Methodology for Global Nitrogen Inventory based on National Population for Domestic Sewage Management (GNINPO-DSM) Dataset

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1. Overview

The Global Nitrogen Inventory based on National Population for Domestic Sewage Management (GNINPO-DSM) provides country-level estimates of nitrogen flows associated with domestic wastewater systems. The dataset spans from 2005 to 2022 and includes structured indicators categorized by sanitation service types and management levels. A conceptual diagram illustrating nitrogen excretion from human activities and its distribution across sanitation facility types and management levels is presented in Figure 1.

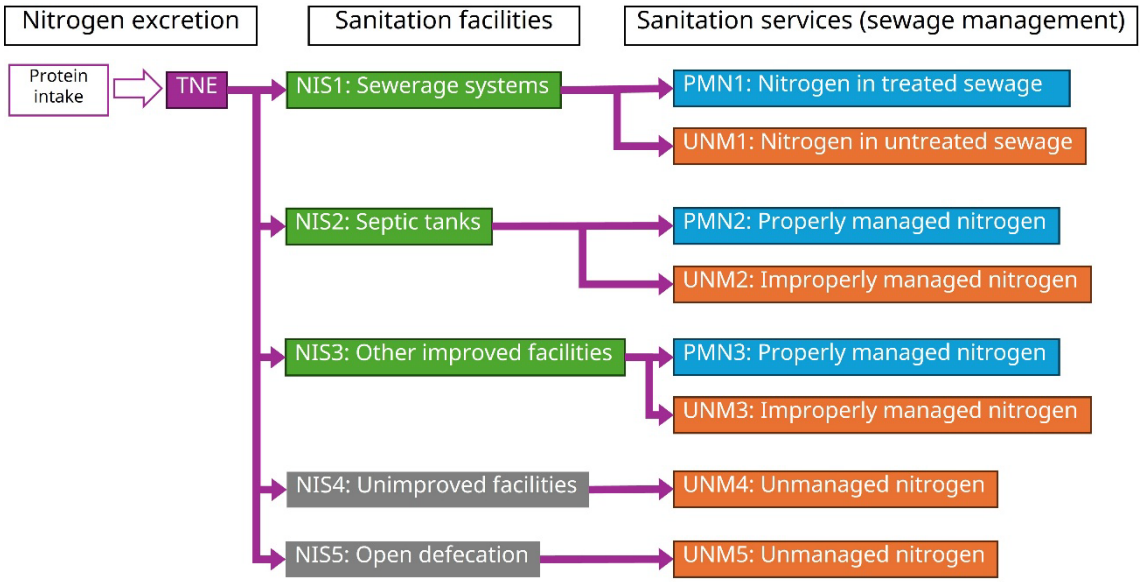

Figure 1 GNINPO-DSM: Nitrogen Flow and Management Structure

2. Data Sources

- WHO/UNICEF Joint Monitoring Programme (JMP; https://washdata.org/data): Provides population-based coverage data on sanitation facilities and service by country and year.
- World Bank Open Data (https://data.worldbank.org/): Utilized to estimate per capita food waste (kcal/day), for determining the food intake ratio, by country and year using national GDP indicators and population.
- FAOSTAT (https://www.fao.org/faostat/en/#data): Used to estimate, by country and year, per capita nitrogen supply (gN/day) from the protein data (g/day) and compile the data on per capita food supply (kcal/day) to quantify food waste ratio.
- FAO (https://www.fao.org/4/Y5022E/y5022e03.htm#TopOfPage): Utilized to define nitrogen content in protein by food items.

- Okadere et al. (2025; https://doi.org/10.1038/s41598-025-01579-x): Referred to per capita food waste (kcal/day) by country between 2005 and 2020.

3. Variable Definitions

3.1 Nitrogen with human excretion and input to sanitation facilities

- TNE: Total nitrogen excretion
- NIS1: Nitrogen input into sewerage systems
- NIS2: Nitrogen input into septic tanks
- NIS3: Nitrogen input into other improved sanitation facilities
- NIS4: Nitrogen input into unimproved sanitation facilities
- NIS5: Human nitrogen excretion not captured by sanitation systems (open defecation)

3.2 Properly Managed Nitrogen through improved sanitation facilities

- PMN1: Nitrogen treated at sewage treatment plants
- PMN2: Nitrogen through properly managed septic tanks
- PMN3: Nitrogen through other improved sanitation facilities with proper management

3.3 Unmanaged Nitrogen

- UNM1: Untreated nitrogen discharge from sewerage systems without treatment
- UNM2: Nitrogen through septic tanks without proper management
- UNM3: Nitrogen through other improved sanitation facilities without proper management
- UNM4: Nitrogen discharge from unimproved sanitation facilities
- UNM5: Nitrogen discharge from open defecation

4. Estimation approach and handling of missing values

1. Total Nitrogen Excretion (TNE) was estimated by the product of population data and annual per capita nitrogen intake by country and year, assuming that all ingested nitrogen is excreted within the same year as consumption.
2. Nitrogen input to sanitation facilities (NIS1–NIS5) was estimated by multiplying the proportion of the population with access to sanitation facilities or practicing open defecation by the TNE, for

each country and year.

3. Properly managed nitrogen for improved sanitation facilities (PMN1–PMN3) was estimated by multiplying the proper management ratio for each type of sanitation facility by the corresponding nitrogen input values (NIS1–NIS3).
4. Unmanaged nitrogen for improved sanitation facilities (UNM1–UNM3) was estimated by subtracting the properly managed nitrogen (PMN1–PMN3) from the corresponding nitrogen input values (NIS1–NIS3). Nitrogen input to unimproved sanitation facilities (NIS4) and open defecation (NIS5) was assumed to be entirely unmanaged, and was assigned to UNM4 and UNM5, respectively.
5. All missing values in the dataset were standardized and represented as 'NA'. This notation indicates that the data point was unavailable or could not be estimated due to insufficient input data. No imputation or extrapolation was applied to fill these gaps.

5. Parameter setting

5.1 Per capita nitrogen intake and excretion

Per capita nitrogen excretion (PCNE), which is originated from protein in food intake to a human body [1], was estimated based on per capita nitrogen supply (PCNS) and protein intake ratio (PIR). Because FAOSTAT (https://www.fao.org/faostat/en/#data) provides per capita protein supply (PCPS; g/capita/cay) of each food items by country and year in food balance sheet (FBS),which this study utilized the historical FBS until 2009 whereas the current FBS from 2010, PCNS (gN/capita/day) could be estimated by multiplying PCPS by nitrogen content. The nitrogen content in protein is generally defined as 16%, but some food items referred to the nitrogen-to-protein conversion factors [2].

It is not available to acquire PIR in all counties. However, since energy gap approach can be globally utilized to estimate per capita food waste (kcal/capita/day) as “positive” food energy imbalance [3, 4], food waste ratio was quantified by dividing the per capita food waste estimates by per capita food supply (kcal/capita/day) compiled from FBS by country and year. In addition, if estimated food energy imbalance indicated “negative” value, food waste ratio was assumed as zero [5]. The food intake ratio, as proxy data for PIR, was calculated by subtracting food waste ratio from 1.

This model assumes that all ingested nitrogen is excreted annually, providing a consistent basis for estimating yearly nitrogen flows, because the previous studies indicate that nitrogen may be temporarily retained in the human body and all consumed nitrogen would be excreted eventually [6, 7]. Ultimately it was defined that per capita nitrogen excretion is the same as per capita nitrogen intake.

Therefore, annual per capita nitrogen excretion (gN/capita/year), which was the product of the estimated daily per capita excretion (gN/capita/day) and 365 days (or 366 days for leap year), was adopted as the supplementary dataset (SupplementaryDataset-1_GNINPO-DSM.xlsx").

5.2 Population

5.2.1 Total population and the population using sanitation facilities.

All parameters on population are referred to the WHO/UNICEF JMP global database on household sanitation (JMP-WASH; https://washdata.org/data/household#!/), consisting of total population and the proportions of population using sanitation facilities and services by country and year. Total population was directly compiled from JMP-WASH dataset and the population using sanitation facilities was estimated by multiplying the proportion of population per sanitation facilities by total population by country and year. The sanitation facilities were categorized into five groups as sewerage systems, septic tanks, other improved sanitation facilities, unimproved sanitation facilities, and open defecation.

5.2.2 Population with access to properly managed improved sanitation facilities

JMP-WASH data defines “safely” managed sanitation services as using improved sanitation facilities (ISF) that are not shared with other households and where excreta are safely disposed of in situ or removed and treated offsite and provides the proportion of population using safely managed sanitation services by country and year. In addition, this indicator consists of the proportions of population using private ISF connected to sewerage systems with wastewater treatment at sewage treatment plants, and private onsite ISF, such as septic tanks, pit latrine, and composting toilet, whose solid waste is emptied, treated, and disposed in situ properly.

The structure of JMP-WASH data implies that ISF is categorized into two groups as facilities managed safely or unsafely. As above, the definition of safe management consists of two elements: 1) using private ISF, and 2) properly managing excreta through the ISF. In terms of sanitation, the first element (private access) must be considered, but for the purpose of estimating nitrogen flow of domestic sewage management, the second element (propriety), including ISF shared with other households, should be considered. Thus, GNINPO-DSM estimated population with access to properly managed ISF (PMISF), both privately and communally.

However, since the JMP-WASH dataset provides data only on the population using PMISF privately, information on PMISF shared with others is not available. In contrast, the data on ISF include both

private and communal facilities. Therefore, the population with access to PMISF, including communal use, was estimated by multiplying the Proper Management Ratio (PMR) by the population using ISF. PMR was computed by dividing the population with access to privately used PMISF, for sewerage systems or onsite facilities, by the estimated population using privately used ISF. The population of privately used ISF for sewerage systems was estimated by multiplying Private Facility Ratio (PFR), which is calculated as the proportion of the population using basic sanitation services divided by that using improved sanitation facilities, based on JMP-WASH data, by the total population of sewerage systems. Then, population of privately used onsite facilities was estimated by subtracting the population of privately used sewerage systems from the population using basic sanitation services.

If the calculated PMR for sewerage systems exceeded 1, the PMR was assumed as 1 and population of onsite facilities recalculated under this assumption, and vice versa. In cases where PMR was missing due to lack of the related parameters, the PMR was assumed as 0 or 0.5 using the decision tree for estimation of safely managed sanitation services of the JMP Methodology [8] if the main form of improved sanitation facility could be confirmed.

5.2.3 Population of unmanaged sanitation services

Population with access to ISF without proper management is estimated by subtracting the population of PMISF from total population using ISF by type. In addition, the population using unimproved sanitation facilities and that of open defecation are defined as unmanaged sanitation services.

Finally, the above population estimates are compiled as the supplementary dataset (SupplementaryDataset-2_GNINPO-DSM.xlsx").

5.3 Note on supplementary data

All missing values in the supplementary datasets have been standardized as 'NA'. This ensures consistency with the main GNINPO-DSM dataset and facilitates reproducible analysis.

6. Limitations

- Some countries have missing or zero values due to lack of data.
- Assumptions may not reflect local variations in sanitation practices.
- Per capita nitrogen excretion is generalized and may vary depending on dietary habits and health conditions.

7. Intended Applications

- Assessment of nitrogen pollution from domestic sources
- Evaluation of sanitation system performance
- Identification of nitrogen recovery potential
- Support for policy development in wastewater and nutrient management

References

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