Chlorine residual behavior in water disinfection using combined sand media with chlorine application

Rezania Asyfiradayati [1]
Lecturer, Department of Public Health,
[1] University Muhammadiyah Surakarta, Surakarta, Indonesia,
e-mail: ra123@ums.ac.id, https://orcid.org/0000-0002-1507-5158;
Windi Wulandari [1]
Lecturer, Department of Public Health,
e-mail: ww122@ums.ac.id, http://orcid.org/0009-0002-4485-4625;
Jenita Berlian N [1]
Student, Department of Public Health,
e-mail: berlianjenita@gmail.com, https://orcid.org/0009-0008-1811-0802;
Siti Rohana Mohd Yatim [2]
Lecturer, Faculty of Health, [2] University Technology MARA, Selangor, Malaysia,
e-mail: sitirohana@uitm.edu.my, https://orcid.org/0000-0002-9714-6203

ABSTRACT

Introduction. Water is a need for every human being in all parts of the world. The demand for water, particularly clean water, is expected to increase in line with population growth. In Indonesia, wells providing access to both shallow and deep groundwater sources serve as the primary source of clean water Microbiological contamination of water causes a bad impact, especially on health. The water supply system is a fundamental component of sustainable urban development. Nevertheless, it frequently encounters a range of complex challenges, especially in developing nations.

The purpose of article. The objective of this study is to investigate the concentration of residual chlorine over varying contact times using different media combinations, namely black sand, silica sand, and white sand, to evaluate their effectiveness in sustaining chlorine levels during water treatment.

Research methods. This research employed a quasi-experimental design to evaluate residual chlorine levels in treated water using various types of sand integrated with chlorine within diffuser pipes. A total of 720 liters of water was used, divided into 36 reservoirs. holding 2.5 mg of chlorine each of which contained 20 litres and 500 grams of one of three types of sand: black sand, white sand, or silica sand. Water samples in 20-litre containers were treated with a chlorine sprayer for exposure periods of 30, 45, and 60 minutes. The study assessed several parameters, including temperature, pH, total dissolved solids (TDS), and residual chlorine. Data were analyzed and presented using univariate and bivariate tables, with statistical testing conducted using one-way ANOVA.

Result. The results indicated that the chlorine diffuser containing white sand exceeded the permissible residual chlorine threshold at contact times of 45 and 60 minutes. Statistical analysis using one-way ANOVA revealed a significant difference in residual chlorine concentrations between the silica sand and black sand media ($p < 0.05$). However, no statistically significant difference was observed in the chlorine concentrations over time for the white sand diffuser. These findings suggest that white sand may lead to prolonged chlorine retention, potentially resulting in concentrations above recommended limits

Scientific novelty and practical value. for the first time, an analysis that the various types of sand in the chlorine diffuser have differences in the remaining chlorine in the water so that it can be used as a reference for further research in water treatment.

Keywords: chlorine residue, silica sand, white sand, black sand, safety drinking water, disinfection, chlorine, media combination.

Introduction

Indonesia, as a tropical nation, possesses rich water resources that include rivers, lakes, reservoirs, swamps, and floodplains [1]. Indonesia, similar to other nations in the Asia-Pacific region, pays great attention to the effects of climate instability, population increase, and human activities on the degradation of water resources and the loss of biodiversity. Therefore, understanding the interactions between biological and hydrological processes, as well as focusing on reducing ecological threats and enhancing harmony within catchment areas, is essential to promote the sustainability of water resources, biodi-versity, and environmental ecosystems. The demand for water, particularly clean water, is expected to increase in line with population growth. Water supply in Indonesia fluctuates with the seasons, and its distribution varies from region to region. Generally, most parts of Indonesia have annual rainfalls of about 2000 to 3500 mm (60%). A few areas (3%) have annual rainfalls higher than 5000 mm, while others have less than 1000 mm per year [2].

Survival for humans relies on having access to clean water. According to the World Health Organization, approximately 2.2 billion individuals lack access to safely managed drinking water [3] [4].

Effective water management is a significant global issue because of its direct impact on human health outcomes. Various studies in Indonesia have demonstrated that microbiological contamination of clean water, particularly by indicator bacteria such as *coliform* and *Escherichia coli*, represents a serious issue that poses a significant threat to public health. The combination of dense population and dependence on shallow wells poses challenges, as only about 19.83% of residents have access to piped water, whereas around 79.53% still rely on privately owned wells. *Escherichia coli* (E. coli) arises from fecal contamination routes that deteriorate the microbial quality of water in household environments [5]. Pathogens transmitted through water, derived from human and animal excreta, can infiltrate drinking water systems via contamination of surface or groundwater sources. This type of microbial pollution presents serious public health hazards, such as gastrointestinal and respiratory infections, viral hepatitis, skin diseases, pregnancy complications, and, in severe instances, death [6].

Significant progress in various urban sectors notwithstanding, cities still encounter substantial and complex water provision challenges. Interventions aimed at hygiene, sanitation, and clean water delivery have demonstrated effectiveness in easing the disease burden. Worldwide, major cities are struggling to meet a persistent demand for clean water that is escalating [7]. According to Indonesian Regulation No. 492/Menkes/PER/IV/2010, the acceptable level of free chlorine in water supply systems ranges from 0.2 to 0.5 mg/L as stipulated by the Ministry of Health [8]. In Central Java Province, 75.88% of households have access to sufficient drinking water sources, whereas 24.2% of the population still does not have access to suitable drinking water sources [9].

Alongside the use of disinfectants, boiling is an effective method for improving water quality. A decrease in the Most Probable Number (MPN) in sampled water indicates that boiling can substantially enhance the microbiological purity of groundwater [10]. Previous research has found that latrines which do not meet health standards may lead to higher Escherichia coli (E. coli) levels in water bodies. The main source of bacterial contamination is not the state of the toilets themselves but rather the poor management of wastewater disposal systems [11].

In Indonesia, wells providing access to both shallow and deep groundwater sources serve as the primary source of clean water. Contaminated water containing chemical or biological agents is a substantial medium for the transmission of waterborne diseases [12]. Households in the studied area have access to improved drinking water sources, indicating that most households obtain water that meets basic hygiene and health standards. However, only approximately 31.3% of households have access to drinking water free from Escherichia coli contamination. Furthermore, merely 11.9% of households have access to drinking water classified as safe based on combined parameters, which include assessments of E. coli presence and heavy metal concentrations in the water [13]. Infections caused by contaminated water sources, resulting from human or animal fecal matter, can cause acute health issues affecting the digestive and respiratory systems, as well as hepatitis, dermatitis, growth stunting in pregnant women, and potentially life-threatening outcomes [12,14,15][3][6]. Clean water contamination has been detected at the household level, specifically within domestic residences. Previous research in Kartasura District found that four out of eight types of housing were contaminated with Coliform bacteria, and two showed contaminations with E. coli.[16]. Rainwater contamination with coliform bacteria has also been identified, making caution necessary before using it [17].

Water distribution systems' residual chlorine levels can be considered a reliable indicator of microbiological contamination [18]. Applying chemical disinfectants, particularly chlorine, is a proven way to decrease microbial numbers. Chlorine is commonly used in developing countries because of its effectiveness and affordable cost [19]. Chlorine is readily available and cost-effective as a chemical agent, enabling its use by local communities [20]. Water treatment entities, including PDAM, and water utilities have widely utilised chlorination. Considering the widespread reliance on well water among Indonesian families, a need exists to develop innovative chlorination techniques suitable for household use. Chlorine diffuser design must take into account residual chlorine levels, piping specifications, including diameter as described [21], and the incorporation of additional materials to neutralise chlorine residues, which optimises water treatment processes as per [22]. According to Clayton et al. (2021), chlorine is considered safe for reducing biological contaminants in drinking water. Regulations necessitate residual chlorine levels to comply with Indonesian Regulation No. 492/Menkes/PER/IV/2010 in order to avert negative impacts on public health [23].

Materials frequently used for the decomposition of chlorine residues include granular media like silica sand (SiO_2), white sand, and black sand. The selection of sand-based materials is based on their natural richness in reactive mineral components, such as amorphous silica and iron oxides, which promote redox reactions that neutralize remaining oxidizing agents [24]. Previous studies have demonstrated varying effectiveness in reducing coliform

concentrations across different sand types [25], thereby highlighting the need for a systematic comparative analysis to quantify the residual chlorine remaining in treated water following the application of the chlorine diffuser method. This research is notable for shedding light on the effects of chlorine levels in drinking water that has been treated with chlorine and different types of sand. The primary aim of this research is to investigate differences in residual chlorine levels in water disinfected with chlorine, combined with various types of sand. There is a need for alternative materials capable of decomposing residual chlorine in water to optimize the chlorination treatment process. Various materials can be employed for chlorine residue removal, including silica sand and black sand. Sand is selected due to its natural content of reactive minerals, such as silica and iron, which contribute to the breakdown of residual chlorine through redox reactions [22].

Method

This study employed a quasi-experimental design and was carried out with the approval of the Ethics Committee of the Faculty of Health Sciences, Universitas Muhammadiyah Surakarta, under reference number 667/KEPK-FIK/XI/2024. The study population consisted of all water sourced from the Pabelan Kartasura Sukoharjo Village area. A total sample of 720 litres of water was distributed across 36 reservoirs, each of which contained 20 litres. A 100 ml water sample was taken from each reservoir, placed in a sterilized bottle, stored in a cool box, and transported to the Microbiology Laboratory at the Faculty of Health Sciences, UMS, for examination. The parameters assessed included temperature, pH, total dissolved solids (TDS), and residual chlorine concentrations.

The study utilised 2-inch diameter pipes as containers for chlorine and sand, featuring evenly spaced perforations along their length, holding 2.5 mg of chlorine each of which contained 20 litres and 500 grams of one of three types of sand: black sand, white sand, or silica sand. Water samples in 20-litre containers were treated with a chlorine sprayer for exposure periods of 30, 45, and 60 minutes. Chemical properties in water samples were examined by placing them in test tubes. Temperature was measured with a digital thermometer, while pH and residual chlorine levels were tested using pH and chlorine test kits. The levels of residual chlorine were then measured using a DR 1500 spectrophotometer. The data were compiled in tables showing one variable and two variables, with statistical analysis conducted using the one-way analysis of variance (ANOVA) method.

Result

The remaining chlorine is present at the time of use of chlorine diffuser with various types of sand. The chlorine diffuser supplemented with various types of sand exhibited different residual chlorine concentrations over time at 0, 30, 45, and 60 minutes. Detailed results are presented in Table 1 and Figure 1.

Table 1

Mean of chlorine residue

	Time (minute)	N	Mean of Chlorine residue	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
Chlorine residue using chlorine diffuser w/ silica sand	0	5	0.5233	0.23116	0.13346	-0.0509	1.0976	0.38	0.79
	30	5	0.4033	0.03786	0.02186	0.3093	0.4974	0.36	0.43
	45	5	0.2800	0.11269	0.06506	0.0001	0.5599	0.15	0.35
	60	5	0.2867	0.10116	0.05840	0.0354	0.5380	0.17	0.35
	Total	20	0.3733	0.15796	0.04560	0.2730	0.4737	0.15	0.79
Chlorine residue using chlorine diffuser w/ black sand	0	5	0.4933	0.17388	0.10039	0.0614	0.9253	0.36	0.69
	30	5	0.3467	0.02309	0.01333	0.2893	0.4040	0.32	0.36
	45	5	0.3000	0.04583	0.02646	0.1862	0.4138	0.26	0.35
	60	5	0.2933	0.04933	0.02848	0.1708	0.4159	0.26	0.35
	Total	20	0.3583	0.11622	0.03355	0.2845	0.4322	0.26	0.69
Chlorine residue using chlorine diffuser w/ white sand	0	5	0.4067	0.09074	0.05239	0.1813	0.6321	0.34	0.51
	30	5	0.3267	0.01155	0.00667	0.2980	0.3554	0.32	0.34
	45	5	0.3233	0.03215	0.01856	0.2435	0.4032	0.30	0.36
	60	5	0.3200	0.02646	0.01528	0.2543	0.3857	0.30	0.35
	Total	20	0.3442	0.05712	0.01649	0.3079	0.3805	0.30	0.51

The findings of this study revealed that the residual chlorine concentration in the chlorine diffuser incorporating silica sand was lower compared to that in diffusers supplemented with white or black sand, although the observed differences were not statistically substantial.

Clean water must contain residual chlorine to ensure its quality and safety during distribution prior
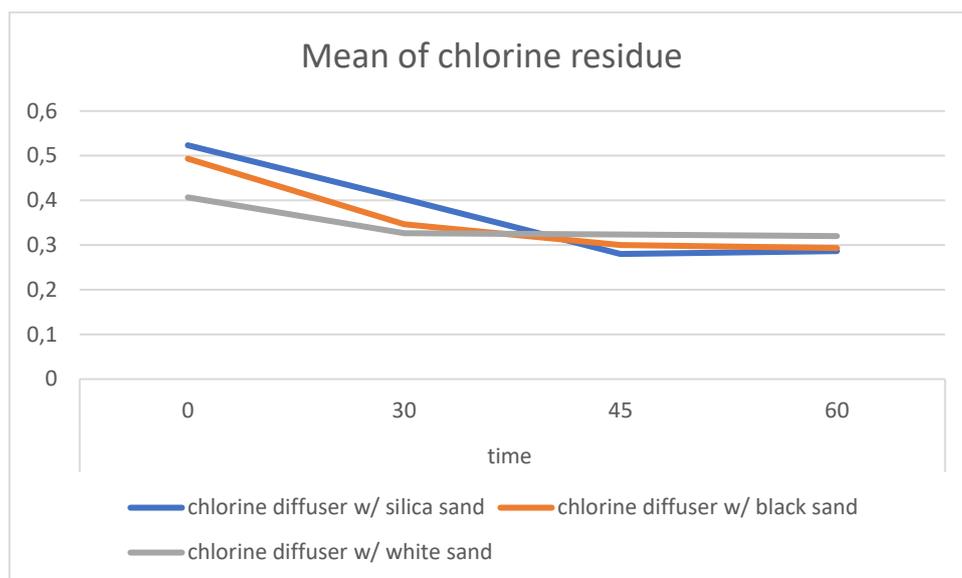
Fig. 1. Mean of Clhorine residue

to consumer use. According to the World Health Organization and the Indonesian Ministry of Health Regulation No. According to the 2023 guidelines regarding Sanitation Regulations, the minimum level of free chlorine residue in water must be between 0.2 mg/L and 0.5 mg/L in order to achieve effective disinfection without posing a health risk.

The results indicated that the chlorine diffuser, utilising white sand at 45 minutes and 60 minutes, exceeded the allowable limit. Residual chlorine plays a crucial role in ensuring the microbiological safety of water because it can safeguard the water distribution system from being compromised and prevent recontamination when the water is initially clean.

Table 2

Statistically Significant Difference in Residual Chlorine

		ANOVA				
		Number of Squares	Df	Square Average	F	Sig.
Chlorine residue using chlorine diffuser w/ silica sand	Intergroup	0.271	7	0.039	44.239	**.001**
	In a Group	0.003	4	0.001		
	Entire	0.274	11			
Chlorine residue using chlorine diffuser w/ black sand	Intergroup	0.141	7	0.020	10.979	**.018**
	In a Group	0.007	4	0.002		
	Entire	0.149	11			
Chlorine residue using chlorine diffuser w/ white sand	Intergroup	0.016	3	0.005	2.072	.182
	In a Group	0.020	8	0.003		
	Entire	0.036	11			

Results from the one-way ANOVA indicate a statistically significant variation in residual chlorine levels among groups using chlorine with silica sand and black sand media, whereas no such variation was observed for the group utilizing white sand. The sum of squares between groups for the silica sand diffuser was 0.271, with a mean square value of 0.039. A calculated F-value of 44.239 corresponds to a p-value of 0.001, indicating a highly significant difference, as indicated by a p-value less than 0.05, in the chlorine residue between various time intervals or treatment conditions. The black sand diffuser resulted in a between-group sum of squares of 0.141 and a mean square of 0.020, yielding an F-statistic

of 10.979 at a p-value of 0.018. Furthermore, a statistically significant difference is found in residual chlorine levels ($p < 0.05$).

The white sand diffuser exhibited a between-group sum of squares of 0.016, a mean square of 0.005, and an F-statistic of 2.072. The significance level associated with the test was 0.182, showing that the variations in chlorine residue across the different treatment groups did not have statistical significance (p value greater than 0.05). The research indicates that the type of sand media employed can greatly impact chlorine retention, with silica and black sand exhibiting considerable differences across various treatments, whereas white sand

sustains more consistent chlorine levels over time.

Discussion

The implementation of household-scale water filtration systems, coupled with educational outreach programs, has been shown to significantly enhance community awareness regarding the importance of safe and clean water. Moreover, it fosters the adoption of more hygienic and health-conscious practices. Technical training and hands-on supervision play a crucial role in facilitating knowledge acquisition and promoting behavioral transformation among residents in the utilization and management of water resources [26]. Chlorine for water treatment is available in various forms, including powder, liquid, and tablets. Typically, chlorine powder is composed of calcium hypochlorite, whereas liquid formulations are primarily made up of sodium hypochlorite. Typically, chlorine is used for disinfection either as chlorine gas (Cl_2) or in the form of calcium hypochlorite [$Ca(OCl)_2$] [27]. Inaccurate chlorine dosing can cause unpleasant sensory effects like a bitter taste and an unappealing odour. As a bactericide, chlorine is highly effective in eliminating pathogenic microorganisms from water. When using powdered forms in wastewater treatment, the chlorine dosage must adhere to set standards to prevent residual chlorine levels from surpassing 5.0 parts per million (ppm). Inadequate dosing of chlorine can lead to corrosion and scaling inside water distribution pipes, but elevated levels may also compromise water quality, making it unsuitable for drinking or household use [28].

Water distribution system residual chlorine concentrations are a reliable indicator of microbiological contamination [18]. Daily activities such as hygiene and sanitation require access to clean water. Significantly, waterborne diseases contribute to the high prevalence of severe and potentially fatal infectious conditions [29]. Inadequate water treatment processes before use can lead to contamination by Escherichia coli (E. coli) [30]. The presence of clean water facilities has been linked to diarrhoea rates in young children [31][32]. Additionally, the quality of water sources has been pinpointed as a contributing factor to stunting [6][33] [3]. Access to water, along with its quality and availability, constitutes a fundamental societal requirement. Clean water provision, in terms of both quality and quantity, must meet community demands and is governed by official regulations [34].

Population density is one of several factors contributing to bacterial contamination in clean water sources. Research conducted by Hafidzna Hanif and Anna in 2021 found that a statistical analysis showed a 4.8% influence of population density on Coliform bacterial content. Applying chlorine is crucial to reduce microbial contamination in drinking water [35]. The levels of residual chlorine in water distribution systems can signify microbiological contamination [18], requiring accurate dosing during the disinfection process. Spraying water with chlorine is a highly effective way to remove pathogenic microorganisms, especially E. coli and Coliform bacteria, from water before it is used by the community. Achieving the Sustainable Development Goals (SDGs) relies heavily on effective water treatment initiatives, especially in guaranteeing access to clean water and satisfactory sanitation facilities [4].

The application of chlorine to water contaminated with microorganisms results in substantial damage to bacterial cell walls, disruption of cellular permeability, and impairment of nucleic acids and enzymes [36]. Chlorine is extensively employed as the primary disinfectant in drinking water treatment due to its high efficacy at low concentrations, cost-effectiveness, and ability to produce residual concentrations when applied in appropriate doses. The use of chlorine in water disinfection is designed to eliminate pathogenic bacteria, while also serving as a potent oxidising agent critical for safeguarding human health (Scott, 2021).

Conventional chlorination in water treatment plants efficiently eliminates most inorganic reactants rapidly, but leaves behind slower organic reactants, which become the main secondary contaminants in the distribution network. Policies should give water quality parameters precedence over physical parameters to enable utility managers to maintain chlorine residue levels within safe limits for public health [38]. These findings enhance our comprehension of microbiology in drinking water and the health hazards associated with microorganisms, thereby facilitating more effective control of infectious diseases via enhanced disinfection methods in water treatment facilities [39].

This research compared the residual chlorine in the chlorine diffuser with the composition of chlorine added to various types of sand, including black sand, white sand, and silica sand. The remaining chlorine in each yield these results. Centralized treatment systems and water distribution networks are no longer feasible in certain areas, leading to an increased focus on point of use drinking water treatment systems [23]. In this study, it has been established that each type of sand used as a chlorine dissolution inhibitor exhibits a distinct difference in statistical analysis. The variation in chlorine residues resulting from the use of silica sand, black sand, and white sand in the chlorine diffuser can serve as a reference point for future research.

One of the ceramic materials, silica sand, features a natural white color and a silica purity of up to 99%, making it a potential ceramic material for fabrication technology [40]. Black sand is a type of

sand which is often found, typically treated with UV to eliminate methylene blue dye through a combination of photocatalytic adsorption and degradation [41]. Different media can be utilised for water treatment, particularly to enhance water quality biologically, including a novel method that incorporates silver, copper, and chlorine without the necessity for electricity which has the potential to be an economical household water treatment solution [42].

In the used piping network, chlorine levels decrease more rapidly at greater downstream distances and high temperatures as a result of increased microbial activity and chlorine mass transfer. To achieve a more optimal seasonal chlorine dosing strategy, system simulations must therefore consider these factors [43]. Monochloramine may be suggested as a safe and effective method for continuously disinfecting building piping systems, which can help prevent people who are susceptible from being exposed to legionellae and harmful disinfection by-products [44], as it is a compound where chlorine substitutes ammonia and is often used as a disinfectant. The presence of coliform bacteria can be used as an indicator for other types of bacteria. The presence of Coliform bacteria as a pollution indicator is determined by the number of its colo-

nies, which correlates directly with the existence of pathogenic bacteria (E. coli). According to Saputri and Efendy (2020), the presence of Coliform can impact the life cycle of bacteria in water, and Coliform and E. coli can persist as pathogens capable of causing disease in humans and other living organisms [45], [46].

Conclusion

This study found the residual chlorine levels in the sample water and identified a significant difference between the groups of equipment used, particularly those using silica sand and black sand chlorine diffusers. No notable difference was found in the chlorine diffuser residue when using white sand. Variables such as pH, TDS, and temperature also showed no substantial discrepancies. This study requires ongoing research that incorporates additional factors, including the use of UV or other methods, which can be combined with chlorine, to improve microbiological contamination reduction.

Acknowledgments

Reference

1. *Adams, E. A., Adams, Y. J., & Koki, C. (2021). Water, sanitation, and hygiene (WASH) insecurity will exacerbate the toll of COVID-19 on women and girls in low-income countries. Sustainability: Science, Practice, and Policy, 17(1), 86–90. https://doi.org/10.1080/15487733.2021.1875682*

2. *Adzura, Mitha, Fathmawati Fathmawati, Y. Y. (2021). Hubungan Sanitasi, Air Bersih dan Mencuci Tangan dengan Kejadian Stunting pada Balita di Indonesia. Frontiers in Neuroscience, 14(1), 1–13. https://doi.org/10.32382/sulolipu.v21i1.2098*

3. *Alftessi, S. A., Othman, M. H. D., Adam, M. R., Farag, T. M., Ismail, A. F., Rahman, M. A., Jaafar, J., Habib, M. A., Raji, Y. O., & Hubadillah, S. K. (2021). Novel silica sand hollow fibre ceramic membrane for oily wastewater treatment. Journal of Environmental Chemical Engineering, 9(1), 104975. https://doi.org/10.1016/j.jece.2020.104975*

4. *Ali, A. S., Gari, S. R., Goodson, M. L., Walsh, C. L., Dessie, B. K., & Ambelu, A. (2023). The impact of wastewater-irrigated urban agriculture on microbial quality of drinking water at household level in Addis Ababa, Ethiopia. Urban Water Journal, 20(9), 1207–1218. https://doi.org/10.1080/1573062X.2023.2253215*

5. *Asyfiradayati, R. (2017). Total Coliform Air Hujan Pada Tempat Penampungan Air Hujan (PAH) Skala Rumah Tangga Penduduk Kabupaten Lamongan. Prosiding - Semnas & Call for Papers, 37–40. https://publikasiilmiah.ums.ac.id/handle/11617/8971*

6. *Asyfiradayati, R., Budiyati, E., Porusia, M., Athaya, M. R., Muzakki, A. Z., Nindyasari, J. B., & Yatim, S. R. M. (2025). Evaluation of Adulticidal Chlorine with Black Sand, White Sand and Silica Sand for Decline Coliform Bacteria. Jurnal Kesehatan Lingkungan, 17(3), 268–276. https://doi.org/10.20473/jkl.v17i3.2025.268-276*

7. *Asyfiradayati, R. M. A. S., S., E., & P, O. (2022). UJi Bakteriologis Air Sumur di Beberapa Perumahan Kecamatan Kartasura.*

8. *Benwic, A., Kim, E., Khema, C., Phanna, C., Sophary, P., & Cantwell, R. E. (2018). Factors associated with post-treatment E. coli contamination in households practising water treatment: a study of rural Cambodia. International Journal of Environmental Health Research, 28(2), 178–191. https://doi.org/10.1080/09603123.2018.1453055*

9. *Clayton, G. E., Thorn, R. M. S., & Reynolds, D. M. (2021). The efficacy of chlorine-based disinfectants against planktonic and biofilm bacteria for decentralised point-of-use drinking water. Npj Clean Water, 4(1). https://doi.org/10.1038/s41545-021-00139-w*

10. *D., H. J., J., H. L. M., Ana, E.-Y., & A., S. J. (2024). Enhancing Microbial Disinfection in Household Water Treatment by Combining a Silver–Ceramic Tablet with Copper and Chlorine Technologies. Journal of Environmental Engineering, 150(7), 4024026. https://doi.org/10.1061/JOEEDU.EEENG-7555*

11. *De Luca, V., Carginale, V., Supuran, C. T., & Capasso, C. (2022). The gram-negative bacterium Escherichia coli as a model for testing the effect of carbonic anhydrase inhibition on bacterial growth. Journal of Enzyme Inhibition and Medicinal Chemistry, 37(1), 2092–2098. https://doi.org/10.1080/14756366.2022.2101644*

12. *Dharmawan, I. W. S., Siregar, C. A., Narendra, B. H., Kadek, N., & Undaharta, E. (2023). Implementation of Soil and Water Conservation in Indonesia and Its Impacts on Biodiversity, Hydrology, Soil Erosion and Microclimate.*

13. *Djamel Ghernaout. (2018). Water Treatment Chlorination : An Updated Mechanistic Insight Review. Chemistry Research Journal, 4(2), 125–138.*

14. *Elvina Sophia Ranti, Maurisa Yuant Khairani, & Triastuti Rahayu. (2024). Improve The Microbiological Quality of Groundwater Around Bonoloyo Cemetery by Boiling. Quagga: Jurnal Pendidikan Dan Biologi, 16(2), 118–126. https://doi.org/10.25134/quagga.v16i2.327*

15. *Fibrianti, E. A., Thohari, I., & Marlik, M. (2021). Hubungan Sarana Sanitasi Dasar dengan Kejadian Stunting di Puseksmas Loceret, Nganjuk. Jurnal Kesehatan, 14(2), 127–132. https://doi.org/10.32763/juke.v14i2.339*

16. *Fisher, I., Kastl, G., & Sathasivan, A. (2023). Validity of chlorine-wall reaction models for drinking water distribution systems. Urban Water Journal, 20(9), 1157–1168. https://doi.org/10.1080/1573062X.2023.2241437*

17. *Griffiths, J. K. (2017). Waterborne diseases.*

18. *Hafidzna Hanif, A., & Anna, A. N. (2021). Analisis Spasial Kandungan Bakteri Coliform Pada Air Tanah Dangkal Di Kecamatan Colomadu Kabupaten Karanganyar. Universitas Muhammadiyah Surakarta. http://eprints.ums.ac.id/id/eprint/93402*

19. *Jesika, P., & Hilal, N. (2016). Hubungan Jenis Sumber Air Dan Personal Hygiene Dengan Kejadian Penyakit Dermatitis Di Desa Kedungrandu Kecamatan Patikraja Kabupaten Banyumas Tahun 2016. 35, 322–327. https://doi.org/10.31983/keslingmas.v36i4.3131*

20. *Jumadi, J., Yuli P, Danaryono, & Umrotun. (2025). Pemberdayaan Masyarakat dalam Pengelolaan Air Bersih Berkelanjutan melalui Program Air Minum Muhammadiyah (PAMMU) di Desa Kadipiro. 5(5). https://doi.org/10.59818/jpm.v5i5.1933*

21. *Permenkes 492/IV/2010, (2010).*

22. *kuswanto., Saudin yuniarto, I. H. (2021). Chlorine Diffuser Aplication to Reduce Coliform Numbers in the Wells. Jurnal Kesehatan Mayarakat, 13, 168–181.*

23. *Kwio-Tamale, J. C., & Onyutha, C. (2024). Influence of physical and water quality parameters on residual chlorine decay in water distribution network. Heliyon, 10(10), e30892. https://doi.org/10.1016/j.heliyon.2024.e30892*

24. *Macedo, D. O., & Janzen, J. G. (2022). Modelling the behaviour of chlorine within a drinking water distribution system following a microbial contamination event. Urban Water Journal, 19(5), 531–537. https://doi.org/10.1080/1573062X.2022.2030370*

25. *Made, N., Putri, A., Nadhifah, D. F., Marques, M. G. J. V, Stephanie, I., & Wikaningrum, T. (2024). Chlorine Residual in Wastewater Treatment : Implication for Pathogen Inactivation and Environmental Impact. 9, 341–347.*

26. *Marchesi, I., Paduano, S., Frezza, G., Sircana, L., Vecchi, E., Zuccarello, P., Oliveri Conti, G., Ferrante, M., Borella, P., & Bargellini, A. (2020). Safety and Effectiveness of Monochloramine Treatment for Disinfecting Hospital Water Networks. International Journal of Environmental Research and Public Health, 17(17). https://doi.org/10.3390/ijerph17176116*

27. *McGrath, J., Maleki, M., Bouchard, C., Pelletier, G., & Rodriguez, M. J. (2021). Bulk and pipe wall chlorine degradation kinetics in three water distribution systems. Urban Water Journal, 18(7), 512–521. https://doi.org/10.1080/1573062X.2021.1893368*

28. *Meehan, K., Jurjevich, J. R., Chun, N. M. J. W., & Sherrill, J. (2020). Geographies of insecure water access and the housing–water nexus in US cities. Proceedings of the National Academy of Sciences of the United States of America, 117(46), 28700–28707. https://doi.org/10.1073/pnas.2007361117*

29. *Regulation of Ministry of Health Republic Indonesia No. 2 Tahun 2023 about Environmental Health, Kemenkes Republik Indonesia 1 (2023).*

30. *Monteiro, L., Carneiro, J., & Covas, D. I. C. (2020). Modelling chlorine wall decay in a full-scale water supply system. Urban Water Journal, 17(8), 754–762. https://doi.org/10.1080/1573062X.2020.1804595*

31. *Nagar, A., & Pradeep, T. (2020). Clean Water through Nanotechnology: Needs, Gaps, and Fulfillment. ACS Nano, 14(6), 6420–6435. https://doi.org/10.1021/acsnano.9b01730*

32. *Pangestu, M. P., & Lusno, M. F. D. (2025). Kualitas Air Minum Rumah Tangga di Indonesia Berdasarkan Parameter Fisik, Kimia, dan Mikrobiologi: Studi Cross-Sectional Mengacu pada Standar Nasional. Jurnal Penelitian Inovatif, 5(2), 1689–1696. https://doi.org/10.54082/jupin.1534*

33. *Porusia, M., Asyfiradayati, R., Ratna, S., Putri, S., & Dwinanda, S. (2022). Comparison of Microbiological Quality of Well Water and Contaminated River Water in Open Defecation Area. 49(Ichwb 2021), 95–100. https://doi.org/10.2991/ahsr.k.220403.013*

34. *Raihani, N., Rahayuwati, L., Yani, D. I., & Rakhmawati, W. (2023). Hubungan Ketersediaan Sarana Sanitasi Dasar Dengan Kejadian Stunting Pada Balita the Relationship Between Availability Basic Sanitation with Toddlers Stunting Incidence At Sukamulya Village. 6(1), 35–43. https://doi.org/http://dx.doi.org/10.24198/jnc.v6i1.44429*

35. *Rongre, A. J. P., Joseph, W. B. S., & Pinontoan, O. R. (2018). Kandungan Escherichia Coli Dan Kondisi Fisik Sumur Gali Di Kelurahan Kakaskasen Iii Lingkungan Iii Kecamatan Tomohon Utara Kota Tomohon. Jurnal KESMAS, 7(4), 1–6. https://ejournal.unsrat.ac.id/index.php/kesmas/article/download/23181/22874*

36. *Saputri, E. T., & Efendy, M. (2020). Kepadatan Bakteri Coliform Sebagai Indikator Pencemaran Biologis Di Perairan Pesisir Sepuluh Kabupaten Bangkalan. Juvenil:Jurnal Ilmiah Kelautan Dan Perikanan, 1(2), 243–249. https://doi.org/10.21107/juvenil.v1i2.7579*

37. *Saputri, N., & Astuti, Y. P. (2019). Hubungan Faktor Lingkungan Dengan Kejadian Diare Pada Balita Di Puskesmas Bernung. Jurnal Ilmu Keperawatan Dan Kebidanan, 10(1), 101–110.* *https://ejr.umku.ac.id/index.php/jikk/article/view/619/378*

38. *Solomon, E. T., Robele, S., Kloos, H., & Mengistie, B. (2020). Effect of household water treatment with chlorine on diarrhea among children under the age of five years in rural areas of Dire Dawa, eastern Ethiopia: A cluster randomized controlled trial. Infectious Diseases of Poverty, 9(1), 1–13.* *https://doi.org/10.1186/s40249-020-00680-9*

39. *Sutapa, I. D. A., Fakhrudin, M., & Yogaswara, H. (2021). Implementation of ecohydrology to support sustainable water resources management in tropical region, Indonesia. Ecohydrology & Hydrobiology, 21(3), 501–515.* *https://doi.org/10.1016/j.ecohyd.2021.08.010*

40. *Suyanto, B., Indraswati, D., Hendrarinata, F., Jayadi, H., Santoso, H., & Nugroho, W. (2022). Potential of Solar Cells as Energy Disinfection Machines for Water Sources. 12, 135–143.* *https://doi.org/10.31838/ecb/2023.12.s3.019*

41. *Vaidya, R., Kumar, K. R. S., Mohan Kumar, M. S., & Rao, L. (2023). Chlorine degradation in continuous and intermittent drinking water supply networks. Urban Water Journal, 20(1), 60–73.* *https://doi.org/10.1080/1573062X.2022.2139275*

42. *Wagdy, R., Mubarak, M. F., Mohamed, R. S., & El Shahawy, A. (2024). Industrial-scale feasibility for textile wastewater treatment via Photocatalysis-adsorption technology using black sand and UV lamp. RSC Advances, 14(15), 10776–10789.* *https://doi.org/10.1039/d4ra00421c*

43. *Wei, Y., Wu, H., Zhang, X., Liang, Y., Shi, D., Wang, L., Li, H., Yu, H., Yang, D., Zhou, S., Chen, T., Yang, Z., Li, J., & Jin, M. (2024). Comparative analysis of chlorine-resistant bacteria after chlorination and chloramination in drinking water treatment plants. Journal of Hazardous Materials, 469, 134075.* *https://doi.org/10.1016/j.jhazmat.2024.134075*

44. *WHO. (2018). E. coli.*

45. *WHO. (2022). Guidelines for drinking-water quality: incorporating the first and second addenda. In WHO (Vol. 11, Issue 1).* *https://www.who.int/publications/i/item/9789240045064*

46. *Yantu, S. S., Warouw, F., & Umboh, J. M. L. (2021). Hubungan Antara Sarana Air Bersih dan Jamban Keluarga dengan Kejadian Diare Pada Balita di Desa Waleure. Jurnal KESMAS, 10(6), 24–30.* *https://ejournal.unsrat.ac.id/v3/index.php/kesmas/article/view/35445*

Залишкова поведінка хлору при дезінфекції води з використанням комбінованих піщаних середовищ із застосуванням хлору

Резанія Асифірадаяті [1]
викладач кафедри громадського здоров'я,
[1] Університет Мухаммадії Суракарта, Суракарта, Індонезія;
Вінді Вуландарі [1]
викладач кафедри громадського здоров'я;
Дженіта Берліан Н [1]
студент кафедри громадського здоров'я;
Сіті Рохана Мохд Ятім [2]
викладач, факультет охорони здоров'я,
[2] Університет технологій MARA, Селангор, Малайзія

Вода є потребою кожної людини в усіх частинах світу. В Індонезії свердловини, що забезпечують доступ як до мілководних, так і до глибоких джерел ґрунтових вод, служать основним джерелом чистої води. Мікробіологічне забруднення води негативно впливає, особливо на здоров'я. Система водопостачання є фундаментальним компонентом сталого міського розвитку. Тим не менш, вона часто стикається з низкою складних проблем, особливо в країнах, що розвиваються. Метою цього дослідження є вивчення концентрації залишкового хлору протягом різного часу контакту з використанням різних комбінацій середовищ, а саме чорного піску, кварцового піску та білого піску, для оцінки їхньої ефективності у підтримці рівня хлору під час очищення води. У цьому дослідженні використовувався квазіекспериментальний дизайн для оцінки рівня залишкового хлору в очищеній воді з використанням різних типів піску, інтегрованого з хлором у дифузійні труби. Загалом було використано 720 літрів води, розділених на 36 резервуарів, що містили 2,5 мг хлору, кожен з яких містив 20 літрів та 500 грамів одного з трьох типів піску: чорний пісок, білий пісок або кварцовий пісок. Зразки води в 20-літрових контейнерах обробляли хлорним розпилювачем протягом періодів експозиції 30, 45 та 60 хвилин. У дослідженні оціню-

вали кілька параметрів, включаючи температуру, pH, загальний вміст розчинених твердих речовин (TDS) та залишковий хлор. Дані аналізували та представляли за допомогою однофакторних та двофакторних таблиць, а статистичне тестування проводили за допомогою однофакторного дисперсійного аналізу (ANOVA). Результати показали, що дифузор хлору, що містить білий пісок, перевищував допустимий поріг залишкового хлору при часі контакту 45 та 60 хвилин. Статистичний аналіз за допомогою однофакторного дисперсійного аналізу виявив значну різницю в концентраціях залишкового хлору між середовищем з кварцовим піском та чорним піском ($p < 0,05$). Однак, статистично значущої різниці в концентраціях хлору з часом для дифузора з білим піском не спостерігалося. Ці результати свідчать про те, що білий пісок може призвести до тривалого затримування хлору, що потенційно може призвести до концентрацій вище рекомендованих меж. Вперше проведено аналіз, який показує, що різні типи піску в дифузорі хлору мають відмінності в залишковому хлорі у воді, що дозволяє використовувати його як орієнтир для подальших досліджень у сфері очищення води.

Ключові слова*: залишок хлору, кварцовий пісок, білий пісок, чорний пісок, безпечна питна вода, дезінфекція, хлор, комбінація середовищ.*