Carbon Footprint Analysis of Environmental Management in Slum Areas of Depok City

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ARTICLE INFO	ABSTRACT
Keywords: slums; carbon footprint; climate change mitigation; Greenhouse gas emissions	Rapid urban population growth and inadequate spatial planning often lead to the formation of informal settlements, which are vulnerable to environmental degradation and contribute to greenhouse gas (GHG) emissions. This study aims to estimate CO_2 emissions from the solid waste, wastewater, and clean water sectors in the slums of Depok City, Indonesia. Data were collected through questionnaires from 137 households and laboratory analysis of wastewater, with calculations based on specific emission factors for each sector. The analysis reveals that total annual emissions reached 76.93 tons of CO_2, with an average of 0.17 tons per person per year. The results are broken down by sector as follows: solid waste accounts for the largest portion of emissions at 72.63%, followed by wastewater at 21.08%, and clean water supply at 6.29%. These findings underscore the significant role of inadequate environmental management in slum areas in contributing to GHG emissions. The study emphasizes the critical need for targeted improvements in waste and wastewater management infrastructure and practices. Implementing sustainable environmental management strategies is essential to support climate change mitigation efforts and enhance the resilience of urban informal settlements, thereby contributing to the achievement of Sustainable Development Goal 11.

Introduction

The high rate of urbanization that is not balanced with the fulfillment of the needs for adequate basic facilities and infrastructure has the potential to cause slums (Jones, 2017; Olthuis, Benni, Eichwede, & Zevenbergen, 2015; Rizvi, 2018; Trindade, MacLean, & Posen, 2021; Uddin, 2018). According to Law No. 1 of 2011, concerning Housing and Residential Areas, slums are uninhabitable settlements due to building irregularities, high levels of building density, and the quality of buildings and facilities and infrastructure that do not meet requirements, such as the low quality of drinking water services (Giama, Giama, Papadopoulos, & Papadopoulos, 2018; Kausar, Rasul, & Asghar, 2024; Pavolini, Gauly, Tasser, & Sabia, 2019; Rosa, Lunkes, Codesso, Mendes, & Costa, 2024; Rouhi, Motlagh, & Dalir, 2023).

In the 2030 agenda for sustainable development, which is a global and national commitment in an effort to prosper the community, with 17 global goals and objectives that have been declared by developed and developing countries at the UN General Assembly in

September 2015, included in the 11th SDGs (Sustainable Development Goals) goals, namely sustainable cities and settlements. Of course, this set of goals is interrelated and supportive to overcome the various global challenges we face, especially to make cities and settlements inclusive, safe, resilient, and sustainable, particularly in the face of climate change that is very urgent today (Abubakar & Aina, 2019; Habitat, 2018; Jaramillo, 2020; Mukim & Roberts, 2023; Satterthwaite, 2016).

Several studies have addressed carbon footprint analysis in urban contexts, though with varying focuses. Adnan et al. (2018) conducted consumption-based carbon footprint analysis in slum and non-slum areas of Rawalpindi, highlighting significant disparities linked to income and infrastructure. Allinson et al. (2016) measured household carbon in a UK city, emphasizing energy use, while Friedrich & Trois (2016) focused on GHG emissions from municipal solid waste management in South Africa. In Indonesia, studies such as Astari (2012) and Rosesar (2020) have analyzed carbon footprints in urban settlements, but these have not specifically quantified emissions from integrated environmental management systems—covering waste, wastewater, and clean water—within slum areas.

As is well known, greenhouse gas emissions are the main triggers of global temperature changes, increasing the frequency of natural disasters and changes in weather patterns that are no longer regular. Greenhouse gases, such as carbon dioxide (CO2) and methane (CH4), have a major impact on global warming as well as environmental quality (Filonchyk, Peterson, Zhang, Hurynovich, & He, 2024; Jogdand, 2020; Kumar, 2018; Rouhi et al., 2023; Yoro & Daramola, 2020). Saleem et al. (2019) stated that energy consumption significantly increases the ecological footprint and greenhouse gas emissions. In addition, poor environmental conditions and lack of infrastructure exacerbate the impacts of climate change, increasing the risk of disease and GHG emissions (Damte et al., 2023).

Although slums contribute to and are significantly affected by greenhouse gas emissions, specific data on the amount of their contribution is still very limited. Until now, research that directly focuses on reducing GHG emissions in slums is still minimal, especially at the urban level. Even basic information related to GHG emissions as a whole in Depok City is not yet available. As one of the capital city buffer cities undergoing very rapid population growth and urbanization, Depok City was chosen as the study location.

In addition, the City of Depok has shown a commitment to supporting the sustainable development agenda and climate change control, which is reflected in various regional strategic planning documents. This commitment can be seen, among others, in the Depok City RPJMD for 2021-2026, which explicitly contains the direction of the environmentally sound development policy and strategies for improving the quality of basic infrastructure, including wastewater and waste management (Depok City Government, 2021). Furthermore, in the Living Environment Protection and Management Plan (RPPLH) document, the Depok City Government stipulates integrated environmental protection efforts through the identification of carrying capacity and environmental tamping capacity as well as emission control and planning (Depok City Government, 2020). In addition, through the Depok City Smart City Masterplan, commitment to the environment is strengthened through the development of a smart environment concept that includes energy efficiency, the use of green technology, and the reduction of carbon emissions towards a climate-resilient city (Depok City Government, 2019).

Therefore, this study aims to estimate GHG emissions specifically from the wastewater treatment sector, clean water supply, and waste management in slums in Depok City. The results of this research are expected to be the basis for formulating recommendations for mitigation strategies that are applicable and contextual, in order to reduce negative impacts on the environment, improve people's quality of life, and support the achievement of low-carbon development that is climate-resilient.

The findings of this study are expected to provide benefits to local communities through environmental education, assist policymakers in designing targeted interventions, and serve as a reference for future academic research. In addition, this study also contributes to the achievement of Sustainable Development Goals (SDGs) 11 on inclusive, safe, resilient, and sustainable cities and settlements. The research focused on informal settlements in RT 3 RW 14, Depok Village, which includes three environmental sectors: solid waste management, clean water consumption, and household wastewater treatment. Solid waste refers to domestic waste, while clean water includes daily activities such as drinking, bathing, washing, sanitation, as well as waste treatment systems such as black water and grey water.

Research Method

The data collection in this study used primary and secondary data sources. Data on solid waste generation was obtained from the Depok City Waste Management Master Plan (2024), with the generation rate for low-income people recorded at 0.43 kg/person/day. Wastewater data were collected through direct sampling of domestic wastewater (greywater) in secondary drainage channels at the three study sites, as communal wastewater treatment plants (WWTPs) were not available. The samples were analyzed to determine the Biochemical Oxygen Demand (BOD) value, which was then used as the basis for calculating CO_2 emissions.

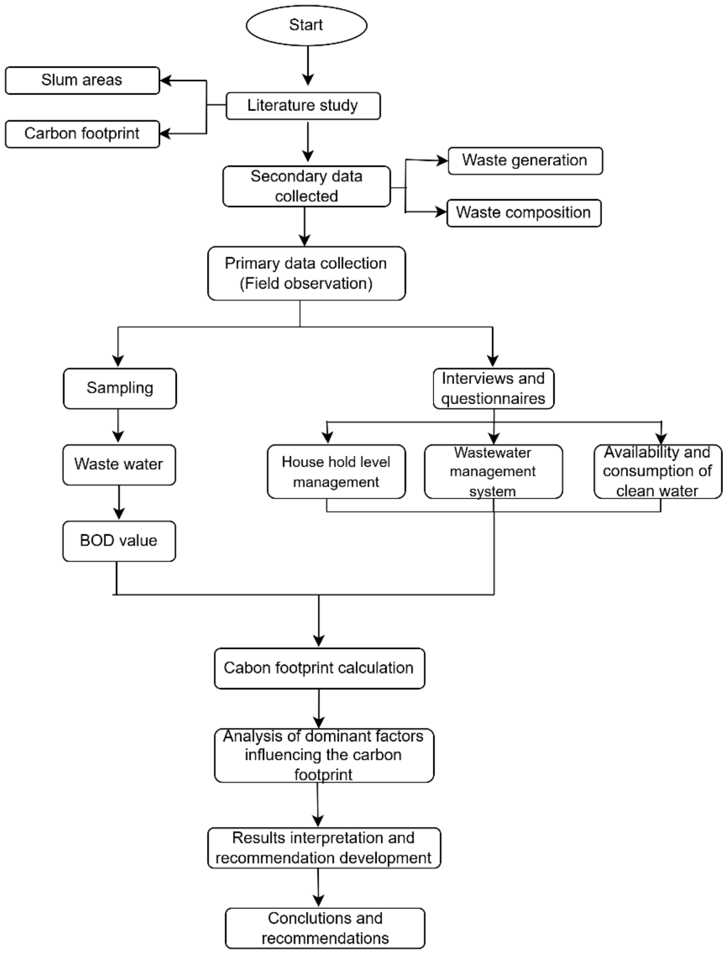


Figure 1. Research flowchart
[Source: Author's Analysis, 2025]

Clean water consumption data was collected through household questionnaires to find out the volume of water use, water sources, and energy consumption for water pumping. In addition, interviews and questionnaires were also conducted with residents of RT 3 RW 14 to collect information on solid waste management practices, clean water, and wastewater, as well as household socio-economic conditions. This data provides a representative picture of the current environmental conditions in the slums studied.

The door-to-door survey method is applied thoroughly or census. The location in Depok Village was chosen because it represents a slum area with high population density, limited infrastructure, and the existence of informal housing. A total of 137 households are considered very relevant because they are located in the city center but show striking social and environmental inequalities.

Data analysis combines descriptive and quantitative approaches. Descriptive analysis is used to describe the characteristics of settlements, while quantitative analysis is applied to calculate CO_2 emissions from domestic activities. Emissions are estimated by converting solid waste generation, BOD values, and clean water consumption into CO_2 equivalent using emission factors from the IPCC and national sources. The results are used to compare emission burdens between locations, identify the largest emission contributing sectors, and evaluate the relationship between socioeconomic characteristics and environmental practices, so that they can be the basis for formulating targeted emission mitigation strategies.

In this study, the calculation of GHG emissions uses emission factor values based on previous research. Primary data on waste generation was obtained through sampling carried out in accordance with the Indonesian National Standard (SNI) No. 19.3964-1994 by the team that drafted the Waste Management Master Plan document issued in Mayor Regulation Number 39 of 2024. Carbon emissions from waste generation are then calculated using emission factors that refer to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, especially Volume 5: Waste, Chapter 3 – Solid Waste Disposal, using the default emission factor (FE) that has been set by the IPCC (IPCC, 2006). In addition, wastewater data is collected through sampling at each location and BOD values are measured using the methods listed in SNI No. 6989.72:2009. This BOD value is then used to calculate carbon emissions by multiplying the domestic wastewater emission factor from the IPCC by 0.6 kg CH4 per kilogram of BOD.

Meanwhile, the calculation of CO_2 emissions from the clean water sector is carried out based on the average amount of household water consumption, which includes bottled drinking water, refillable water, and water for bathing, washing, and toilet (MCK) purposes. Emissions are calculated taking into account the electricity consumption in the process of extraction, in particular if water is obtained through an electric pump. However, not all households use electrical energy to obtain clean water. Some households use water sources that do not require electrical energy, such as dug well water with manual pumps. In such cases, CO_2 emissions are calculated based on total water usage. Therefore, the calculation approach is adjusted to the type of water source used by households to ensure more accurate and contextual emission estimates. Interviews were conducted with households at the research site, and the resulting data was multiplied by each emission factor.

Results and Discussion

Overview of Study Locations and Interview Results

This location is an area that reflects the dynamics of the urban environment with various social and physical characteristics. The number of respondents was 137 houses (449 people in total) that developed on the land that was commensurate. Most houses are built in stages by the community, who generally pay rent for land use to the 'cultivators'. The settlements in the area are dense, with houses built irregularly using simple materials such as zinc, wood, asbestos and plywood. This condition is in stark contrast to the life of the capital's buffer city which is orderly and orderly.

Figure 2 Contrasting portrait of the settlement
[Source: Personal documentation]

This slum located in the middle of Depok city, is directly adjacent to government buildings and modern apartments. A striking contrast can be seen from the physical condition of the dense and disorganized buildings amidst the hustle and bustle of a modern and organized city center, this area shows the socio-economic reality of low-income people who still face limitations in meeting the needs of a decent life. This area is 61% inhabited by people with identities outside Depok with diverse ethnic backgrounds, including Javanese, Sundanese, and Betawi, with a middle to lower economic level and the majority of the population works as scavengers who depend on the collection and sale of used goods. This scavenger activity is not only the main source of livelihood, but also reflects the socio-economic conditions of residents who still face limitations in access to formal jobs.

The results of interviews on household waste management in RT 3 RW 14 Depok Village show that waste produced by households is not managed formally. The waste produced is not sorted, the waste is collected in containers in the form of buckets or plastic or small sacks near the house and then transported by waste officers with personal payment. However, there are also people who dispose of their garbage by taking it to the nearest polling station, namely the TPS in the Depok Jaya Market or the Jalan Baru TPS, and there are even people who burn their garbage.

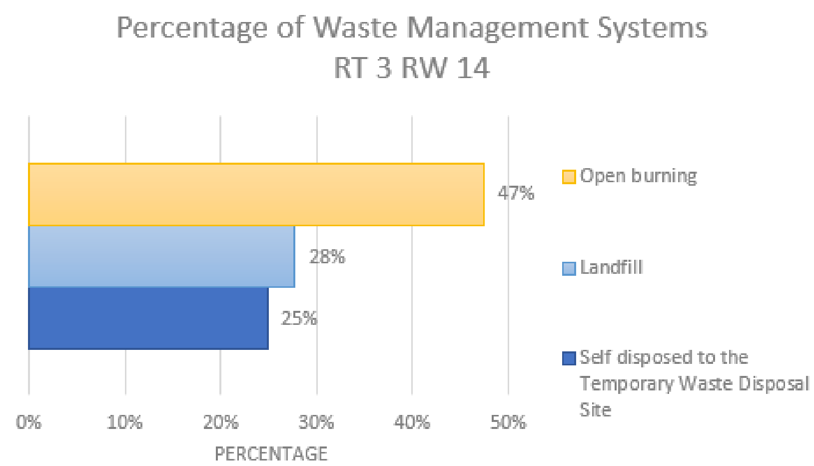
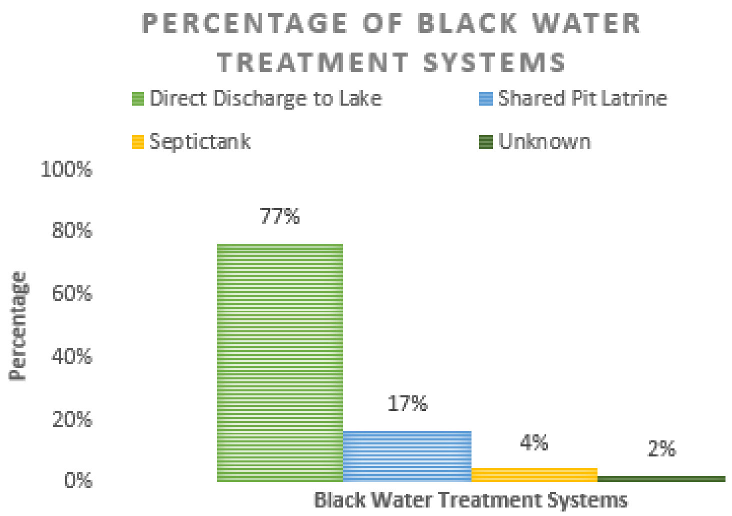


Figure 3 Household waste management system RT 3 RW 14, Depok Village
[Source : Questionnaire]

The high percentage of waste burning practices reflects low access and awareness of environmentally friendly waste management systems. This practice not only causes air pollution, but also has the potential to endanger the health of the surrounding community. These findings reinforce the characteristics of unorganized settlements, with a lack of basic services, including in terms of waste management.

In this study, the wastewater in question refers to wastewater that comes from domestic or household activities. This wastewater is categorized into two types, namely wastewater from toilets or black water and non-toilet wastewater or grey water. Domestic wastewater in the form of grey water is drained through an open channel from concrete that empties into a water body, or is directly discharged into Situ Rawa Besar without going through a processing process first.



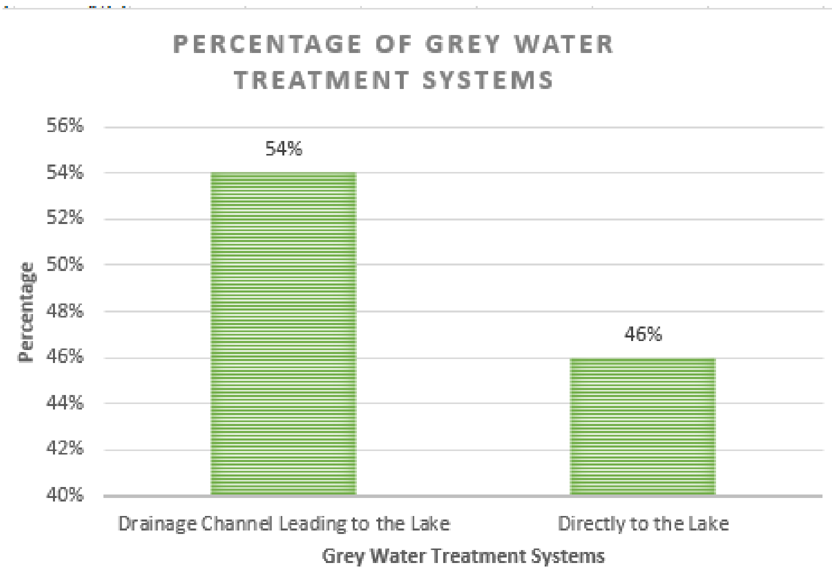


Figure 4 Diagram of *black water* and *grey water* system RT 3 RW 14, Depok Village
[Source : Questionnaire]

Based on the results of the questionnaire asked to residents in the study area, the majority of respondents did not have an adequate domestic liquid waste treatment system. Grey water, which comes from washing, bathing, and kitchen activities, is generally directly drained into an open channel without going through a processing process first. Around 54% of respondents stated that liquid waste from their homes flows directly into the environmental drainage and 46% is directly discharged into the nearest water body, namely Situ Rawa Besar.

Meanwhile, for black water, some respondents stated that they already had private toilet facilities at home. However, of all respondents who have a toilet, only about 4% stated that their sewer system is connected to a septic tank. Furthermore, the septic tank has never been drained since it was first made, which shows the weak maintenance practices of sanitation facilities. This raises concerns about the potential for environmental pollution, both to the soil and water bodies, due to the possibility of fecal waste seepage from a properly managed septic system. These findings confirm the low implementation of safe and sustainable domestic wastewater management systems in the study area. Without regular treatment or draining, septic tanks can actually become a new source of pollution, as well as increase the risk of spreading waterborne diseases.

Others still use latrine systems that directly drain sewage into rivers, open channels, or untreated water bodies, indicating low access to safe sanitation. This condition reflects that the wastewater management system in the area is still on-site and has not been integrated. A sample test of grey water wastewater has been carried out at this location through Depok City DLHK Laboratory officers.

Figure 5 Water sampling in RT 3 RW 14, Depok Village
[Source: Personal documentation]

The absence of grey water treatment and the use of improper black water disposal systems certainly contribute to environmental pollution, especially to the quality of surface water around the area, as can be seen from the results of the following laboratory checks:

Table 1 Wastewater Quality RT 3 RW 14 Depok Village

Parameter	Unit	Standard Limit	Laboratory Test Results
Physical			
TSS	mg/L	30	8,4
Chemical			
pH		6-9	6,98
Amonia	mg/L	10	1,7
BOD	mg/L	30	29,1
COD	mg/L	100	47,3
Biological			
Total Coliform	MPN/100ml	3000	$1,7 \times 10^{6}$
Fecal Coliform	MPN/100ml	$3,5 \times 10^{4}$	Standard I : 100 Standard II : 1.000 Standard III : 2.000 Standard IV : 2.000

[Source : Laboratory Test Results]

Most physics and chemical parameters show results that meet quality standards or are below the specified limits. However, the biological parameters (Total Coliform) still exceed the threshold, so there is a need for additional treatment processes to reduce the bacterial content before wastewater is discharged into the environment. Poorly managed fecal waste has the potential to pollute the environment, especially surface water sources and groundwater. One of the main indicators of the presence of fecal waste in water is total coliforms, which are groups of bacteria that naturally live in the digestive tract of humans and animals. High concentrations of total coliform in water indicate the presence of biological contamination that generally comes from direct fecal disposal or from sanitation systems that do not meet technical standards, such as septic tanks that are not impermeable or never drained. The presence of high total coliform also has the potential to be an indicator of the presence of other pathogenic microorganisms that can pose public health risks.

In addition, situ water quality testing was also carried out using fecal coliform parameters as an indicator of microbiological pollution. The test results showed that the fecal coliform content in the situ water reached 35,000 MPN/100 mL, which significantly exceeded the water quality standard threshold according to Government Regulation No. 22 of 2021 for Class II (direct contact water recreation) of 1,000 MPN/100 mL.

This value indicates that the water has been heavily contaminated by fecal waste, which is suspected to have come from domestic wastewater discharge without prior treatment from surrounding settlements. This condition not only reduces the quality of aquatic ecosystems, but also increases the risk of exposure to waterborne diseases, especially for people who are active around it. These findings reinforce the urgency of the need to improve sanitation systems and the arrangement of residential areas, especially in border areas, to reduce the burden of pollutants while reducing the potential for greenhouse gas emissions from the wastewater sector.

The source of clean water used by the people in this region comes from groundwater, which is generally obtained through the use of 84% of mechanical pumped wells and 16% of the use of electric pump wells. There is no PDAM network in this area yet.

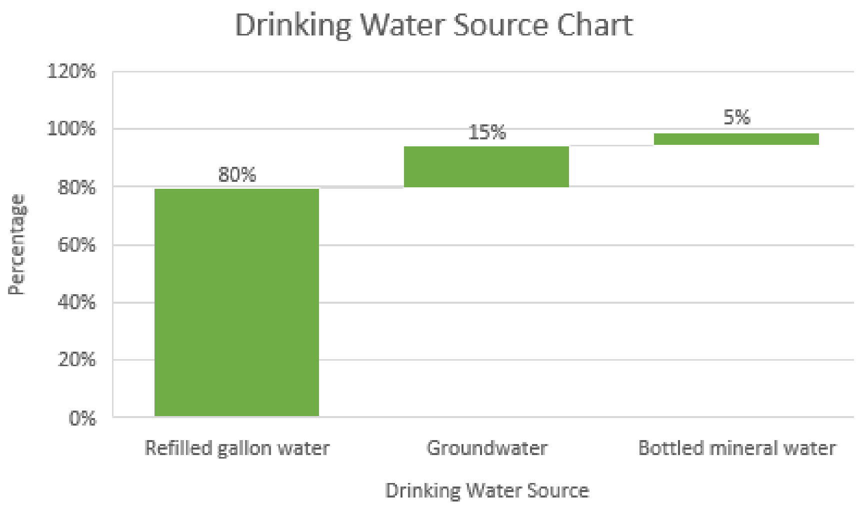


Figure 6 Graph of household drinking water sources in RT 3 RW 14, Depok Village
[Source : Questionnaire]

Based on the Waste Management Master Plan (2024) by the Depok City DLHK, the waste generation rate for low-income households is 0.43 kg/person/day or 2.97 liters/person/day. With a total population of 449 people, waste-related emissions are calculated as follows.

Table 2 Emission Calculation

No	Emission Source	Type of Waste Management	Emission Factor		Unit	Waste Weight (ton/year)	Total Emissions ($kgCO_2eq/year$)
			CH_4	600	kg CH_4 per ton MSW		
			CO_2	Insignificant	kg CO_2 per ton MSW		

1	Waste management	Landfill	N_2O	1	kg C_2O per ton MSW	37,35	**22.446,98**
			Total	601	kg CO_2 per ton MSW		
		Open burning	CH_4	801,2	kg CH_4 per ton MSW	33,12	**33.399,38**
			CO_2	162,5	kg CO_2 per ton MSW		
			N_2O	44,7	kg C_2O per ton MSW		
			Total	1.008,4	kg CO_2 per ton MSW		
2	Transportation emissions from waste collection	House hold – Temporary Waste Disposal Site	CO2	69.300	(kg/TJ)	36,5	**28,78**
			N2O	3,2			
			CH4	33			
		Temporary Waste Disposal Site - Landfill	CO2	74.100			
			N2O	3,9			
			CH4	3,9			
			Emission Factor		Water Consumption		**Total Emissions ($kgCO_2eq$/year)**
3	Clean water management		0,59 kg CO_2/m^3		8.194,25	m3/year	**4.834,61**
4	Waste water management		Black water + Grey water				**16.221,01**
						Total	**76.930,76**

The results of the estimated total carbon footprint in RT 3/14 show that the waste management sector is the main contributor to carbon emissions with a value of 55,875.14 kg of CO_2e per year. This figure is much higher than the wastewater management sector (16,221.01 kg CO_2e per year) and the clean water management sector (4,834.61 kg CO_2e per year). In total, RT 3/14 produces 76,930.76 kg of CO_2e emissions per year, with the largest contribution reaching more than two-thirds coming from waste management activities.

The dominance of emissions from the waste management sector in RT 3/14 reflects the high dependence of the community on the practice of open burning and disposal of waste without an adequate management system. This is in line with the general phenomenon in dense and slum areas, where the limitations of formal waste management services encourage people to manage waste independently in an environmentally unfriendly way. These conditions have serious implications for air quality, public health, and contribution to greenhouse gas emissions.

Meanwhile, emissions from the wastewater and clean water management sectors are relatively lower, but still significant. The wastewater management sector produces methane and CO_2 emissions from domestic waste disposal processes, while the clean water management sector is concerned with the use of energy in the water distribution and consumption process. Although the portion is smaller, these two sectors still need to be considered as part of an integrated emission reduction strategy.

Conclusion

The total annual emissions amounted to 76,930.76 kg of CO_2e, predominantly from waste management at 55,875.14 kg of CO_2e, largely due to informal disposal practices in illegal settlement areas lacking formal waste services. Inadequate wastewater management further increased emissions and degraded site quality, as shown by high fecal coliform levels. Addressing these issues requires relocating settlements to enable integrated waste and wastewater management systems. Priority should be given to strengthening community-based waste management initiatives like sorting, composting, and waste banks, supported by policies to facilitate relocation or legalization. Future research could focus on evaluating the effectiveness and social impact of such relocation and community-led waste interventions, exploring sustainable models tailored to informal settlements.

References

Abubakar, I. R., & Aina, Y. A. (2019). The prospects and challenges of developing more inclusive, safe, resilient and sustainable cities in Nigeria. *Land Use Policy, 87*, 104105.

Adnan, M. N., Safeer, R., & Rashid, A. (2018). Consumption-based approach of carbon footprint analysis in urban slum and non-slum areas of Rawalpindi. *Habitat International, 73*, 16–24.

Allinson, D., Irvine, K. N., Edmondson, J. L., Tiwary, A., Hill, G., Morris, J., et al. (2016). Measurement and analysis of household carbon: The case of a UK city. *Applied Energy, 164*, 871–881.

Badan Pusat Statistik Indonesia. (2016). *Potret awal tujuan pembangunan berkelanjutan: Mengakhiri kelaparan, kesetaraan gender, pekerjaan layak dan pertumbuhan ekonomi (Sustainable Development Goals) di Indonesia.* Badan Pusat Statistik Indonesia.

Baker, J. L. (2008). *[Data tidak lengkap, mohon lengkapi judul sumber jika diperlukan.]*

Filonchyk, M., Peterson, M. P., Zhang, L., Hurynovich, V., & He, Y. (2024). Greenhouse gases emissions and global climate change: Examining the influence of CO_2, CH_4, and N_2O. *Science of The Total Environment, 935*, 173359.

Friedrich, E., & Trois, C. (2016). Current and future greenhouse gas (GHG) emissions from the management of municipal solid waste in the eThekwini Municipality, South Africa. *Journal of Cleaner Production, 112*, 4071–4083.

Giama, E., & Papadopoulos, A. M. (2018). Carbon footprint analysis as a tool for energy and environmental management in small and medium-sized enterprises. *International Journal of Sustainable Energy.* https://doi.org/10.1080/14786451.2016.1263198

Habitat, U. N. (2018). *Tracking progress towards inclusive, safe, resilient and sustainable cities and human settlements: SDG 11 Synthesis Report—High Level Political Forum 2018.*

Jaramillo, L. G. (2020). Make cities and human settlements inclusive, safe, resilient and sustainable. In *Mining, materials, and the Sustainable Development Goals (SDGs)* (pp. 99–116). CRC Press.

Jogdand, O. K. (2020). Study on the effect of global warming and greenhouse gases on environmental system. In *Green chemistry and sustainable technology* (pp. 275–306). Apple Academic Press.

Jones, P. (2017). Formalizing the informal: Understanding the position of informal settlements and slums in sustainable urbanization policies and strategies in Bandung, Indonesia. *Sustainability, 9*(8), 1436.

Kausar, A., Rasul, F., & Asghar, N. (2024). How to get green with agricultural footprint: A global analysis of carbon emissions, environmental taxes, and agrochemical use. *Journal of Environmental Management.* https://doi.org/10.1016/j.jenvman.2024.122665

Kumar, A. (2018). Global warming, climate change and greenhouse gas mitigation. In *Biofuels: Greenhouse gas mitigation and global warming: Next generation biofuels and role of biotechnology* (pp. 1–16). Springer.

Mukim, M., & Roberts, M. (2023). *Thriving: Making cities green, resilient, and inclusive in a changing climate.* World Bank Publications.

Olthuis, K., Benni, J., Eichwede, K., & Zevenbergen, C. (2015). Slum upgrading: Assessing the importance of location and a plea for a spatial approach. *Habitat International, 50*, 270–288.

Pavolini, M., Gauly, M., Tasser, E., & Sabia, E. (2019). *Carbon footprint analysis of South Tyrolean Grey Alpine dairy cows based on two different concentrate levels in the diet* [Master's thesis, University of Bozen-Bolzano]. Retrieved from https://www.semanticscholar.org/paper/56b9df91053c2f923eddaddb40a753f765cd2036

Rizvi, Z. M. (2018). Urbanization, slum growth and the challenges posed by a low-income habitat. *Housing Finance International, 3*, 39–43.

Rosa, F., Lunkes, R. J., Codesso, M., Mendes, A., & Costa, G. (2024). Effects of green innovation ecosystem coopetition, environmental management practices and digital innovation on carbon footprint reduction. *International Journal of Contemporary Hospitality Management.* https://doi.org/10.1108/ijchm-01-2024-0021

Rosesar, J. S. (2020). *Analisis jejak karbon di perkampungan kumuh kota: Studi kasus Kampung Markisa, Kampung Cimone, Kampung Gedongpompa, dan Kampung Cikini Kramat.*

Rouhi, K., Motlagh, M. S., & Dalir, F. (2023). Developing a carbon footprint model and environmental impact analysis of municipal solid waste transportation: A case study of Tehran, Iran. *Journal of the Air & Waste Management Association.* https://doi.org/10.1080/10962247.2023.2271424

Satterthwaite, D. (2016). Successful, safe and sustainable cities: Towards a New Urban Agenda. *Commonwealth Journal of Local Governance, 19*, 3–18.

Trindade, T. C. G., MacLean, H. L., & Posen, I. D. (2021). Slum infrastructure: Quantitative measures and scenarios for universal access to basic services in 2030. *Cities, 110*, 103050.

Uddin, N. (2018). Assessing urban sustainability of slum settlements in Bangladesh: Evidence from Chittagong city. *Journal of Urban Management, 7*(1), 32–42.

Yoro, K. O., & Daramola, M. O. (2020). CO_2 emission sources, greenhouse gases, and the global warming effect. In *Advances in carbon capture* (pp. 3–28). Elsevier.