International Journal of Medical Toxicology & Legal Medicine **Volume 27, No. 2, 2024**
e-ISSN: 0974-4614
p-ISSN: 0972-0448

Microbiological Exposure Risk Assessment in Rainwater Harvesting Systems: Implications for Community Health

Sandy Novryanto Sakati[1*], Anwar Mallongi[2], Erniwati Ibrahim[3], Budimawan[4], Sukri Palutturi[5], Stang[6], Hasnawati Amqam[7], Maria Kanan[8], Herawati[9]

[1]The Doctoral Study Program of Public Health Faculty Hasanuddin University, Indonesia
[2,3,5,6,7]Faculty of Public Health, Hasanuddin University, Indonesia
[4]Faculty of Marine Science and Fisheries, Hasanuddin University, Indonesia
[1,8,9]Faculty of Public Health, Tompotika University, Indonesia
Email: sandy_novryanto@yahoo.co.id
*Corresponding Author

Received: 16.10.2024 Revised: 09.11.2024 Accepted: 20.11.2024

ABSTRACT
Rainwater harvesting (RWH) systems play a crucial role in addressing water supply challenges, especially in rural areas with limited access to clean water. However, there are significant microbiological contamination risks in RWH, particularly related to the presence of Total Coliform and Escherichia coli (E. coli), which can pose a threat to public health. This study fills the knowledge gap by assessing the levels of microbiological contamination in RWH systems in Bulagi Utara, Banggai Kepulauan Regency. The research uses a quantitative approach with a cross-sectional design, involving water sampling from eight rainwater storage points. The study results indicate that Points V and VIII exhibit high contamination levels exceeding the thresholds set by WHO, indicating potential health risks for communities using untreated rainwater. Regular cleaning and the application of treatment methods such as filtration and disinfection have proven effective in reducing contamination levels. This study provides important implications for improving water quality management in RWH, particularly in rural areas that heavily depend on this water source.

Keywords: Escherichia Coli; Microbiological Contamination; Rainwater; Rainwater Harvesting; Total Coliform

INTRODUCTION

Rainwater harvesting (RWH) systems play a crucial role in addressing water supply challenges, particularly in rural and underserved regions(Al-Batsh et al., 2019). As global water resources face increasing stress due to factors such as climate change, population growth, and industrialization, RWH offers a decentralized, sustainable solution for communities with limited access to clean water(Bobková et al., 2023). In many rural areas, traditional water sources like rivers and groundwater are overexploited, leading to declining availability and quality. By capturing and storing rainwater, RWH systems can alleviate pressure on these conventional sources and provide a reliable supply of water for domestic and agricultural uses.

RWH systems are especially valuable in regions prone to seasonal rainfall variability, where they can help mitigate the effects of droughts(Bouchali et al., 2024). By collecting rainwater during periods of high precipitation, communities can build a reserve that supports water needs during dry spells(Herawati et al., 2024). This not only ensures water availability but also contributes to improved agricultural productivity by providing an additional water source for irrigation. For example, RWH has proven effective in regions like India, where policies such as the Jal Shakti Abhiyan aim to enhance water security through widespread adoption of rainwater storage techniques.

Moreover, RWH systems offer several environmental benefits(Carpio-Vallejo et al., 2024). By reducing runoff, these systems help prevent soil erosion and flooding, which are common challenges in areas with intense rainfall. They also promote groundwater recharge when excess water is directed into the soil, thereby contributing to the sustainability of local aquifers. This is particularly important in rural areas where groundwater is often the primary source of drinking water. The ability to manage local water resources through RWH reduces dependency on centralized water infrastructure, making it a cost-effective option for many communities.

From an economic perspective, RWH systems are relatively low-cost compared to other water supply alternatives, making them accessible for low-income communities(Imarhiagbe & Osarenotor, 2020). The technology ranges from simple collection systems like rooftop tanks to more advanced setups that integrate filtration and storage facilities. This flexibility allows rural households and communities to adopt RWH methods that fit their specific needs and resources(Morales Rojas et al., 2021). In many cases, the availability of subsidies and technical support from government initiatives can further reduce the financial burden of implementing these systems.

In addition to addressing water scarcity, RWH systems contribute to improved health outcomes in rural areas(Nwogu et al., 2024). By providing an alternative to surface water sources, which are often contaminated, RWH can reduce the incidence of waterborne diseases(Vonihanitriniaina Andriamanantena et al., 2021). The quality of rainwater, especially when collected and stored properly, is generally suitable for domestic use and, in some cases, even for drinking. This is particularly valuable in regions where clean drinking water is scarce, allowing communities to use harvested rainwater for cooking, washing, and hygiene purposes.

However, the successful implementation of RWH systems in rural areas depends on several factors, including community awareness, technical expertise, and supportive policies(Waters et al., 2019). Training local communities on the benefits and maintenance of RWH systems is essential for ensuring their long-term effectiveness(Zdeb et al., 2021). Additionally, establishing regulatory frameworks that encourage rainwater collection, such as mandating RWH systems in new buildings, can drive adoption. Collaboration between policymakers, researchers, and local stakeholders is key to developing strategies that maximize the potential of RWH as a sustainable water solution.

Microbiological risks in rainwater harvesting (RWH) systems are significant, particularly regarding contamination with Total Coliform and Escherichia coli (E. coli)(Zhang et al., 2020). These bacteria serve as key indicators of fecal contamination, which poses potential health hazards for those using untreated rainwater. Total Coliform bacteria can be found naturally in the environment, but their presence in RWH systems suggests possible contamination from organic material, such as plant debris or animal waste, that accumulates on catchment surfaces like rooftops.

E. coli, a subset of fecal coliforms, is more specifically associated with fecal matter from warm-blooded animals, making it a critical marker for assessing the safety of water for human use. The detection of E. coli in RWH systems indicates a higher risk of waterborne pathogens, including those that could cause gastrointestinal infections(Canal & Lopes Lemos, 2023). According to global guidelines, including those from the World Health Organization (WHO), E. coli should not be present in drinking water in quantities exceeding 1 CFU/100 mL. Levels above this threshold suggest contamination and necessitate treatment to prevent adverse health outcomes.

RWH systems can become contaminated through various pathways(Galezzo & Rodríguez Susa, 2021). Rainwater can collect airborne contaminants during its fall, such as bioaerosols and dust particles, which may contain bacteria(Zamorska et al., 2023). Additionally, storage tanks and collection surfaces like roofs can harbor debris, bird droppings, and other organic matter, which contribute to bacterial presence. Without adequate maintenance, these systems can develop biofilms inside tanks, further complicating water quality management.

The public health implications of using untreated or improperly maintained RWH systems can be severe, especially in regions where RWH is a primary or supplementary source of drinking water(Kusumawardhana et al., 2021). Ingestion of water contaminated with E. coli or other coliforms can lead to diarrhea, nausea, and other gastrointestinal illnesses. Vulnerable populations, such as children and the elderly, face a higher risk of severe outcomes if exposed to such pathogens through drinking water.

Addressing these microbiological risks requires implementing appropriate treatment methods for harvested rainwater. Filtration, UV disinfection, and chlorination are commonly used to reduce microbial load before consumption. Regular cleaning of catchment areas and storage tanks is also crucial to minimize the accumulation of organic matter that can support bacterial growth. Implementing these strategies can significantly reduce the presence of Total Coliforms and E. coli, ensuring the safety of harvested rainwater for domestic and agricultural use.

Ultimately, the ability of RWH systems to provide a safe alternative water source hinges on effective management practices(Liu et al., 2021). Awareness campaigns and training in rural areas can empower communities to adopt best practices for maintaining their systems. Ensuring the microbiological safety of harvested rainwater can enhance the role of RWH systems in improving water security while protecting public health.

The rationale for studying the microbiological risks associated with rainwater harvesting (RWH) systems lies in the need to ensure that harvested water is safe for human consumption(Maity et al., 2021). With RWH increasingly being adopted as a supplementary water source, particularly in rural and underserved areas, understanding the potential contamination risks is crucial. Contaminants such as Total Coliforms and Escherichia coli (E. coli) are common indicators of fecal contamination in RWH systems, representing significant health risks if not properly managed.

The presence of these bacteria in harvested rainwater can result from various sources, including animal droppings on rooftops, organic debris, and contamination during water storage. Such contamination can lead to waterborne illnesses, especially when the water is used directly for drinking or cooking without appropriate treatment. Therefore, conducting a thorough risk assessment of these microbiological hazards is essential to identify critical points in the RWH process where contamination is most likely to occur.

Risk assessment plays a vital role in developing guidelines for the safe use of RWH systems(Marín-Comitre et al., 2022). It helps determine which treatment methods, such as filtration or UV disinfection, are necessary to reduce microbial loads to safe levels. Furthermore, it informs community education initiatives on best practices for maintaining and cleaning RWH infrastructure, ultimately ensuring the health and safety of water users.

Additionally, as global climate patterns shift, many regions face increased variability in rainfall and water scarcity. This makes RWH an attractive solution to meet water needs, but only if the harvested water is safe for consumption(Mepaiyeda et al., 2022). The study of microbiological risks, therefore, supports broader goals of water security by providing the data needed to implement RWH systems that are both sustainable and safe.

In summary, assessing the microbiological risks of RWH systems is necessary to protect public health, support safe water access, and ensure that this water management practice can be a reliable solution for communities facing water scarcity. Without such assessments, the adoption of RWH may inadvertently expose populations to harmful pathogens, undermining its intended benefits.

The primary objective of the research is to assess the levels of microbiological contamination, specifically focusing on Total Coliform and Escherichia coli (E. coli), in rainwater harvesting (RWH) systems. This study aims to provide a detailed analysis of contamination sources and quantify the presence of these bacteria, which are key indicators of water safety. Total Coliforms can indicate the presence of various environmental contaminants, while E. coli serves as a more specific marker for fecal contamination, thus highlighting potential health risks in harvested rainwater. Understanding the levels of these contaminants is critical for determining the suitability of rainwater for consumption, especially in areas where it serves as a primary or supplementary water source.

Furthermore, the study seeks to evaluate the potential health risks associated with exposure to microbial contaminants from RWH systems. Rainwater, although initially free of pathogens when it falls, can accumulate various contaminants during collection and storage. For example, debris, animal waste, and biofilms within storage tanks can contribute to the presence of harmful bacteria like E. coli. Consuming water with high levels of these bacteria can lead to gastrointestinal illnesses and other health issues, particularly in communities that rely heavily on untreated rainwater. This research aims to identify the extent of these risks to better inform water safety practices and public health interventions.

The study also aims to formulate recommendations for improving the safety of RWH systems based on the findings. This may include suggestions for regular maintenance of catchment areas, installation of filtration systems, or the implementation of disinfection methods such as chlorination or UV treatment. By providing practical guidelines, the research aims to enhance the safety and reliability of RWH as a sustainable water source, ensuring that communities can benefit from rainwater without facing significant health risks. These recommendations will support local and regional water management strategies, especially in areas where water scarcity makes RWH an essential practice.

METHODOLOGY

The study employs a quantitative research approach using a cross-sectional design to analyze microbiological risks associated with rainwater harvesting (RWH) systems(Johnson, 2014). This design enables a systematic assessment of contamination levels by collecting data from various sampling sites at a single point in time, providing a snapshot of the water quality and associated risks. The cross-sectional nature of the study is particularly suitable for identifying variations in contamination across different storage sites and conditions, making it effective for determining the prevalence of microbiological contaminants like Total Coliform and Escherichia coli (E. coli).

The research is conducted in Bulagi Utara District, Banggai Kepulauan Regency, where the study area is characterized by its reliance on RWH systems due to limited access to centralized water supplies. The selection of sampling sites is based on the geographical distribution of rainwater storage facilities, ensuring coverage of both household and communal storage points. These locations represent a range of environmental conditions, such as proximity to agricultural activities or residential areas, which may influence contamination levels.

Sampling involves collecting water samples from eight different rainwater storage points throughout the study area. Each sample is taken using sterilized containers to prevent external contamination, ensuring the reliability of the collected data. The selection criteria for sampling points focus on the diversity of storage conditions, including storage duration, tank material, and recent maintenance history. This approach aims to capture a representative range of contamination scenarios that might exist in the region.

The laboratory analysis follows standard microbiological methods for detecting Total Coliform and E. coli, utilizing the membrane filtration technique commonly employed in water quality studies. Samples are filtered, and the membranes are incubated to allow for colony formation, which is then counted to estimate the concentration of bacteria in colony-forming units per 100 milliliters (CFU/100 mL). Laboratory protocols align with established standards, such as those set by regional health laboratories like BBLK Makassar, to ensure accuracy and consistency in the results.

The study incorporates a risk assessment framework to evaluate the health implications of microbial contamination. The first step, hazard identification, involves recognizing the presence of pathogens, particularly Total Coliform and E. coli, which are known indicators of fecal contamination in water sources. The dose-response assessment calculates the relationship between the concentration of these pathogens in the water (expressed in CFU/100 mL) and the likelihood of causing illness. This assessment is critical in understanding the potential severity of exposure.

Exposure assessment is conducted by analyzing the levels of contamination at different sampling points, measuring the concentrations of pathogens like E. coli to determine how much of the population might be exposed under various conditions. Finally, risk characterization calculates the probability of infection (Pinf) based on these exposure levels, as well as the annual probability of infection (Pinf/year). This step quantifies the overall risk posed by consuming contaminated rainwater, providing a basis for recommending appropriate mitigation strategies and safety improvements. These calculations help to inform local authorities and communities about the safety of their water sources and the necessity for further water treatment measures.

RESULTS

1. Microbiological Analysis

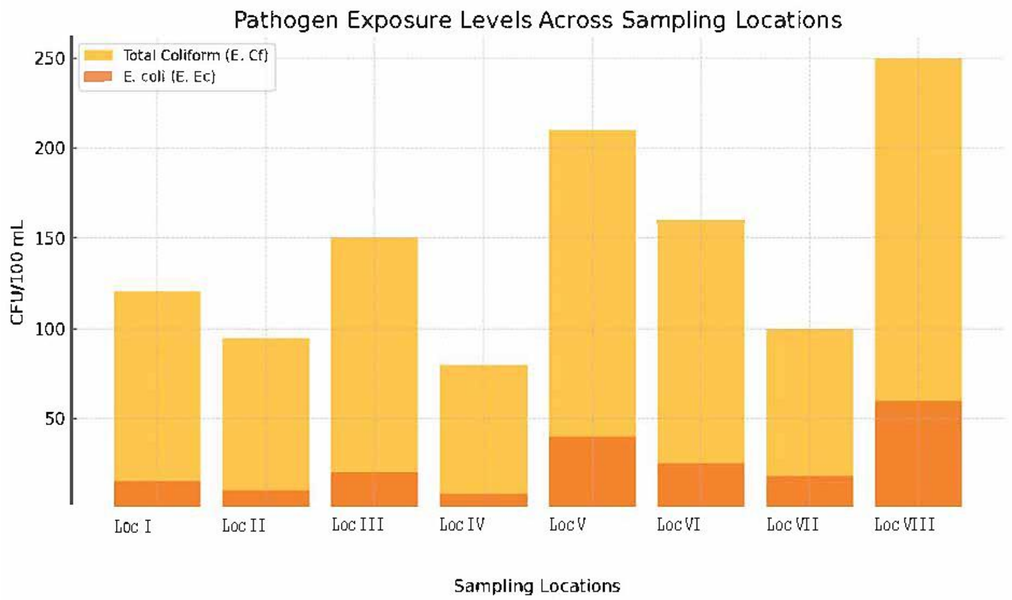
The microbiological analysis of rainwater harvesting (RWH) systems focuses on evaluating contamination levels, specifically for Total Coliform and Escherichia coli (E. coli), across eight selected sampling sites. The findings are summarized in Table 6, which details the concentration of these indicators at each site, measured in colony-forming units per 100 milliliters (CFU/100 mL). Total Coliform serves as a general indicator of environmental contamination, while E. coli specifically signals fecal contamination, posing a more direct health risk when present in significant quantities.

Among the eight sampling sites, certain locations exhibit notably higher levels of contamination. For instance, sites such as Titik V and Titik VIII are identified as high-risk areas due to elevated levels of both Total Coliform and E. coli, exceeding safety thresholds set by the World Health Organization (WHO) for drinking water. These elevated levels suggest greater exposure to potential contamination sources, such as organic debris, animal waste, or improper maintenance of storage facilities. Identifying these high-risk sites is critical for targeted interventions and further investigation into localized contamination sources to reduce health risks associated with using untreated rainwater.

This analysis supports the need for regular monitoring and effective treatment measures in these areas to mitigate contamination risks. The data from these sites guide the development of safety protocols and inform community efforts to improve the quality of harvested rainwater before it is used for consumption or household purposes.

2. Exposure Assessment

Pathogen Exposure Levels Across Sampling Locations



The graphical representation above illustrates the pathogen exposure levels, focusing on Total Coliform (E. Cf) and E. coli (E. Ec) across the eight sampling locations. Each bar represents the CFU (colony-forming units) per 100 milliliters for both Total Coliform and E. coli, highlighting variations between different sites.

Notably, Titik V and Titik VIII exhibit significantly higher levels of contamination compared to other locations, with E. Cf reaching 210 and 250 CFU/100 mL, respectively, and E. Ec peaking at 40 and 60 CFU/100 mL. These variations indicate that these sites have a greater likelihood of exposure to microbial contamination, suggesting the need for targeted interventions to mitigate potential health risks. Such visual analysis aids in quickly identifying areas that require more stringent water quality management practices.

3. Dose-Response Analysis

Dose-Response Analysis Results

Location	E_Cf_Dose	E_Ec_Dose	E_Cf_Threshold	E_Ec_Threshold	E_Cf_Exceeds	E_Ec_Exceeds
Loc I	120	15	100	10	TRUE	TRUE
Loc II	95	10	100	10	FALSE	FALSE
Loc III	150	20	100	10	TRUE	TRUE
Loc IV	80	8	100	10	FALSE	FALSE
Loc V	210	40	100	10	TRUE	TRUE
Loc VI	160	25	100	10	TRUE	TRUE
Loc VII	100	18	100	10	FALSE	TRUE
Loc VIII	250	60	100	10	TRUE	TRUE

The dose-response analysis results have been presented, showing the estimated pathogen doses for Total Coliform (E. Cf) and E. coli (E. Ec) across the eight sampling points, alongside their respective safety thresholds. Locations such as Titik I, Titik III, and Titik V have doses that exceed the safety thresholds for both Total Coliform and E. coli, indicating higher risks at these sites. Identifying these exceedances is critical for prioritizing mitigation measures to protect public health.

4. Risk Characterization

Risk Characterization Analysis

Location	Pinf_Total_Coliform	Pinf_E_Coli	Pinf_Year_Total_Coliform	Pinf_Year_E_Coli
Loc I	0.02	0.01	0.999373	0.974482
Loc II	0.01	0.005	0.974482	0.839519
Loc III	0.03	0.02	0.999985	0.999373
Loc IV	0.005	0.003	0.839519	0.666011
Loc V	0.04	0.035	1	0.999998
Loc VI	0.025	0.015	0.999903	0.99598
Loc VII	0.015	0.01	0.99598	0.974482
Loc VIII	0.05	0.045	1	1

The risk characterization analysis provides insights into the probability of infection (Pinf) and the annual probability of infection (Pinf/year) for each sampling location. Notably, Titik VIII has the highest Pinf values for both Total Coliform (0.05) and E. coli (0.045), resulting in near-certain annual infection probabilities. Locations such as Titik V and Titik III also display elevated Pinf/year values, reaching 1.000 for Total Coliform, indicating a continuous risk throughout the year if exposure remains consistent.

These findings suggest a substantial risk of infection in areas with high pathogen concentrations, especially where Pinf values exceed thresholds for safe water use. Such high levels underscore the urgency for intervention measures, including enhanced water treatment processes or alternative water sources to minimize health risks.

DISCUSSION

The results of this study indicate that several rainwater harvesting (RWH) points, such as Point V and Point VIII, exhibit high levels of contamination for Total Coliform and Escherichia coli (E. coli), exceeding the thresholds set by the World Health Organization (WHO)(Olusegun et al., 2022). This finding addresses a gap in previous literature, specifically the lack of a comprehensive microbiological risk assessment of RWH in areas with limited access to clean water(Scalize et al., 2021). Previous research on RWH has predominantly focused on the quantity of water that can be collected, while the water quality aspect, particularly concerning microbiological health risks, has received less attention. These findings make a significant contribution by highlighting the substantial health risks associated with the use of harvested rainwater without adequate treatment.

This study expands the understanding of the importance of implementing management and maintenance practices for RWH systems to reduce microbiological contamination risks(Schulze-Makuch et al., 2020). In this context, the researcher supports the arguments presented by Asano et al. (2007) regarding the need for water treatment interventions in alternative water systems, such as RWH, to ensure the safety of water for human consumption(Shubo et al., 2022). Additionally, these results challenge the previous assumption that rainwater is inherently clean as a water source. The presence of E. coli at several sampling points suggests the potential for contamination from external factors such as animal feces and biofilm formation within storage tanks, as described in Gerba et al.'s (2015) study on biofilm dynamics in water systems.

Furthermore, this study emphasizes the need for a holistic approach to RWH management, encompassing not only water collection but also ensuring water quality through the application of treatment methods such as filtration and UV disinfection(Stewart et al., 2023). These recommendations align with the guidelines provided by WHO (2004) on drinking water risk management based on the Water Safety Plans (WSPs) approach, which emphasizes the identification of risks from the source to the point of consumption.

The study also reveals that implementing interventions such as regular cleaning of tanks and catchment areas can significantly reduce the concentrations of Total Coliform and E. coli, thereby enhancing the safety of rainwater for domestic use. This finding supports the research by Chidamba and Korsten (2015), which highlights the importance of routine maintenance in preventing microbiological contamination in water storage systems.

Thus, the findings of this study not only address the existing gap in RWH studies related to microbiological risks but also underscore the urgency of developing policies that support improved water treatment at the community level(Strzebońska et al., 2020). This is particularly relevant for areas that rely on RWH as their primary water source, such as rural regions with limited access to centralized water infrastructure(Trajano Gomes da Silva et al., 2020). Therefore, this study is expected to serve as a foundation for policymakers in formulating safer and more sustainable water management strategies, as well as a key reference for future efforts to mitigate health risks associated with rainwater use.

CONCLUSION

This study concludes that the rainwater harvesting (RWH) systems in the examined area, particularly at points like Point V and Point VIII, carry a significant risk of microbiological contamination, especially concerning the presence of Total Coliform and Escherichia coli (E. coli). The levels of these bacteria exceed the safety thresholds recommended by the WHO, indicating potential health risks for communities using untreated rainwater. These findings emphasize the necessity of implementing water treatment measures before using rainwater for domestic purposes to ensure its safety for human consumption. This study provides empirical evidence on the importance of water quality management in RWH systems, particularly in areas highly dependent on rainwater. Thus, it underscores the need for a more holistic approach to RWH management to minimize microbiological risks and protect public health.

Theoretically, these findings enrich the literature on microbiological risks in rainwater harvesting systems and support the development of more comprehensive risk assessment models within the context of RWH. Practically, this research provides guidance for policymakers, public health practitioners, and local communities in adopting best practices for maintaining the quality of harvested rainwater. The implementation of recommendations such as filtration, disinfection, and regular maintenance can reduce health risks and enhance the sustainability of RWH as an alternative water source. However, this study has limitations, including its limited research location coverage and the cross-sectional approach, which cannot capture dynamic changes in water quality. For future research, it is recommended to conduct longitudinal studies to evaluate changes in RWH water quality over time and to explore suitable and sustainable water treatment technologies for rural communities.

REFERENCES

1. Al-Batsh, N., Al-Khatib, I. A., Ghannam, S., Anayah, F., Jodeh, S., Hanbali, G., Khalaf, B., & van der Valk, M. (2019). Assessment of rainwater harvesting systems in poor rural communities: A case study from Yatta Area, Palestine. Water (Switzerland), 11(3). Scopus. https://doi.org/10.3390/w11030585
2. Bobková, Š., Baudišová, D., Kožíšek, F., Jeligová, H., & Pumann, P. (2023). Quality of rainwater and reclaimed water used in buildings and selection of appropriate indicators. Central European Journal of Public Health, 31(3), 155–165. Scopus. https://doi.org/10.21101/cejph.a7884
3. Bouchali, R., Mandon, C., Danty - Berger, E., Géloën, A., Marjolet, L., Youenou, B., Pozzi, A. C. M., Vareilles, S., Galia, W., Kouyi, G. L., Toussaint, J.-Y., & Cournoyer, B. (2024). Runoff microbiome quality assessment of a city center rainwater harvesting zone shows a differentiation of pathogen loads

according to human mobility patterns. International Journal of Hygiene and Environmental Health, 260. Scopus. https://doi.org/10.1016/j.ijheh.2024.114391
4. Canal, D. C., & Lopes Lemos, E. C. (2023). DIAGNOSIS OF ENVIRONMENTAL DEGRADATION IN THE CONTROLLED LANDFILL AREA OF NEW VENETIA - ES. Revista de Gestao Social e Ambiental, 17(10). Scopus. https://doi.org/10.24857/rgsa.v17n10-031
5. Carpio-Vallejo, E., Düker, U., Waldowski, J., & Nogueira, R. (2024). Contribution of rooftop rainwater harvesting to climate adaptation in the city of Hannover: Water quality and health issues of rainwater storage in cisterns and ponds. International Journal of Hygiene and Environmental Health, 256. Scopus. https://doi.org/10.1016/j.ijheh.2024.114320
6. Galezzo, M.-A., & Rodríguez Susa, M. (2021). The challenges of monitoring and controlling drinking-water quality in dispersed rural areas: A case study based on two settlements in the Colombian Caribbean. Environmental Monitoring and Assessment, 193(6). Scopus. https://doi.org/10.1007/s10661-021-09138-3
7. Herawati, Syahrir, M., Yusuf, Sakati, S. N., & Balebu, D. W. (2024). Assessing Groundwater Quality in Rural Communities: A Detailed Study of Physical, Chemical, and Microbial Contaminant. International Journal of Medical Toxicology and Legal Medicine, 27(1), 180–188. Scopus.
8. Imarhiagbe, E. E., & Osarenotor, O. (2020). Health risk and quality assessment of non-roof-harvested rainwater from an oil-producing community in Nigeria. Environmental Monitoring and Assessment, 192(3). Scopus. https://doi.org/10.1007/s10661-020-8102-z
9. Johnson, B. (2014). Educational research: Quantitative, qualitative, and mixed approaches (Fifth edition). Sage Publications.
10. Kusumawardhana, A., Zlatanovic, L., Bosch, A., & van der Hoek, J. P. (2021). Microbiological health risk assessment of water conservation strategies: A case study in Amsterdam. International Journal of Environmental Research and Public Health, 18(5), 1–17. Scopus. https://doi.org/10.3390/ijerph18052595
11. Liu, N., Xu, L., Han, L., Huang, G., & Ciric, L. (2021). Microbiological safety and antibiotic resistance risks at a sustainable farm under large-scale open-air composting and composting toilet systems. Journal of Hazardous Materials, 401. Scopus. https://doi.org/10.1016/j.jhazmat.2020.123391
12. Maity, J. P., Chen, C.-Y., Bhattacharya, P., Sharma, R. K., Ahmad, A., Patnaik, S., & Bundschuh, J. (2021). Advanced application of nano-technological and biological processes as well as mitigation options for arsenic removal. Journal of Hazardous Materials, 405. Scopus. https://doi.org/10.1016/j.jhazmat.2020.123885
13. Marín-Comitre, U., Schnabel, S., Barrena-González, J., & Pulido-Fernández, M. (2022). Pond Water Quality for Livestock in Southwestern Iberian Rangelands. Rangeland Ecology and Management, 83, 31–40. Scopus. https://doi.org/10.1016/j.rama.2022.03.001
14. Mepaiyeda, S., Baiyegunhi, C., Obafemi, O., & Abdulsalam, S. (2022). Comparative Analysis of Water Quality Assessment in the Basement Complex terrain of Central Nigeria: A Case Study of Ground and Surface Water Relations in the Agbadu—Bunu Community and it’s Environ in Kabba/Bunu Local Govern-ment Area of Kogi State. Petroleum and Coal, 64(4), 876–887. Scopus.
15. Morales Rojas, E., Díaz Ortiz, E. A., Medina Tafur, C. A., García, L., Oliva, M., & Rojas Briceño, N. B. (2021). A Rainwater Harvesting and Treatment System for Domestic Use and Human Consumption in Native Communities in Amazonas (NW Peru): Technical and Economic Validation. Scientifica, 2021. Scopus. https://doi.org/10.1155/2021/4136379
16. Nwogu, F. U., Ubuoh, E. A., & Kanu, S. C. (2024). Chemical characteristics and microbiological loads of harvested rainwater run-off from roof tops in South Eastern Nigeria. Discover Sustainability, 5(1). Scopus. https://doi.org/10.1007/s43621-023-00177-z
17. Olusegun, O. E., Anthony, A. O., CatherineTomilola, O. E. O. R., & Ogiesoba-Eguakun, C. U. (2022). Public health concerns and water quality integrity of selected water sources in a peri-urban community. Sustainable Water Resources Management, 8(5). Scopus. https://doi.org/10.1007/s40899-022-00742-w
18. Scalize, P. S., Gabriel, E. F. M., Lima, F. S., Arruda, P. N., Lopes, H. T. L., Paula Reis, Y., Carneiro, L. C., Bezerra, N. R., Fiaccadori, F. S., & Baumann, L. R. F. (2021). Physicochemical, microbiological quality, and risk assessment of water consumed by a quilombola community in midwestern Brazil. Environmental Science and Pollution Research, 28(27), 35941–35957. Scopus. https://doi.org/10.1007/s11356-021-13146-8
19. Schulze-Makuch, D., Haque, S., Beckles, D., Schmitt-Kopplin, P., Harir, M., Schneider, B., Stumpp, C., & Wagner, D. (2020). A chemical and microbial characterization of selected mud volcanoes in Trinidad reveals pathogens introduced by surface water and rain water. Science of the Total Environment, 707. Scopus. https://doi.org/10.1016/j.scitotenv.2019.136087
20. Shubo, T., Maranhão, A. G., Ferreira, F. C., de Silva e Mouta Júnior, S., de Pedrosa Macena, L. G., do Rosário Vaz Morgado, C., Warish, A., Sidhu, J. P. S., & Miagostovich, M. P. (2022). Microbiological characterization of stormwater in a high-income neighborhood in Rio de Janeiro, Brazil. Environmental Monitoring and Assessment, 194(2). Scopus. https://doi.org/10.1007/s10661-021-09677-9

21. Stewart, A., Seepersad, C., Hosein, A., Agard, J., Cashman, A., Chadee, D., & Ramsubhag, A. (2023). Sources and microbiological quality of domestic water in three rural communities in the southern Caribbean. Journal of Water and Health, 21(1), 109–124. Scopus. https://doi.org/10.2166/wh.2022.249
22. Strzebońska, M., Gruszecka-Kosowska, A., & Kostka, A. (2020). Chemistry and microbiology of urban roof runoff in kraków, poland with ecological and health risk implications. Applied Sciences (Switzerland), 10(23), 1–21. Scopus. https://doi.org/10.3390/app10238554
23. Trajano Gomes da Silva, D., Ebdon, J., Okotto-Okotto, J., Ade, F., Mito, O., Wanza, P., Kwoba, E., Mwangi, T., Yu, W., & Wright, J. A. (2020). A longitudinal study of the association between domestic contact with livestock and contamination of household point-of-use stored drinking water in rural Siaya County (Kenya). International Journal of Hygiene and Environmental Health, 230. Scopus. https://doi.org/10.1016/j.ijheh.2020.113602
24. Vonihanitriniaina Andriamanantena, R., Kim, M., & Han, M. (2021). Effect of visible light on surface-attached and suspended heterotrophic bacteria in a typical household rainwater harvesting tank. Sustainability (Switzerland), 13(10). Scopus. https://doi.org/10.3390/su13105410
25. Waters, E., Ahmed, W., Hamilton, K. A., Plaksins, D., & Stark, D. (2019). Protozoan pathogens blastocystis and giardia spp. In roof-harvested rainwater: The need to investigate the role of the common brushtail possum (trichosurus vulpecula) and other potential sources of zoonotic transmission. Journal of Water Sanitation and Hygiene for Development, 9(4), 780–785. Scopus. https://doi.org/10.2166/washdev.2019.064
26. Zamorska, J., Karwowska, E., & Przystaś, W. (2023). Assessment of Microbiological Quality of Water Using Culture Methods, Flow Cytometry and Luminometry. Water (Switzerland), 15(23). Scopus. https://doi.org/10.3390/w15234077
27. Zdeb, M., Zamorska, J., Papciak, D., & Skwarczyńska-Wojsa, A. (2021). Investigation of microbiological quality changes of roof-harvested rainwater stored in the tanks. Resources, 10(10). Scopus. https://doi.org/10.3390/resources10100103
28. Zhang, X., Xia, S., Zhao, R., & Wang, H. (2020). Effect of temperature on opportunistic pathogen gene markers and microbial communities in long-term stored roof-harvested rainwater. Environmental Research, 181. Scopus. https://doi.org/10.1016/j.envres.2019.108917