Identification and Quantification of Nitrogen Flow in the Sanitation System of the Identity Territory of Southernmost Bahia

Nicole Príncipe C. da Silva[1]*, Francisco Ramon Nascimento[1], Karla Esquerre[1]
[1]Federal University of Bahia, UFBA; Salvador, Bahia, Brazil

Sewage is a rich source of nitrogen, phosphorus, and potassium, and its efficient management can reduce pollution, promote sustainable water use, and enable its use as fertilizer. Material Flow Analysis (MFA) has been effective in managing these nutrients within the sanitation system. This study conducted a Nitrogen Flow Analysis (NFA) in the Identity Territory of the Southernmost Region of Bahia (TI07) for 2022, revealing that 46.31% of the sewage is discharged directly into the hydrosphere, possibly contaminating water bodies. Therefore, technologies such as vermifilters and green septic systems are recommended for treating sewage and recycling nitrogen for use as fertilizer or in food production. The NFA also showed that waste management accumulated 23.49% of the system's total nitrogen, highlighting the potential for composting, fertilizer supply, and strengthening local family farming.
Keywords: MFA. Nutrients. Environmental Management.

The composition of sewage is primarily feces, urine, and gray water, with urine being the primary source of nutrients (80% of nitrogen, 55% of phosphorus, and 60% of potassium) [1,2]. This means that the sanitation system is a rich source of nutrients, whose efficient management can bring benefits across a broad spectrum of applications. The recovery of nutrients from feces and urine aligns with the concept of ecological sanitation, contributing to the rational use of water, reducing pollution of water resources, and also having potential use as fertilizer.

To manage the nutrients present in the sanitation system, such as nitrogen, Material Flow Analysis (MFA) provides a comprehensive and consistent set of information on all flows and stocks within the system. Therefore, it has proven to be a highly relevant tool for assisting in decision-making, especially in environmental management and the formulation of public policies aimed at the environment [3].

Considering the increasing amount of nitrogen fertilizer imports in recent years to meet the agricultural systems in Bahia, this study aimed to conduct a Nitrogen Flow Analysis (NFA) in the sanitation system of the Identity Territory of the Southernmost Region of Bahia (TI07) for the base year of 2022. The analysis focused on identifying and quantifying primary nitrogen inflows and outflows, evaluating key opportunities for nutrient recovery, and assessing the potential environmental impacts associated with their losses, according to the types of sanitation systems used by local households.

Materials and Methods

Study Area

The scope of the problem encompasses 13 municipalities in TI07 – Southernmost Region of Bahia, as indicated in the State Solid Waste Plan of Bahia (PERS/BA), which includes the municipalities of Alcobaça, Caravelas, Ibirapuã, Itamaraju, Itanhém, Jucuruçu, Lajedão, Medeiros Neto, Mucuri, Nova Viçosa, Prado, Teixeira de Freitas, and Vereda. The TI07 region covers an approximate area of 18,538 km² and is notable for its production of coffee, sugarcane, papaya, and cow's milk. Caravelas, Itanhém, Jucuruçu, Lajedão, Prado, and Vereda are the municipalities where agriculture and livestock are the sectors that contribute the most to the local GDP.

Received on 18 March 2025; revised 21 May 2025.
Address for correspondence: Nicole Príncipe C. da Silva. Prof. Aristídes Novis, 2 - Federação, Salvador, Bahia, Brazil. Zipcode: 40210-630. E-mail: nicoleprincipe@gmail.com.

J Bioeng. Tech. Health 2025;8(3):299-304

Flows and Processes

The NFA of TI07 corresponds to the region's sanitation system, characterized by internal processes that involve the input of nitrogen through food consumption, as well as activities related to the management of human excreta and organic solid waste. The study system involves ten processes within the sanitation system, three stocks, and 24 flows. The detailed NFA is shown in Figure 1 in the Results and Discussion section.The execution of the NFA will be carried out using the free software SubSTance Flow ANalysis (STAN), which helps create a graphical representation of the mathematical model and, as the final product, presents the Sankey diagram, facilitating the visual understanding of the substance flows.

Data Collection

For the nitrogen input flow contained in the food consumed by the population of TI07, data from the 2017 Household Budget Survey (POF) were used, supplemented with information on food consumption outside the home [4]. The nitrogen content of these foods was calculated based on the Brazilian Food Composition Table (TBCA 7.2). Sanitation data was obtained from the 2022 Census via the IBGE Automatic Recovery System (SIDRA), and information on Sewage Treatment Plants (STE) came from the 2020 Sewage Atlas (ANA). As for solid waste, the data was extracted from PERS/BA, with primary data collection carried out in the municipalities of Ibirapuã, Jucuruçu, Lajedão, and Vereda between 2020 and 2021, and secondary data from PAC 2 diagnostics, from 2018 and 2019, provided by the Urban Development Company of the State of Bahia (CONDER).

Nitrogen Content of Flows

The conversion of the protein content of foods from the POF into the amount of nitrogen was calculated by dividing the percentage of crude protein in the food by the nitrogen-to-protein conversion factor from Jones. For calculating the nitrogen content in solid waste flows, a percentage of 2.6% of the organic matter in the municipal solid waste (MSW) was adopted [5]. For determining the nitrogen content in feces and urine flows, values of 1.8 g N/ N/person/day and 11 g N/ N/person/day were used, respectively [6].

Uncertainty Assessment

The uncertainty assessment was based on a method involving sensitivity analysis of the data and the enhancement of established techniques, such as the pedigree matrix and the HS method, for characterizing uncertainty in Material Flow Analysis (MFA) [7].

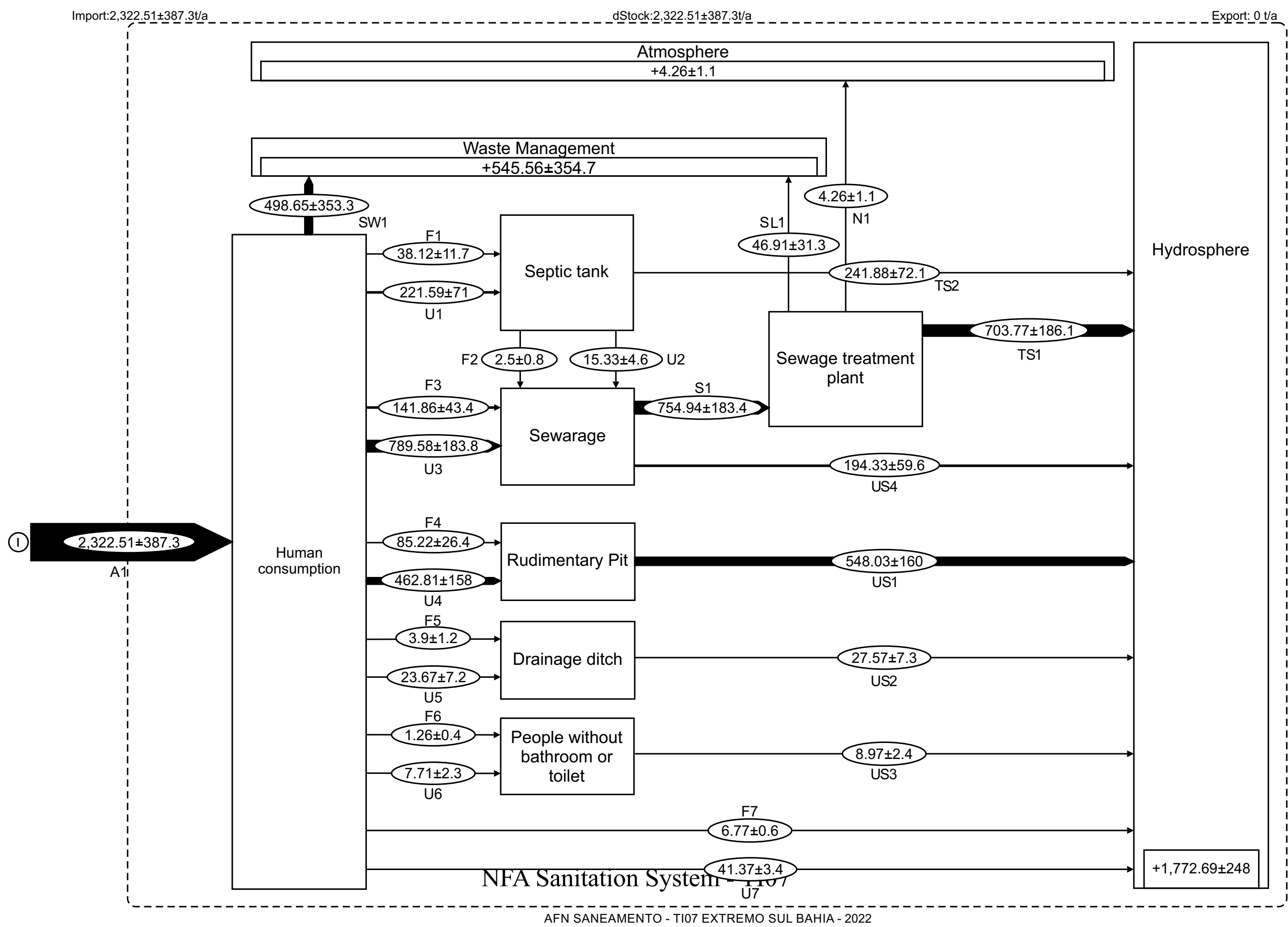
Results and Discussion

The nitrogen balance for the sanitation system of TI07 in the base year 2022 is depicted in Figure 1. This balance reveals that the total nitrogen content in the food consumed by the TI07 population amounted to 2322.51 ± 387.3 t·year^{-1}.

Out of this total, 498.65 ± 353.7 t·year^{-1} was lost as organic waste, which, under the current waste management practices in the region, is disposed of in three active landfills or open dumps. The nitrogen output from the Human Consumption process that was directed into the sanitation system corresponds to 78.53% of the remaining amount.

The flows of feces and urine were distributed according to the categories of excreta management technology adopted by each household, as per the IBGE. The types of sanitation responsible for the largest nitrogen flows into the hydrosphere are general sewerage (53.54%); rudimentary pits (30.92%); and septic tanks not connected to the sewage network (13.64%). The nitrogen fractions resulting from excreta disposed of in drainage ditches (1.56%) or directly into the hydrosphere (2.72%) are significantly smaller. The percentage of nitrogen from sewage generated by the population that reported not having a bathroom is

Figure 1. Nitrogen balance for TI07, base year 2022 - Sanitation System.



the lowest of all, corresponding to 0.51% of the total nitrogen flow discharged into the hydrosphere. Nitrogen from feces and urine flows directed to the general sewerage system is partially treated at the region's four active sewage treatment plants (STPs), located in Caravelas, Itamaraju, Mucuri, Nova Viçosa, and Teixeira de Freitas (754.94 ± 183.4 t·year-1 of N). In contrast, the remaining portion (194.33 ± 59.6 t·year-1) is discharged untreated into water bodies. The nitrogen output from the STPs follows three potential pathways: discharge into the hydrosphere after effluent treatment (703.77 ± 186.1 t·year-1 of N); final disposal of sewage sludge in waste management areas (46.91 ± 31.3 t·year-1 of N); and atmospheric emissions of N2O (4.26 ± 1.1 t·year-1 of N).

When it comes to the discharge of treated sewage into water bodies, only the municipalities of Caravelas, Itamaraju, Mucuri, Nova Viçosa, and Teixeira de Freitas treat part of their sewage through STPs, accounting for 39.70% of the nitrogen released into the hydrosphere. The Itamaraju STP channels its effluents into the Jucuruçu River, the Mucuri STP into the Mucuri River, and the Teixeira de Freitas STP into the Itanhém River. In Caravelas, effluents are directed to the Caravelas River, while in Nova Viçosa, they are sent to a tributary of the Peruípe River. The nitrogen from sewage treated by these STPs could potentially be used in irrigated agriculture, as studies in Brazil have demonstrated the feasibility and effectiveness of such applications

[8]. However, it is essential to evaluate the current conditions of these STPs before implementing any irrigation systems.

A persistent issue in municipalities is the overflow of sewage onto the streets, leading to problems such as foul odors and the proliferation of disease-carrying vectors. Furthermore, numerous points in the region discharge untreated sewage. A recent study conducted at 12 locations within the Water Planning and Management Region (RPGA), which encompasses the TI07 municipalities, found that although the Water Quality Index (IQA) is generally considered good, the Itanhém, Jucuruçu, and Peruípe river basins showed elevated levels of ammonia at some monitoring sites, according to the standards set by CONAMA Resolution 357/2005 [9]. These high ammonia levels are directly associated with sewage discharges and land use practices in the basins [10]. Runoff from fertilizers and soil leaching are among the primary sources of these pollutants. It is crucial to note that nitrogen in the form of free ammonia is highly toxic to fish [8].

To address the issue of raw sewage being discharged directly into the hydrosphere, alternative solutions to traditional septic or rudimentary pits can be considered, such as green cesspools and vermifilters. The green cesspool is a buried and waterproofed basin with filtering layers covered by soil, where plants like banana trees, taro, or lily of the valley are cultivated [11]. Vermifilters, on the other hand, function as aerobic filters that do not produce sludge and require no energy, yet they offer performance comparable to conventional treatment systems [12,13]. The humus generated by the vermifilter can serve as a nutrient source for fertilization, though it is not advisable for use in vegetable gardens. However, the food and leaves produced in green cesspools remain uncontaminated and safe for human consumption [11].

It is worth noting that a portion of the TI07 population reported not having access to a bathroom. A practical solution to this issue could be the implementation of dry toilets, which are a low-cost and easy-to-install alternative [14]. In these toilets, urine and feces are separated by a specialized toilet bowl. The feces are directed to composting for use as fertilizer. At the same time, the urine is stored for approximately a month before being utilized as a source of nitrogen and potassium for perennial, fruit, or annual crops [15]. Regarding nitrogen flows beyond excreta, food waste also accounts for a significant portion of the system's nutrients, representing 21.47%.Domestic composting of organic waste can significantly reduce the volume of urban solid waste collected, leading to cost savings, reduced material usage, and lower energy consumption for infrastructure, while also conserving landfill space and extending the operational lifespan of landfills [16,17]. The compost produced is an organic material rich in micronutrients, which can be used as fertilizer, supporting local family farming or recycling nutrients back into the soil [17].

As for the nitrogen from sewage sludge generated by the STPs, its contribution corresponds to 2.02% of the total nitrogen in the system, being directed to the regional waste management system. The chemical composition of sludge varies depending on the type of effluent, the treatment system, and seasonal factors. However, improper disposal in landfills or open dumps can lead to contamination problems and the proliferation of disease vectors [18]. After treatment and stabilization, the sludge becomes biosolid —a material rich in macronutrients (nitrogen and phosphorus), micronutrients (zinc, copper, iron, manganese, and molybdenum) [19], and organic matter, with potential applications in agriculture or the recovery of degraded areas. Like organic waste, sludge can be treated and transformed into biosolids through composting.

By combining the nitrogen flows from sewage sludge and organic waste, a nitrogen stock is formed in the waste management process. Considering an average loss of 25% of the nutrient after composting [20] and the recommendation of organic nitrogen fertilization (NOrganic = 60 kg·ha-1) for papaya cultivation [21], this stock has the potential to produce enough fertilizer to cover approximately 7,000 hectares.

Conclusion

The nitrogen flow analysis provided an overview of the nitrogen pathways in the TI07 sanitation system. The Sankey diagram presented in Figure 1 provides a visual understanding of how the system is organized in terms of flows, processes, and stocks, as well as the magnitude of the nitrogen quantities associated with each.

Through the Nitrogen Flow Analysis (NFA), it was found that a significant amount of sewage from TI07, approximately 46.31%, is being directly discharged into the hydrosphere, potentially contaminating water bodies. This situation is supported by studies indicating alarming levels of ammonia, highlighting the urgent need for interventions. The adoption of alternative technologies for decentralized sewage treatment, such as vermifilters and green pits, is a viable solution for utilizing nitrogen, either through the production of fertilizer or local food consumption.

It was also observed that the combination of nitrogen flows from food waste and sewage sludge resulted in an accumulation of 23.49% of the total nitrogen in the sanitation system. This indicates a significant potential for waste recycling, which could strengthen the still-limited local family farming.

References

1. Jönsson H, Vinnerås B, Höglund C, Stenström TA. Source separation of urine. Wasser and Boden. 1999;51(11):21-25.
2. Vinnerås B, Jönsson H. The performance and potential of faecal separation and urine diversion to recycle plant nutrients in household wastewater. Bioresour Technol. 2002;84(3):275-282.
3. Brunner PH, Helmut R. Pratical Handbook of Material Flow Analysis [Internet]. [s.l: s.n.]. Available from: http://linkinghub.elsevier.com/retrieve/pii/B9781856178099100039
4. Bezerra IN, Vasconcelos TM, Cavalcante JB, Yokoo EM, Pereira RA, Sichieri R. Evolução do consumo de alimentos fora do domicílio no Brasil de 2008–2009 a 2017–2018. Rev Saude Publica. 2021;55(Supl.1):1–11. Available from: https://www.revistas.usp.br/rsp/article/view/194148.
5. Tchobanoglous G, Thiesen H, Vigil SA. Integrated solid waste management - engineering principles and management issues. New York: McGraw-Hill International Editions; 1993. 978 p.
6. Rose C, et al. The characterization of feces and urine: A review of the literature to inform advanced treatment technology. Crit Rev Environ Sci Technol. 2015;45(17):1827–1879.
7. Laner D, et al. A Novel Approach to Characterize Data Uncertainty in Material Flow Analysis and its Application to Plastics Flows in Austria. J Ind Ecol. 2016 Oct;20(5):1050–1063. Available from: http://doi.wiley.com/10.1111/jiec.12326
8. Mota FSB, Sperling M von. Nutrientes de esgoto sanitários: Utilização e remoção. Rio de Janeiro: ABES; 2009. Available from: http://www.finep.gov.br/images/apoio-e-financiamento/historico-de-programas/prosab/prosab5_tema_2.pdf
9. Quinelato RV, et al. Análise espaço temporal da qualidade da água dos rios Peruípe, Itanhém e Jucuruçu, Bahia. Sci Plena. 2020 Jul 7;16(7):1–12. doi: 10.14808/sci.plena.2020.071701. Available from: https://www.scientiaplena.org.br/sp/article/view/5400/2301
10. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Agricultura e Qualidade da Água: Contaminação da Água por Nitrato. Planaltina: Embrapa Cerrados; 2002. 28 p.
11. Tonetti AL, et al. Tratamento de Esgotos Doméstico em Comunidades Isoladas: referência para a escolha de soluções. Campinas: UNICAMP; 2018. 153 p. Available from: http://www.fec.unicamp.br/~saneamentorural/wp-content/uploads/2018/11/Livro-Tratamento-de-Esgotos-Dom%C3%A9sticos-em-Comunidades-Isoladas-ilovepdfcompressed.pdf
12. Singh R, Bhunia P, Dash RR. A mechanistic review on vermifiltration of wastewater: Design, operation and performance. J Environ Manag. 2017 Jul 15;197:656–672. https://doi.org/10.1016/j.jenvman.2017.04.042
13. Sugimoto L. Vermifiltração é alternativa para o tratamento de esgoto: Tecnologia ainda pouco conhecida alia a degradação bacteriana com a vermicompostagem. J Unicamp. 2016 Jun;9.
14. Sabei TR, Bassetti FJ. Alternativas ecoeficientes para tratamento de efluentes em comunidades rurais. IX Fórum Ambiental da Alta Paulista. 2013;9(11):487-503. Available from: https://mac.arq.br/wpcontent/uploads/2016/03/saneamento-ecoeficiente-em-comunidades-rurais.pdf
15. Teixeira MB, Motta ALTS. Sanitário Seco Compostável, uma Alternativa Viável de Saneamento Ambiental. V Congr Nac Excelência em Gestão. RJ; 2008. Available from: https://biowit.files.wordpress.com/2010/10/sanitario-seco.pdf

16. Colón J, Martínez-Blanco J, Gabarrell X, Artola A, Sánchez A, Rieradevall J, Font X. Environmental assessment of home composting.
17. Pelegrino ECF, Flizikowski LC, Souza JB. Compostagem de lodo de estação de tratamento de esgoto. In: VI Semana de Estudos de Engenharia Ambiental. Unicentro; 2008.
18. Neto SP, Júnior CH, Muraoka T. Uso de Biossólido em Plantios Florestais. 2007.
19. Bettiol W, Camargo OA, coords. Lodo de Esgoto: Impactos Ambientais na Agricultura. Jaguariúna: Embrapa Meio Ambiente; 2006. 11 p.
20. Yang F, Li GX, Yang QY, Luo WH. Effect of bulking agents on maturity and gaseous emissions during kitchen waste composting. Chemosphere. 2013 Oct;93(7):1393-1399.
21. Oliveira AMG, Coelho EF. Calagem e adubação para o mamoeiro. In: Borges AL, et al. Recomendações de calagem e adubação para abacaxi, acerola, banana, citros, mamão, mandioca, manga e maracujá. 2nd ed. Brasília: EMBRAPA; 2021. p. 187-203. ISBN 978-65-87380-38-4. Available from: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/226951/1/livro-RecomendacaoCalagemAdubacao.