# The dual burden of poor sanitation and climate variability on public health: A case study of diarrhea incidence in Surakarta

*Nurhasan Agung* Prabowo[1,2*], *Desy Puspa* Putri[1,2], *Dhani* Redhono[2], *Evi* Nurhayatun[1,2], and *Narulita Brillianti Fajariani* Putri[2]

[1]Department of Internal Medicine, Faculty of Medicine, Universitas Sebelas Maret, Indonesia
[2]Department of Internal Medicine, Universitas Sebelas Maret Hospital, Indonesia

**Abstract.** Surakarta, Indonesia, faced an acute public health challenge, with diarrhea cases surging by 58.6% (rising from 7,209 in 2023 to 11,434 in 2024). This study aimed to examine the temporal relationship between this rapid increase and the dual environmental burden: chronic sanitation failure (solid waste volume) and acute climatic instability (rainfall and temperature). We employed an ecological, retrospective correlational approach, integrating 3 years (2022–2024) of annual data from the City Health Office (Dinkes), the Central Statistics Agency (BPS), and the Meteorology, Climatology, and Geophysics Agency (BMKG). The results revealed a direct association. The disease outbreak occurred concurrently with a 5.66% surge in annual solid waste volume and a marked increase in heavy precipitation, from 1,743.40 mm to 2,456.60 mm. The persistent solid waste acted as a chronic pathogen reservoir, and the extreme rainfall exceeded hydrological thresholds, inundating infrastructure and flushing contaminants into public water systems. Furthermore, increasing mean ambient temperatures (up to 27.60 °C) promoted microbial multiplication. The high case rates, particularly in Jebres and Banjarsari, illustrate a systemic breakdown at the community level. The study highlights the urgent need for integrated, climate-adaptive strategies to consolidate waste disposal and protect water-hygiene infrastructure.

## 1 Introduction

Diarrheal disease continues to be an important challenge in global public health, particularly as a predominant cause of morbidity and mortality in rapidly growing developing countries [1]. The susceptibility of any population to this disease stems largely from the quality of their environmental context, highlighting that they face two mutually reinforcing risks: the inadequate level of urban sanitation facilities and increasing unpredictable climate variation [2]. In many developing urban areas, infrastructure simply cannot keep pace with population growth, as waste and sanitation systems are often weak and fragile, eroding or disrupting their effectiveness. To identify the causes of diarrheal outbreaks, we must address the

* Corresponding author: dr.nurhasan21@staff.uns.ac.id

complex interplay between microbial activity and human health threats in densely populated urban areas [3].

The first environmental threat was determined to be unsafe conditions, specifically uncontrolled solid waste. Incomplete handling and disposal of garbage from constant, year-round sources of enteric pathogens [4]. The densities are ideal for feeding and breeding sites for vectors, such as flies and rodents, that spread bacteria and viruses and transmit diarrheal diseases. High, sustained solid waste production, therefore, is bad for health, sowing the seeds of mass infection long before environmental perturbations occur.

Climate variability intensifies the current sanitation crisis and creates a dual burden. Dramatic rainfall events are a key, unexpected trigger for epidemics. Too much rain inundates urban sewage and drainage systems, bringing about significant runoff that actively washes contaminants (human waste, solid refuse, and leachate) into public drinking water [5]. Furthermore, higher ambient temperatures are an essential catalyst; at higher temperatures, they accelerate the reproductive cycles of pathogens, leading to a higher load of infectious agents, increased survival in unsafe food and water, and, therefore, higher transmission rates of the pathogens in threatened environments [6].

The example of Surakarta (Solo), a densely populated metropolis in Central Java, Indonesia, demonstrates how overlapping pressures can impact a health system. The data from Surakarta City Health Office indicate a comparable problem: total diarrhea cases increased from 7,209 in 2023 to 11,434 in 2024, a 58.6 percent increase in one year. You need to examine the underlying environmental and climatic factors driving these rapid, acute escalations. Some initial signs suggested this outbreak might arise from two measurable, converging phenomena: a sudden surge in the citys annual solid waste generation and a record-high annual precipitation [7].

There is a research gap in moving beyond single-factor or short-term explanations of diarrheal outbreaks to assess the combined, synergistic impact of chronic sanitary failure and acute climatic stress. While the individual effects of poor sanitation and climate on health are well known, the concurrent and compounding influence of both factors—the dual burden—on specific acute urban outbreaks remains underexplored. The novelty of this study is performing a systematic correlational analysis to empirically link the rapid upturn in diarrhea in Surakarta (2022–2024) with these two principal and converging environmental determinants: (1) the annual solid waste volume (as a surrogate measure of chronic sanitation failure), and (2) the essential climatic variables (total rainfall and the mean ambient temperature) as drivers of acute variability. By measuring the components of this two-level burden, this research seeks to provide the empirical evidence needed to design and implement integrated, climate-adapted urban approaches and public health interventions in Surakarta and similar cities.

The objective of this study is therefore to perform in a systematic correlational analysis the temporal link between the rapid upturn in diarrhea exposure in Surakarta (2022 – 2024) and the two principal environmental determinants that can directly be considered: (1) the annual solid waste volume (as a surrogate measure of chronic sanitation failure), and (2) the essential climatic variables (total rainfall and the mean ambient temperature) as drivers of acute variability. By measuring the components of this two-level burden and identifying high-risk areas, this research seeks to provide the empirical evidence needed to design and implement integrated, climate-adapted urban approaches and public health interventions in Surakarta and similar cities [8].

## 2 Methods

This study combined an ecological and retrospective correlational approach to precisely portray the temporal relationship between specific environmental contributors and diarrheal

disease in Surakarta City, Central Java, Indonesia. The main analysis was based on annual data collected over three years (2022–2024). Surakarta is selected as a research setting because its densely populated urban region, with changing infrastructure/environmental conditions, provides an ideal ecological setting for exploring the interactive, single, or twin effects of sanitation vulnerabilities and climate instability on local public health. All data used was collected solely by official, authoritative government bodies in Indonesia to ensure correctness and uniformity. Information was collected through 3 primary categories for the variables. The dependent variable, Total Annual Diarrhoea Cases by the five districts (Kecamatan), was obtained directly from the Surakarta City Health Office (Dinas Kesehatan). Independent variables are prepared from the specialised departments: Climatic data: Total Annual Rainfall (mm) and Mean Annual Ambient Temperature (°C), from the meteorology, climatology, and geophysics agency. The meteorology region was collected by the regional station of the BMKG (Meteorology, Climatology, and Geophysics). The sanitation (total annual volume of solid waste (tons)) was obtained according to the reports produced of the appropriate City Environmental Agency and in association with contextual statistics from the Central Statistics Agency (BPS) Surakarta office. Raw annual totals and means of all variables were calculated in the run-up to data analysis and tabulated. The central descriptive technique was to calculate the percentage change for each variable between 2023 and 2024, which was necessary to quantify the magnitude of the observed synchronous spikes (e.g., a peak of 58.6% for diarrhoea cases).

## 3 Results

The analysis of public health data showed a substantial shift in diarrheal disease patterns. The incidence rate remained relatively stable between 2022 (7,422 total cases) and 2023 (7,209 cases). But the trend would suddenly change dramatically, moving to a severe, abrupt flare-up in 2024 with a devastating crisis that peaked at 11,434 total cases. This was a shocking increase of well over 58.6% in one year – see Table 1. Furthermore, the magnitude of the load was geographically skewed and the geographic vulnerabilities were indicated. In 2024, Jebres (3,533) and Banjarsari (3,064) had the highest number of cases [8]. Both districts also make up more than 57.0% of the cases, suggesting a systemic failure in their local environmental settings when compared with a less impactful location in Serengan (820 cases). Data on solid waste generation exhibit a straightforward, concurrent increase, mirroring the rise in diarrheal incidents. The annual solid waste content grew from 135,997 tons in 2023 to 143,696 tons in 2024. That growth can mean a 5.66% increase in waste production during the same period, while disease incidence rose 58.6%. This continuing increase in waste volume was also seen as evidence of a growing deficit in sanitation capacity in Surakarta during the analysed period (Table 1).

**Table 1.** Comparison of Total Diarrhea Cases and Annual Solid Waste Volume, Surakarta (2023–2024).

| Year | Total Diarrhea Cases | Volume Solid Waste (tons) | % Change (Diarrhea) | % Change (Waste) |
|---|---|---|---|---|
| 2023 | 7,209 | 135,997 | - | - |
| 2024 | 11,434 | 143,696 | +58.6% | +5.66% |

The immediate time frame of the dramatic rise in diarrhea prevalence has shown that two climatic variables were also shifted, as reported in Table 2. The greatest variation in annual rainfall was found among the environmental drivers of change. Precipitation volume increased sharply: from 1,743.40 mm in 2023 to 2,456.60 mm in 2024. This stark increase in rainfall corresponded directly with a 58.6 percent increase in total illness related to diarrhea.

For all of the variations in case numbers between 2022 and 2023 (although there was some rain variation), however, the exceptionally high precipitation volume in 2024 appears to have decisively crossed a critical ecological threshold. This occurrence directly caused severe environmental contamination, leading to a subsequent spike in disease transmission. During the study period, the average annual ambient temperature continued to warm and increase slightly (27.47 °C in 2023, 27.60 °C in 2024). The numerical effect of this temperature change is small; a long-term high temperature is critical. This persistent warmth ensures a uniformly favorable context for microbial growth and microbial proliferation and transmission of infectious threats caused by the combination of heavy precipitation and waste accumulation [7].

**Table 2.** Comparison of Total Diarrhea Cases and Climatic Variables, Surakarta (2022–2024).

| Year | Total Diarrhea Cases | Total Rainfall (mm) | Mean Temperature (°C) |
|---|---|---|---|
| 2022 | 7,422 | 130.00 | 26.85 |
| 2023 | 7,209 | 1,743.40 | 27.47 |
| 2024 | 11,434 | 2,456.60 | 27.60 |

## 4 Discussion

The findings in this ecological study strongly support the hypothesis that the dramatic 58.6% rise in diarrheal incidence in Surakarta in 2024 was a direct and severe consequence of the dual environmental burden—an unavoidable interaction between chronic sanitary failures and severe acute climatic instability. Our findings are not purely statistical results; the observed temporal co-occurrence of increases in disease cases with greater solid waste and severe precipitation represents potent evidence for environmental health models that favour systemic over single-factor explanations.

The 5.66 percent annual increase in solid waste volume was the years condition, one that would have considerably magnified the potential scope of 2024 outbreaks. Such continuously growing refuse volumes of the system are typical of the chronic incapacity of municipal sanitation infrastructure to process refuse waste [9]. From a scientific perspective, uncontrolled solid waste is more than just a non-preferred product; it also helps establish a low, stable, nutrient-rich system that serves as a long-term reservoir for enteric bacterial and viral pathogens. This accumulation results in an elevated baseline pathogen load. Also, it increases the production of mechanical vectors, which can actively promote their wide reproductive potential as they form the cross-pollination link between the contaminated drainage system in polluted water and human populations. The weak spots in the vulnerability distribution made it unevenly distributed. We observed very high case burdens in Jebres and Banjarsari, accounting for more than half of the citys cases, indicating that the citys chronic challenge had transformed into an acute neighborhood threat due to weak infrastructure, poor drainage, and proximity to waste hotspots [10]. This chronic sanitary absence laid the groundwork for an outbreak, and it took as little as a strong external event to set it in motion. These climatic variables generated the kinetic energy needed to turn this hidden pathogenic threat into tangible action. Furthermore, chronic sanitation failure, evidenced by high solid waste volumes, creates an ideal environmental reservoir for pathogens. This aligns with findings demonstrating that local environmental conditions significantly influence microbial diversity and activity [11], suggesting that waste accumulation directly contributes to the proliferation of disease-causing bacteria in the surrounding environment.

Annual precipitation increased sharply in 2024 (2,456.60 mm) at the exact time that the most significant environmental stimulus to the outbreak occurred [5]. This excessive precipitation, in turn, exceeded a global hydrological threshold and often overran Surakartas drainage and wastewater treatment system [12]. System failures led to significant surface

runoff that proactively mobilized and flushed infectious pathogens through sewers, septage, and large amounts of solid waste leachate that poured directly into critical community drinking water sources [10]. This route of contamination — the direct result of climatic stress on the vulnerable infrastructure — accounts for the population-wide spike in the city far more than a slowdown in minor pieces of the puzzle.

Further, an additional, more long-term, slightly higher mean ambient temperature (27.60 °C) was assumed to serve a second important role as a biological kickoff [6]. The role of higher temperature on microbial kinetics is clear: the rapid emergence of the most common diarrheal pathogens (e.g., E. coli and Vibrio cholerae) and the long-term persistence in water or damp environments are significantly shortened [13,14]. And then there was the combination of the extreme rainfall (a vector for transmission) and the sustained warmth (because the latter boosted the virulence of the infectious dose), which provided the perfect synergistic basis for the sweeping, volatilizing spread of disease and resulted in a 58.6% increase in case rates over and beyond anything they could achieve independently. The acute climatic instability observed in the study area, characterized by increased rainfall, is a critical regional concern. Local studies focusing on the Central Java volcanic toposequence confirm that climate change-induced uncertainty in precipitation patterns fundamentally disrupts regional systems [15], which, in the context of urban environment, exacerbates the risk of waterborne disease transmission by overwhelming hydrological infrastructure

Its consequences require a radical and aggressive revision of Surakartas public health planning strategy, moving towards an integrated environmental management system that considers both environmental burdens simultaneously [8]. The answer is that policy action is required not only to rely on two, but also to be based on two strategic pillars that cannot be broken. First, rapid and high cash inflows are crucial for upgrading urban drainage and sewerage systems as needed and for urban expansion. The infrastructure needs to have a protection buffer coverage with substantial rainfall levels well above their 2024 peak (e.g., 2,500 mm) to avoid prolonged, climate-driven water contamination. Second, urgent mandatory formalized waste processing, segregation, and high-frequency collection are necessary. Importantly, it is an action that promises to significantly reduce solid waste volume and create a continuously monitored, tightly controlled source of pathogens that will be extracted from the underlying system in time to prevent future outbreaks.

We recognized the established limitation of this study: its reliance on annual cumulative data and an ecological approach. Although such an approach can help test population-level correlations, its very nature can also preclude causal intervention at the individual patient level. However, the research will need to build on the scientific insights from this investigation, also including temporal information (monthly/weekly) to analyze delays in climatic events, waste management indicators, and disease reporting. Therefore, the insufficient response to this synergistic environmental risk will make Surakarta more susceptible to being seriously exposed to more frequent and severe disease in a rapidly evolving global climate change environment.

## 5 Conclusion

This study successfully determined the two principal environmental factors influencing the transmission risk of diarrheal disease in the study area. Chronic sanitation failure, proxied by the annual solid waste volume, establishes the necessary background risk by providing a persistent source and reservoir of pathogens, making the environment vulnerable to contamination. Superimposed on this chronic vulnerability are the essential climatic variables that act as acute drivers of disease variability. Specifically, high total rainfall triggers acute transmission spikes by overwhelming drainage and sanitation infrastructure, resulting in rapid contamination of water sources. Simultaneously, elevated mean ambient temperatures

increase the risk by accelerating pathogen proliferation in the environment and shortening the incubation periods of various waterborne pathogens, thereby increasing the overall incidence rate. Therefore, managing diarrheal disease requires a dual strategy: addressing the foundational issue of poor solid waste and sanitation management, and implementing targeted public health interventions that anticipate and mitigate the acute risks posed by extreme climatic events.

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## References

1. A. G. Miller, M. K. Miller-Petrie, R. B. Williams, C. Klohmann, B. O'Neill, J. Hess, and K. Levy, Projections of climate change-attributable diarrhea burden: a systematic review. Environmental Research Letters. **20**, 5 (2025). https://doi.org/10.1088/1748-9326/adccd8
2. J. A. Grembi, A. T. Nguyen, M. Riviere, G. B. Heitmann, A. Patil, T. S. Athni, S. Djajadi, A. Ercumen, A. Lin, Y. Crider, A. Mertens, J. M. Colford, B. F. Arnold, M. A. Karim, M. O. Islam, R. Miah, S. L. Famida, M. S. Hossen, P. Mutsuddi, S. Ali, M. Z. Rahman, Z. Hussain, A. K. Shoab, R. Haque, M. Rahman, L. Unicomb, S. P. Luby, A. Bennett, and J. Benjamin-Chung, Influence of climatic and environmental risk factors on child diarrhea and enteropathogen infection and predictions under climate change in rural Bangladesh. (2022). https://doi.org/10.1101/2022.09.26.22280367
3. E. J. Carlton, Invited Perspective: Climate Changes the Effectiveness of Water, Sanitation, and Hygiene Interventions. Environmental Health Perspectives. **132**, 4 (2024). https://doi.org/10.1289/EHP14771
4. K. F. CANN, D. R. THOMAS, R. L. SALMON, A. P. WYN-JONES, and D. KAY, Extreme water-related weather events and waterborne disease. Epidemiology and Infection. **141**, 4 (2013). https://doi.org/10.1017/S0950268812001653
5. T. Gobena and D. A. Mengistu, Impact of Climate Variability on Foodborne Diarrheal Disease: Systematic Review and Meta-Analysis. Public Health Reviews. **46**, (2025). https://doi.org/10.3389/phrs.2025.1607859
6. Y. Zhang, Q.-L. Wang, W. Peng, M.-Y. Zhang, Y. Qin, L. Zhang, R.-J. Wei, and D.-J. Kang, Interpretable machine learning analysis of environmental characteristics on bacillary dysentery in Sichuan Province. Frontiers in Public Health. **13**, (2025). https://doi.org/10.3389/fpubh.2025.1598247
7. S. B. Abegaz, K. A. Molla, and S. E. Ali, Practices and Challenges of Household Solid Waste Management in Woldia Town, Northeastern Ethiopia. Journal of Health and Pollution. **11**, 30 (2021). https://doi.org/10.5696/2156-9614-11.30.210605
8. Badan Pusat Statistik Kota Surakarta, Kota Surakarta Dalam Angka 2024 (Badan Pusat Statistik Kota Surakarta, 2024)

9. R. Anderson, P. E. Bayer, and D. Edwards, Climate change and the need for agricultural adaptation. Current Opinion in Plant Biology. **56**, (2020). https://doi.org/10.1016/j.pbi.2019.12.006
10. K. Levy, S. M. Smith, and E. J. Carlton, Climate Change Impacts on Waterborne Diseases: Moving Toward Designing Interventions. Current Environmental Health Reports. **5**, 2 (2018). https://doi.org/10.1007/s40572-018-0199-7
11. M. Sembiring, J. M. Hutahuruk, D. N. Susilowati, E. Yuniarti, T. Sabrina, and L. A. M. Siregar, Functional diversity of bacteria in various saline soil plant vegetations around Sialang Buah Coast, North Sumatra, Indonesia. SAINS TANAH - Journal of Soil Science and Agroclimatology. **21**, 2 (2024). https://doi.org/10.20961/stjssa.v21i2.80075
12. B. S. S. Wibawa, A. T. Maharani, G. Andhikaputra, M. S. A. Putri, A. P. Iswara, A. Sapkota, A. Sharma, A. D. Syafei, and Y.-C. Wang, Effects of Ambient Temperature, Relative Humidity, and Precipitation on Diarrhea Incidence in Surabaya. International Journal of Environmental Research and Public Health. **20**, 3 (2023). https://doi.org/10.3390/ijerph20032313
13. D. Paul, K. Mukherjee, J. K. Pandey, and A. Dutta Roy, Assessing the Urban Environmental Quality: A Case Study of Kolkata Metropolitan Area, India. IOP Conference Series: Earth and Environmental Science. **1164**, 1 (2023). https://doi.org/10.1088/1755-1315/1164/1/012001
14. A. B. Sekaranom, M. Fianggoro, and R. M. Wicaksono, Spatial Analysis of Rainfall Return Period and Probable Maximum Precipitation over Central Java-Indonesia in *IOP Conference Series: Earth and Environmental Science* (IOP Publishing, 2021), p. 012090
15. S. Sumani, K. Komariah, S. Suntoro, M. Mujiyo, and H. Ullah, Rainfall, drought, and irrigation in relation to crop patterns in the volcanic topo sequence of Central Java, Indonesia. SAINS TANAH - Journal of Soil Science and Agroclimatology. **22**, 1 (2025). https://doi.org/10.20961/stjssa.v22i1.87786