Statistical Analysis

We interpreted the data from the research results using univariate and bivariate data tables, along with the *Kruskal-Wallis* statistical test. We use the univariate test to provide a detailed description of the results for each parameter tested. The *Kruskal-Wallis* test was used to determine the differences in each treatment of temperature, pH, and coliform because, according to the homogeneity test, the data was abnormally distributed.

RESULT

Household-level chlorine in drinking water may serve as a pragmatic interim measure to reduce the burden of diarrhoeal diseases while broader efforts to achieve universal access to safe water supplies are implemented (14). Potable water is an essential prerequisite for public health, necessitating rigorous adherence to physical, chemical, and microbiological quality standards regardless of its source. These standards, as defined by the Minister of Health Regulation No. 2/2023, ensure water safety for human consumption. The assessment of bacterial contamination in potable water requires targeted microbiological testing, particularly for the enumeration of coliform bacteria. The subsequent section outlines descriptive data for key parameters derived from this study.

Contaminated water poses significant health risks due to the spread of pathogenic microorganisms. Notable waterborne pathogens include Vibrio cholerae, Giardia lamblia, typhoid-causing organisms, and enteric viruses associated with hepatitis and poliomyelitis (15). This study demonstrates that parameter values vary across different chlorine diffuser configurations. The following section presents descriptive data for coliform bacteria, pH, total dissolved solids (TDS), and temperature measurements collected from each chlorine diffuser system.

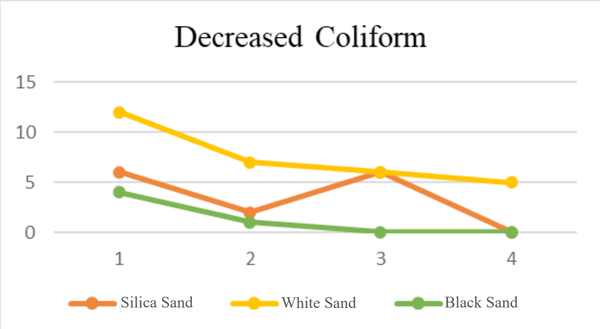
Table 2. Measurement Results of Coliform, pH, TDS and Temperature Parameters

No	Tool	Time	Coliform	pH	TDS	Temperature
1	Silica sand	0 minutes	6	7.85	252	25.4
2	Silica sand	0 minutes	5	7.89	262	25.5
3	Silica sand	0 minutes	5	7.85	256	25.5
4	Silica sand	30 minutes	4	8.00	256	25.7
5	Silica sand	30 minutes	0	7.97	254	25.8
6	Silica sand	30 minutes	0	7.97	258	25.8
7	Silica sand	45 minutes	8	8.23	256	25.5
8	Silica sand	45 minutes	5	8.19	256	25.8
9	Silica sand	45 minutes	3	8.10	256	25.9
10	Silica sand	60 minutes	0	8.18	243	25.7
11	Silica sand	60 minutes	0	8.02	246	25.8
12	Silica sand	60 minutes	0	8.02	249	25.9
13	White sand	0 minutes	11	8.10	250	25.5
14	White sand	0 minutes	12	8.10	239	25.8
15	White sand	0 minutes	12	8.15	251	25.6
16	White sand	30 minutes	7	8.12	258	25.5
17	White sand	30 minutes	7	8.10	258	25.7
18	White sand	30 minutes	5	8.05	258	25.8
19	White sand	45 minutes	5	8.18	231	25.5
20	White sand	45 minutes	7	8.05	243	25.7
21	White sand	45 minutes	4	8.05	243	25.8
22	White sand	60 minutes	5	8.10	249	25.9
23	White sand	60 minutes	4	8.08	249	25.9

No	Tool	Time	Coliform	pH	TDS	Temperature
24	White sand	60 minutes	4	8.06	233	25.7
25	Black sand	0 minutes	3	7.99	251	25.5
26	Black sand	0 minutes	5	7.99	251	25.5
27	Black sand	0 minutes	3	7.99	256	25.6
28	Black sand	30 minutes	0	8.02	246	25.6
29	Black sand	30 minutes	1	7.96	254	25.8
30	Black sand	30 minutes	2	7.92	254	25.8
31	Black sand	45 minutes	0	8.29	248	25.9
32	Black sand	45 minutes	0	8.26	258	26.0
33	Black sand	45 minutes	0	8.26	258	26.0
34	Black sand	60 minutes	0	8.07	252	26.1
35	Black sand	60 minutes	0	8.05	247	26.0
36	Black sand	60 minutes	0	7.97	249	26.0

Coliform bacteria are important microbiological indicators for assessing water quality because they detect possible faecal contamination. Analysis of temporal trends reveals distinct patterns of coliform reduction across diffuser types. Chlorine diffusers with silica sand show fluctuating coliform levels at first, followed by a gradual decline, with most samples reaching complete elimination (0 CFU/mL) after 60 minutes of chlorination. In contrast, white sand-based systems have elevated baseline coliform counts, with partial reduction observed after 30 minutes, though residual contamination persists in several samples when compared to other media. Black sand configurations have consistently lower coliform counts from the start, reaching zero detectable levels (≤1 CFU/mL) within 30 minutes.

Statistical analysis suggests that black sand-based systems are more effective in reducing coliform counts within 30 minutes, whereas white sand configurations have delayed disinfection kinetics. Silica sand systems perform intermediately, with microbial reduction occurring gradually but consistently.



Information:
1-14 : average content of Coliform bacteria
1 : 0 minutes time
2 : 30 minutes
3 : Time 45 minutes
4 : 60 minutes

Figure 1. Decreased of Coliform by Using Various Combinations of Chlorine Diffusers

We conducted microbiological testing using the Compact Dry method, a standardised chromogenic technique for quantitative enumeration of coliform bacteria. At the 60-minute mark, both silica sand and black sand diffusers had eliminated bacteria (0 CFU/mL) in all replicates, whereas white sand diffusers still had detectable coliform levels. The figure 1 shows a detailed analysis of coliform bacterial reduction kinetics.

The *Kruskal-Wallis* test indicated statistically significant variations in coliform reduction efficacy among chlorine diffusers that utilise different sand types. White sand, black sand, and silica sand—prevalent in natural settings—demonstrate diverse physicochemical characteristics and particle sizes, which seem to affect their ability to diminish coliform bacteria. These disparities in microbial reduction were evident despite the lack of statistically significant differences in pH, temperature, and total dissolved solids (TDS) among the experimental conditions.

Table 3. Kruskal-Wallis Test

Test Statistics^{a,b}				
	Number of Coliform Bacteria	**Sample pH**	**Sample TDS**	**Sample Temperature**
Kruskal-Wallis H	9.906	4.277	3.616	3.400
Df	2	2	2	2
Asymp. Sig.	**0.007**	0.118	0.164	0.183

a. Kruskal Wallis Test
b. Grouping Variable: a tool used

DISCUSSION

Residual chlorine concentrations within water distribution systems serve as critical indicators of microbiological contamination (16). Disinfection constitutes a cornerstone of water treatment, primarily aimed at eliminating pathogenic microorganisms through commonly employed methods such as chlorination and ultraviolet (UV) irradiation (17). Contamination with *Escherichia coli* and coliform bacteria in potable water poses significant health risks, particularly in relation to diarrhoeal diseases (19). Prior community-based studies have explored participatory approaches for independent water quality monitoring, though these initiatives demonstrate limited efficacy due to variable community engagement (18).

Findings from this study reveal microbial contamination in 70% of sampled water sources, with 44% of surveyed locations exceeding acceptable contamination thresholds (18). *E. coli* and *coliform* bacteria function as key microbial indicators of faecal pollution, with their prevalence strongly correlated with diarrhoeal disease incidence linked to the consumption of contaminated drinking water (19).

Laboratory analyses of shallow groundwater quality in Kartasura District, Sukoharjo Regency, indicate predominantly moderate to poor water quality indices. The National Sanitation Foundation Water Quality Index (NSF-WQI), a widely utilised assessment tool, evaluates water quality based on nine parameters: biochemical oxygen demand (BOD), dissolved oxygen (DO), nitrate, total phosphate, temperature, turbidity, total solids, pH, and faecal coliform (20).

Addressing water contamination challenges necessitates targeted interventions at the household level, given the public health implications of microbial pollutants. Treatment protocols incorporating lime and alum coagulation-filtration processes, alongside activated charcoal, silica sand, and black sand filtration systems, demonstrate efficacy in reducing water hardness, *E. coli* counts, and turbidity in dug well water (21). Effective interventions further require active community participation, as associations between knowledge, attitudes, and personal hygiene practices significantly influence water safety outcomes (22).

Prior research has demonstrated that numerous well water sources in Indonesia exhibit coliform contamination exceeding Indonesian regulatory thresholds for microbial quality standards (23). A critical public health challenge requiring urgent intervention lies in addressing household-scale pollution, as a significant proportion of households continue to rely on wells for domestic water supply. The prevalence of coliform bacteria in well water is influenced by multiple environmental and infrastructural factors, including proximity to septic tanks, inadequate separation between water sources and sanitation systems, and contamination risks stemming from neighbouring septic tanks within residential clusters (24-25).

Chlorine-based disinfection systems incorporating silica sand or black sand filtration media represent a viable intervention strategy for mitigating coliform contamination at the household level. These systems, designed for decentralised implementation, offer a practical means to enhance microbial water safety in resource-constrained settings.

The use of chlorine diffusers in the treatment of drinking water presents a potentially efficacious intervention for community-level disinfection (26). Bacteriological contamination of potable water sources poses a significant public health concern, necessitating effective mitigation strategies. Among these, chlorination remains a widely implemented method. A chlorine diffuser—comprising a polyvinyl chloride (PVC) column packed with sand and solid chlorine tablets—provides a simple yet functional system for the controlled release of chlorine into water supplies. Chlorine, as a potent oxidising agent, acts by disrupting microbial cellular structures, thereby inhibiting the growth of pathogenic organisms. Available in solid, liquid, or gaseous forms, chlorine plays a critical role in safeguarding public health due to its ability to effectively neutralise waterborne pathogens during the disinfection process (27).

The availability of sufficient and microbiologically safe water supplies has been epidemiologically associated with a reduced incidence of diarrhoeal diseases among children under the age of five (28-29). Moreover, exposure to contaminated water has been implicated as a contributing factor to childhood stunting, in conjunction with broader environmental, socio-economic, and nutritional influences (1,7,30). Ensuring universal access to water resources that meet established standards of quality, quantity, and accessibility is therefore a fundamental public health imperative. National regulatory frameworks, such as those delineated in official water quality guidelines (31), stipulate the legal obligations for providing water supplies that satisfy both sanitary and domestic needs for all population groups.

Numerous factors can lead to the contamination of drinking water with bacteria, one of which is elevated population density. Research indicates that statistical analyses reveal a 4.8% impact of population density on the concentration of coliform bacteria in water supplies (32). The cleanliness of your home and the efficacy of your handwashing are significant determinants in the presence of pathogens such as *E. coli* and *coliform* bacteria. Improving sanitary conditions has been demonstrated to significantly reduce the levels of bacteria and other waterborne contaminants (33). These findings enhance our understanding of the microbial species present in drinking water and the associated health risks. This information is critical to establishing improved methods to prevent and manage infectious diseases, particularly by enhancing the disinfection protocols of drinking water treatment facilities (34).

The deployment of water management technologies must be tailored to the characteristics of local water sources, as well as socioeconomic, cultural, and human resource factors. Chlorination is a widely utilised technique in well water treatment for the elimination of *Escherichia coli* and total *coliform* bacteria. Chlorine's rapid and effective neutralisation of microbial contaminants makes this method preferred for the continuous disinfection of substantial quantities of groundwater. Moreover, chlorine is cost-effective and readily available. A primary benefit of utilising a chlorine diffuser for controlled release is its ease of use, as the residual chlorine decomposes naturally over time without producing malodorous by-products. Silica sand serves as an auxiliary filtration medium, where its combination with chlorine enables a dual mechanism: chlorine functions as a chemical disinfectant, while silica sand offers physical filtration to improve the elimination of particulate matter and microbial agents. Furthermore, silica sand extends the contact time between chlorine and microorganisms, thereby enhancing disinfection efficacy (35) .

The level of residual chlorine in water distribution systems can serve as an indicator of potential microbiological contamination (16), and therefore requires precise control of dosage during the disinfection process. One effective method for eliminating harmful microorganisms, particularly *E. coli* and *coliform* bacteria, prior to water being supplied to the community is the use of a chlorine diffuser. Water treatment plays a crucial role in the achievement of the Sustainable Development Goals (SDGs), especially in ensuring universal access to safe drinking water and adequate sanitation (2). Traditional chlorination methods employed in water treatment facilities primarily target rapidly reacting inorganic substances; however, they may leave behind slower-reacting organic compounds, which can act as the primary secondary contaminants within the water distribution system. A key policy recommendation is to prioritise water quality indicators over physical parameters, as this approach will enable water utility managers to maintain residual chlorine levels within safe and acceptable limits for public health (36).

Monochloramine may be proposed as an efficient and safe method for the continuous disinfection of building piping systems, thereby reducing the risk of exposure to *Legionella* and harmful disinfection by-products among vulnerable populations (37). Monochloramine is an organic compound formed through the substitution of one or more hydrogen atoms in ammonia with chlorine atoms, and it is commonly used as a disinfectant. *Coliform* bacteria are widely employed as indicators of potential microbial contamination, as their presence is positively correlated with the presence of pathogenic microorganisms (38). The presence of *coliform* bacteria can influence the life cycle of other bacterial species in water, and both *coliforms* and *Escherichia coli* may act as pathogens capable of causing disease in humans and other organisms (39).

This study did not quantify the residual chlorine present in treated water; therefore, further research is required to assess the levels of residual chlorine in potable water. During the pandemic, chlorine was utilised as a disinfectant to inactivate SARS-CoV-2; however, excessive use of such disinfectants has been associated with adverse environmental impacts (40). Additional processes are necessary to decompose reactive chlorine residues in drinking water, including further oxidation, which is expected to reduce chlorine contamination prior to domestic use (41). A measurable free chlorine residual is essential for ensuring the safety of drinking water (42).

Technological advancements play a crucial role in mitigating various forms of contamination in potable water, particularly bacteriological contamination. Previous research has provided useful information about the disinfection process using the conventional chlorine diffuser method. Subsequent research may seek to integrate both traditional and electrochlorination techniques to optimise the reduction of bacteriological contaminants in drinking water. The findings indicate that in situ electrochlorination offers a more effective alternative to decentralised chlorination methods. Nevertheless, further fundamental research is necessary to fully understand the formation of disinfection by-products under different water composition conditions (43).

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CONCLUSION

This study detected coliform bacteria in the water samples, revealing a significant variation in their concentration among the various types of chlorine diffusers tested—specifically those utilising silica sand, white sand, and black sand. No statistically significant differences were observed in other variables, specifically pH, total dissolved solids (TDS), and temperature. Additional research is necessary to examine further parameters, such as residual chlorine concentrations in the treated water and the effects of chlorine addition on water quality.

AUTHORS' CONTRIBUTION

RA, EB, and MP: conceptualization. RA, JBN, MRA, and AZM: methodology. RA, JBN, and MP: formal analysis. RA: writing—original draft preparation. RA and SRMY: writing—review and editing. RA: supervision. All authors: have read and agreed to the published version of the manuscript.

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