

Multidimensional Determinants of Childhood Wasting among Children Under Five in West Africa

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Abstract

Childhood wasting remains a major public health challenge in West Africa, yet evidence on the combined influence of climate, environmental, water-resource, socioeconomic, and health system factors remains limited. The determinants of childhood wasting among children under five years in the sixteen West African countries were studied using a Beta Generalized Linear Mixed Model (BGLMM) and Random Forest (RF) with Shapley Additive Explanations (SHAP). Data were obtained from the World Bank panel data (2000–2023). The Beta GLMM showed that agricultural water withdrawal, N₂O emissions, basic sanitation, health expenditure, access to basic drinking water, and forest area remained significantly associated with childhood wasting in West Africa. The Random Forest model ranked agricultural water withdrawal, urban population, average precipitation, PM_{2.5} exposure, access to basic drinking water, and water productivity as the most informative predictors of childhood wasting. Of these, agricultural water withdrawal and access to basic drinking water were consistently identified by both the BGLMM and RF model, signifying that they remain priority areas for policies aimed at reducing childhood wasting in West Africa. Promotion of efficient use of water in agriculture by expanding drip irrigation, rainwater harvesting, and other water-saving irrigation technologies should be prioritized by governments in West Africa to reduce excessive agricultural water withdrawal and sustain food production throughout drought stages. Also, access to safe drinking water through the construction and maintenance of boreholes and community water supply systems. Improving water availability meant for farming and household use can increase food production, reduce childhood infections, and help lower the prevalence of childhood in West Africa.

Keywords: Childhood Wasting, Climate Change; Random Forest; Under-Five Children; West Africa

Introduction

Childhood malnutrition remains a major public health challenge worldwide. The World Health Organization (WHO) defines malnutrition as deficiencies, excesses, or imbalances in the intake of energy and nutrients (Abdalameer et al., 2022). Since wasting reflects acute undernutrition and is linked to a high risk of illness and death among young children in the malnutrition domain (Abdalameer et al., 2022). Wasting continues to impact child health globally despite efforts to improve child nutrition. In 2024, data showed that an estimated 42.8 million (6.6%) children under five years of age were wasted, with Africa associated with more than 27% of this burden, indicating the wasting remains a major concern across the continent (Daniel et al., 2025; Organization, 2024).

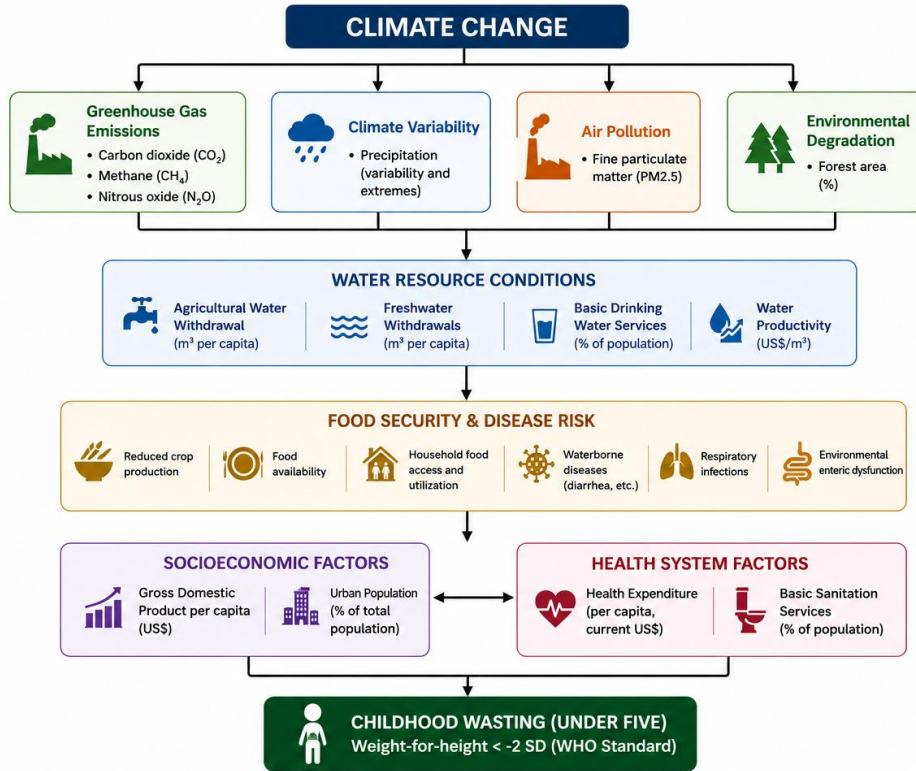
Wasting remains a persistent public health challenge in West Africa, threatening child survival and development. This is evident by figures in countries like Senegal, with a reported prevalence of 10.29%, and Mauritania, which also recorded levels above the 10% threshold (Beni et al., 2024). The biological impact of wasting is severe, characterized by an acute loss of muscle and adipose tissue that compromises mucosal immunity and renders children nine to eleven times more likely to die from common infections like pneumonia or malaria (Tamir et al., 2025a). In West Africa, this vulnerability is not merely a product of isolated dietary intake; it is increasingly driven by a vicious cycle of environmental and structural shocks (Silva et al., 2025; Tamir et al., 2025a).

Rising temperatures and fluctuations in average precipitation, coupled with climatic shifts, are highlighted by current research progress in reducing wasting is being undermined by these factors. These fluctuations are key drivers of lean seasons and seasonal drought crises, characterized by rising CO₂, CH₄, and N₂O emissions as part of a broader environmental crisis (Tamir et al., 2025a). Also, basic sanitation and drinking water infrastructure development in West Africa is not increasing at a rate to match the rapid development of the urban population in the region, leading to millions of children exposed to environmental enteric dysfunction and respiratory stressors linked to the potential high PM_{2.5} exposure from unhygienic cooking fuels (Beni et al., 2024; Tamir et al., 2025a). Environmental metrics such as water productivity and forest area preservation have often not been integrated into nutritional strategies, limiting our understanding of how landscape-level factors influence child survival, particularly in West Africa (Elmighrabi et al., 2023; Tamir et al., 2025a).

Various components of socioeconomic and demographic factors have been known to impact childhood wasting, including household wealth, antenatal care use, birth weight, and maternal education (Tamir et al., 2025a). Nevertheless, the combined effect of environmental conditions, water resources, and climate has been given less attention, in addition to the focus on individual countries (Mali, Burkina Faso, or Ethiopia), providing limited evidence on regional patterns across West Africa as a whole. This is a major concern since most of West Africa continues to experience the effect of climate change on child health, food production, and water availability (Sahiledengle et al., 2022).

Tamir et al. (2025b) pointed out that multilevel logistic and logistic regression have been used by most previous works concerning the determinants of childhood wasting. However, childhood wasting is often measured as a proportion, with values bounded between 0 and 1, for which beta regression provides a more appropriate analytical approach (Kubinec, 2023). Despite this advantage, Beta regression has received little attention in studies of childhood wasting, particularly in West Africa. Also, most researchers often use machine learning models like gradient boosting models and random forest models using mean decrease in accuracy (MDA) and mean decrease in node impurity (MDI), with some potential variable explainers like Shapley Additive Explanations (SHAP) (Islam et al., 2024), whereas a few have combined these methods with Beta regression to examine bounded health outcomes such as the prevalence of wasting concerning children under five in West Africa.

This study combined Beta GLMM (Verkuilen & Smithson, 2012), a Random Forest model (Breiman, 2001), and SHAP (Lundberg & Lee, 2017) to examine the climate, environmental, water-resource, socioeconomic, and health system factors associated with childhood wasting in West Africa. The findings can inform policies and programmes that expand access to safe drinking water, strengthen Integrated Management of Acute Malnutrition (IMAM), improve community nutrition services, promote climate-smart agriculture, and support national food security strategies in the region.



This framework illustrates the hypothesized relationships between climate change, environmental, water-resource, socioeconomic, and health system factors and childhood wasting in West Africa.

Figure 1: Conceptual framework illustrating the hypothesized pathways through which climate, environmental, water-resource, socioeconomic, and health system factors influence childhood wasting among children under five years in West Africa.

Methodology

Data

Data for this project were obtained from the World Bank's World Development Indicators (WDI) database, which is available at <https://databank.worldbank.org/source/world-development-indicators#> concerning West Africa. The dependent variable was the prevalence of wasting (% of children under 5). The World Bank defines wasting as the proportion of children under five whose weight for height is more than two standard deviations below the median of the international reference population. A detailed description of each explanatory variable (covariate), together with its justification for inclusion and potential pathway to wasting, is provided in Table S1. Missing values were handled using MissForest (Bofa & Zewotir, 2022).

Beta Generalized Linear Mixed Model (BGLMM)

A logit link function was used in the beta generalized linear mixed model because the outcome variable was a proportion bounded between 0 and 1.

$$Y_{it} \sim \text{Beta}(\mu_{it}, \phi),$$

$$\text{logit}(\mu_{it}) = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \dots + \beta_p X_{pit} + \vartheta_i,$$

where: $\text{logit}(\mu_{it}) = \log\left(\frac{\mu_{it}}{1-\mu_{it}}\right)$, Y_{it} = adjusted proportion of wasting in the country i at year t , μ_{it} = expected mean proportion of wasting, X_{pit} = independent variables, β_p = fixed effect coefficients, ϑ = country-level random effect, $\vartheta \sim N(0, \sigma_\vartheta^2)$, and ϕ = precision parameter.

The regression coefficients were not directly interpretable as changes in the prevalence of wasting, since the Beta GLMM used a non-linear logit link function. To improve interpretation, average marginal effects (AMEs) were computed to estimate the average change in predicted wasting prevalence associated with a one-unit increase in each predictor while holding other variables constant and accounting for country-level random effects. This approach makes the result more useful for policy and health decision-making, as it reflects changes in wasting prevalence as a percentage, as evident by Barbanti and Hothorn (2024).

Machine Learning Approach

The Random Forest (RF) model was chosen because it can capture complex non-linear relationships and interactions among predictors without strict distributional assumptions. The model is built using multiple decision trees, with predictions obtained by averaging across the trees to improve prediction accuracy and reduce overfitting. The RF was evaluated with Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and R-squared (R^2). A 70:30 train-test split was used for accessing the RF model. For a detailed mathematical explanation of the random forest, readers can refer to (Scornet & Hooker, 2025).

To improve the interpretation of the machine learning model, SHAP values were computed (Bofa & Zewotir, 2025b; Napa et al., 2025). SHAP values measured the influence of individually predictor to the model predictions. This helped identify the importance and direction of the impacts of climate and environmental factors on childhood wasting prevalence (Napa et al., 2025). Global SHAP importance values were used to find the most informative predictors, while SHAP dependence plots were used to show the magnitude, distribution, and direction of the predictor effects (Bofa & Zewotir, 2025b; Napa et al., 2025).

Results

The findings from both the statistical and machine learning frameworks concerning wasting among children under five in West Africa are presented in this section. Findings from the Beta

GLMM based on marginal effects and the Random Forest model are presented, followed by SHAP-based interpretation of the most important predictors.

Before the BGLMM, the multicollinearity assessment revealed that all the variance inflation factors (VIF) were between 1 and 2, indicative of a low level of correlation between the covariates. The VIF results are not reported since all values were well less-than the commonly accepted threshold of less than or equal to 10(Kalnins & Praitis Hill, 2025). Hence, there was no indication of stability or interpretation of the BGLMM. The outcomes from the BGLMM for assessing the association between climate, environmental, and socioeconomic factors and childhood wasting in West Africa is presented in Table 1.

Table 1. Association Between Climate, Environmental, and Socioeconomic Factors and Childhood Wasting in West Africa: Average Marginal Effects from the Beta GLMM

Variable	Coefficient	Std Error	Marginal Effect	P value
N2O emissions (Total)	0.020732	0.009092	0.001645	0.022598*
Year	-0.0143	0.002064	-0.00113	4.31E-12***
Health expenditure	-0.01379	0.006175	-0.00109	0.025514*
Basic drinking water	-0.00603	0.001823	-0.00048	0.000941***
Freshwater withdrawals	0.005173	0.014282	0.00041	0.717221
Basic sanitation	0.005136	0.001644	0.000407	0.00178**
Forest area	-0.00463	0.001013	-0.00037	4.91E-06***
Agricultural water withdrawal	0.003128	0.000905	0.000248	0.000546***
CO2 emissions (Total)	-0.00265	0.003108	-0.00021	0.394477
PM2.5 exposure	0.001648	0.001193	0.000131	0.167202
Water productivity	-0.00148	0.000928	-0.00012	0.11191
CH4 emissions (Total)	-0.00086	0.000935	-6.80E-05	0.359461
Urban population	-7.48E-05	0.002695	-5.93E-06	0.97787
GDP per capita	-3.63E-05	3.39E-05	-2.88E-06	0.284565
Average precipitation	3.49E-05	4.39E-05	2.77E-06	0.426532

Note: *** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$. Variables without *, **, or *** were not statistically significant ($p \geq 0.05$).

There was evidence that some relatively small variation (variance=0.00196 and standard deviation=0.0443) in wasting prevalence remained across West Africa after accounting for the included predictors. The estimated beta dispersion parameter was 628, which gives a good indication of good precision in the model with an AIC of -2314.7, a BIC of -2243.6, and a log-likelihood of 1175.4.

N₂O emissions were positively associated with wasting prevalence (AME = 0.0016, $p = 0.023$). In contrast, health expenditure (AME = -0.0011, $p = 0.026$), access to basic drinking water (AME = -0.0005, $p < 0.001$), and forest area (AME = -0.0004, $p < 0.001$) were associated with lower wasting prevalence. Also, Agricultural water withdrawal was positively associated with wasting

prevalence (AME = 0.0002, $p < 0.001$). Access to basic sanitation also remained positive associated with wasting (AME = 0.0004, $p = 0.002$). The year variable showed a negative association with wasting prevalence (AME = -0.0011, $p < 0.001$), indicating that wasting generally declined during the study period (Table 1).

The RF model with MAE=0.006, RMSE=0.009, and $R^2 = 0.81$ was used to rank predictor importance and capture potential non-linear effects that may not have been fully represented in the Beta GLMM. Figure 1 reports the SHAP values of the global importance from the RF model, ranking covariates according to their overall contribution to the prediction of childhood wasting prevalence. Higher mean absolute SHAP values point to greater importance in explaining variations in childhood wasting across West Africa (Figure 2).

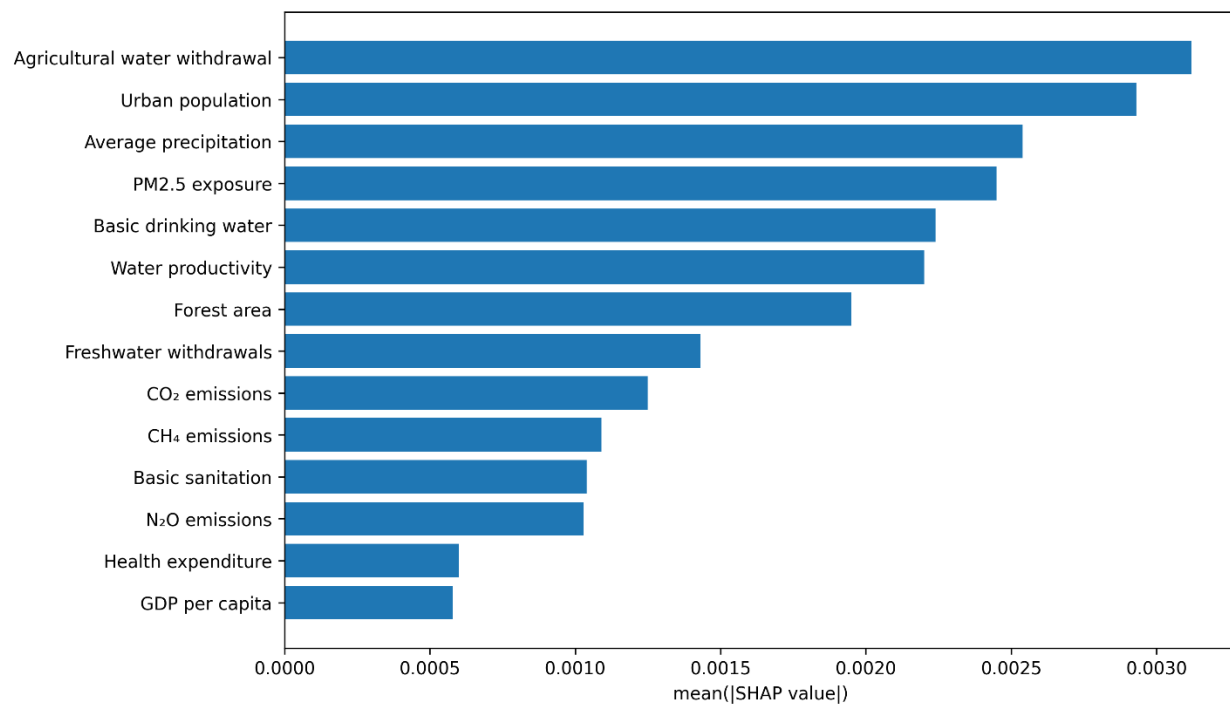


Figure 2: Ranking of key determinants of childhood wasting in West Africa based on global SHAP values. The y-axis represents the predictor variables included in the Random Forest model, while the x-axis shows the mean absolute SHAP value, which evaluates the average influence of individual predictors on the model's predictions.

Agricultural water withdrawal was the most influential predictor of childhood wasting in West Africa. This was followed by urban population, average precipitation, PM2.5 exposure, access to basic drinking water, water productivity, and forest area. These variables made the largest contributions. Freshwater withdrawals, CO₂ emissions, CH₄ emissions, basic sanitation, and N₂O emissions were of moderate importance for predicting wasting prevalence. In contrast, health expenditure and GDP per capita had the lowest SHAP values (Figure 2).

While Figure 2 identifies the essential predictors of childhood wasting, it does not show how these predictors influence the predictions of wasting among children under five in West Africa. Figure 3, therefore, reports SHAP dependence plots for the five (5) most influential predictors. These plots show how changes in each predictor are associated with the predicted prevalence of wasting and provide further insight into their relationship with childhood wasting in West Africa.

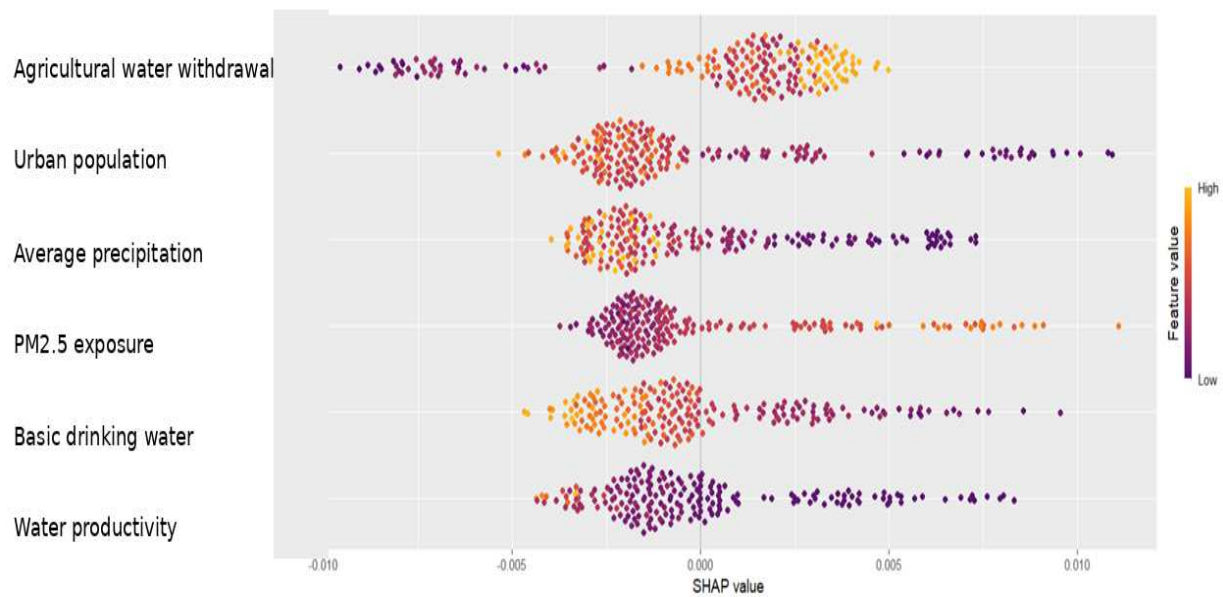


Figure 3. SHAP beeswarm plot for the five most important predictors of childhood wasting in West Africa. Positive SHAP values indicate higher predicted wasting prevalence, whereas negative SHAP values indicate lower predicted wasting prevalence. Colours represent the predictor values, ranging from low (purple) to high (yellow).

Higher values of agricultural water withdrawal are linked with high childhood wasting prevalence, whereas higher values of urban population and average precipitation were associated with lower prevalence of wasting. For PM2.5 (air pollution) exposure, higher values were mostly associated with positive SHAP values, indicating higher predicted wasting prevalence. Access to basic drinking water also showed that lower levels of access were associated with higher wasting predictions, while higher levels were associated with lower predictions. Water productivity varied across observations, with higher values generally associated with lower SHAP values and lower predicted wasting prevalence (Figure 3).

Discussions

The Beta GLMM showed a positive association between agricultural water withdrawal and wasting prevalence, while the Random Forest model ranked it as the most influential predictor. This finding may reflect increasing pressure on limited water resources due to climate variability and recurrent droughts in the region. High levels of water withdrawal can reduce water availability

for household use, affecting food preparation, hygiene, and overall child health. Water shortages may also affect agricultural production and food availability, increasing the risk of wasting (undernutrition). Similar findings have been reported in previous studies (Ingrao et al., 2023; Lieber et al., 2022), which showed that water scarcity and climate-related droughts can contribute to poor child nutritional outcomes through their effects on food security, water access, and sanitation.

Access to basic drinking water is essential in supporting food preparation, hygiene, and childcare practices that are important for child health. This is in line with the Beta GLMM, which showed that increased access to safe drinking water reduced wasting prevalence, and also the RF model, identifying it as one of the most important predictors. Access to safe water helps reduce the incidence of waterborne diseases, particularly diarrhoea, which can affect nutrient absorption and increase the risk of malnutrition (Lee et al., 2023). In areas affected by climate variability and water shortages, reliable access to drinking water may help protect households from conditions that contribute to undernutrition. Improved access to safe water is associated with better child growth and lower risks of wasting and other forms of undernutrition, as reported by Okesanya et al. (2024) and Dunga (2026).

Exposure to fine particulate matter (PM_{2.5}) may increase the risk of wasting among children through several pathways. Air pollution can increase respiratory infections, inflammation, and weakened immune function, all of which can affect a child's nutritional status. These conditions may reduce appetite, increase nutrient requirements, and interfere with normal growth. Children are particularly vulnerable because their respiratory and immune systems are still developing. In West Africa, major sources of air pollution include vehicle emissions, open waste burning, the use of solid fuels for cooking, and dust from the Sahara Desert. This finding is corroborated by growing evidence (Gheissari et al., 2022; Spencer-Hwang et al., 2023) linking air pollution to adverse child health and nutritional outcomes.

Average precipitation and urban population were among the five most important predictors according to the machine learning framework. Rainfall is closely linked to agricultural production, food availability, and household livelihoods in West Africa, where many communities depend on rain-fed farming. Low rainfall can reduce crop yields and food availability, while excessive rainfall and flooding can damage crops and increase the risk of disease. Both situations can contribute to child undernutrition. The urban population was also an important predictor. Although urban areas often provide better access to healthcare and other services, rapid urban growth can lead to overcrowding, poor living conditions, environmental pollution, and food insecurity among vulnerable households. Together, these findings point to the fact that both climate conditions and population changes may influence wasting through their effects on food security, health, and access to basic services (Desta et al., 2024; Dimitrova et al., 2022).

Higher N₂O emissions were associated with a higher prevalence of wasting. This may reflect the effects of intensive agricultural practices and climate-related pressures on food systems. In countries such as Burkina Faso, Mali, Niger, Nigeria, and Senegal, agricultural production often

depends on fertilizer use and rainfall-dependent farming. These activities contribute to N₂O emissions. As a greenhouse gas, N₂O contributes to climate change, which can lead to droughts, irregular rainfall, and lower agricultural yields(Bofa & Zewotir, 2025a). These conditions may reduce food availability and increase the risk of child undernutrition. The finding also points to a close link between SDG 2 (Zero Hunger) and SDG 13 (Climate Action), showing that efforts to reduce child malnutrition should go hand in hand with climate-resilient, environmentally sustainable agricultural practices(Filonchyk et al., 2024).

In contrast, higher health expenditure was associated with lower wasting prevalence. This gives an indication that greater investment in healthcare may improve access to nutrition services, disease prevention programmes, and child health interventions(Ayipe & Tanko, 2023; Osei et al., 2024). Forest area was also negatively associated with wasting prevalence. Countries with greater forest cover, such as Liberia, Sierra Leone, Guinea, and Guinea-Bissau, may benefit from the food, income, and environmental resources provided by forest ecosystems. Forests can support household food security through the provision of wild foods and other livelihood opportunities(Timilsina et al., 2025). They also help maintain environmental conditions that support agricultural production. Together, these benefits may contribute to better nutrition and lower levels of wasting among children under five(Timilsina et al., 2025).

A one-unit increase in access to basic sanitation was associated with an average increase of about 0.04 percentage points in wasting prevalence. Although this finding may seem unexpected, it may reflect broader social and environmental conditions rather than a harmful effect of sanitation itself. In countries such as Nigeria, Ghana, Côte d'Ivoire, and Benin, sanitation improvements often occur alongside rapid population growth, urban expansion, informal settlements, and persistent food insecurity. As a result, access to sanitation amenities alone may not be adequate to overcome the effects of poverty, poor diets, unsafe water, and frequent childhood illnesses. Similar findings(Islam et al., 2022; Patlán-Hernández et al., 2022; Sahiledengle et al., 2022) have been reported in other low-resource settings, where sanitation improvements alone had little effect on child nutrition when not accompanied by boosts in water access, hygiene practices, and food security.

There is the likelihood of masking important within-country variation as a result of our country-level data usage in this study, as potential predictors like child feeding practices, disease burden, and household income were excluded. Also, spatial random effects were not accounted for in this current study. In future research, we anticipate mitigating this by exploring spatial and longitudinal models.

Figure 4 summarizes the major findings of this study, illustrating the significant determinants identified by the Beta GLMM, the influential predictors identified by the Random Forest model, and their implications for childhood wasting in West Africa.

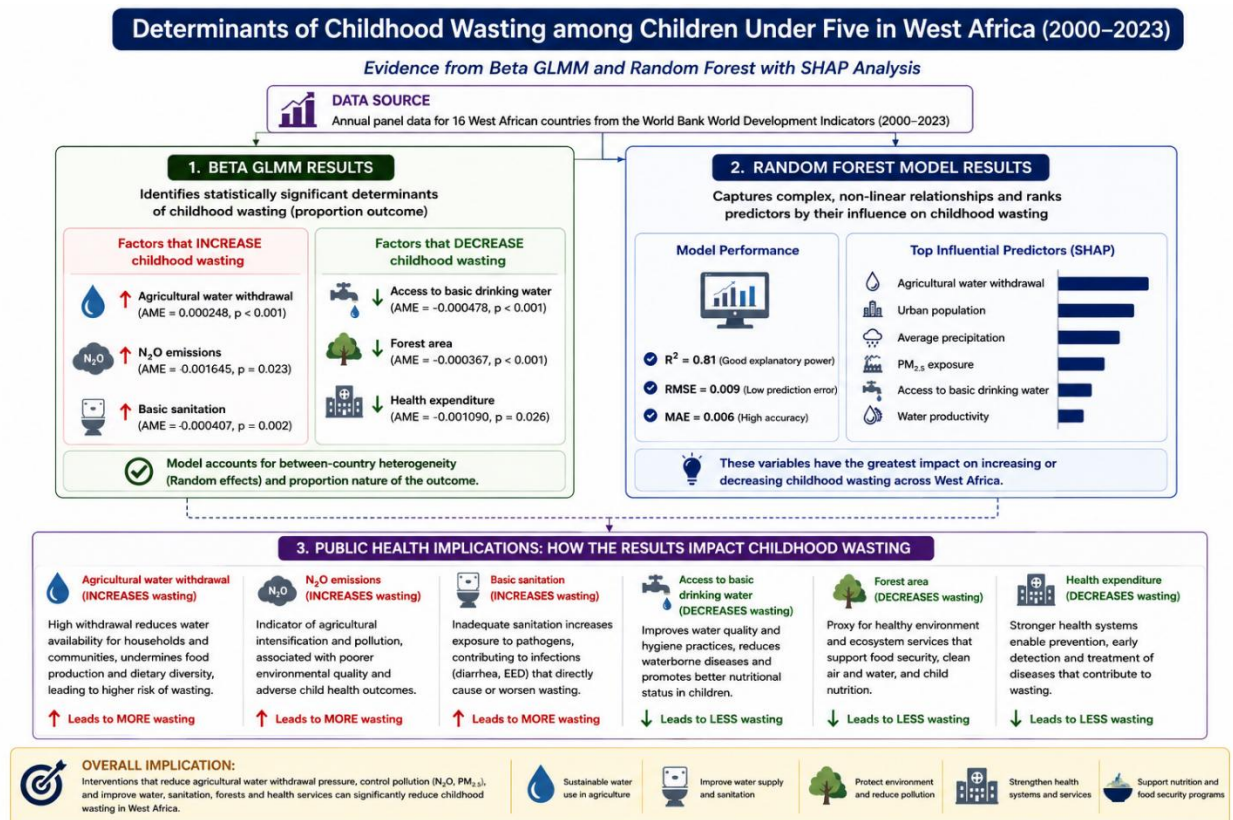


Figure 4: Summary framework of the determinants of childhood wasting among children under five in West Africa

Conclusion

Our findings revealed that environmental and socioeconomic factors are associated with wasting among children under five in West Africa. The Beta GLMM identified significant associations with N₂O emissions, agricultural water withdrawal, health expenditure, access to basic drinking water, forest area, and basic sanitation. Air pollution(PM 2.5) and average precipitation were also vital predictors of wasting. Agricultural water withdrawal and access to basic drinking water were key predictors of childhood wasting under statistical learning and machine learning frameworks.

Families should adopt practices, such as rainwater harvesting and small household gardens, which can help improve food availability and dietary diversity throughout the year. Households must seek early treatment for common childhood illnesses, and must reduce children's exposure to smoke from cooking by using improved cookstoves(liquefied petroleum gas (LPG)), which may also help lower the risk of childhood wasting at the household level.

Sustainable food production is critical under climate-changing conditions; therefore, governments in West Africa can invest in drought-tolerant crops such as millet, sorghum, and cowpea. Interventions that can supplement nutrition, like school feeding programs, are also important in combating wasting. Efforts to improve waste management, such as recycling programmes and

restrictions on open waste burning, may further improve environmental conditions and child health.

Finally, addressing childhood wasting in West Africa requires integrated approaches that simultaneously strengthen food security (SDG 2: Zero Hunger), environmental sustainability and climate resilience (SDG 13: Climate Action), and water resource management (SDG 6: Clean Water and Sanitation). Such efforts are essential for improving child nutritional outcomes and advancing sustainable development across the region.

Supplementary Material

Table S1: Conceptual justification, climate mechanisms, and pathways linking the explanatory variables to wasting among children under five in West Africa.

Code Name	Variable	Domain	Conceptual Justification	Climate Mechanism	Pathway to Wasting
x16	N ₂ O emissions (Total) excluding LULUCF	Climate & Environmental	Indicator of greenhouse gas emissions from agricultural and industrial activities.	Contributes to global warming and climate variability.	Climate-related disruptions to food production may increase wasting risk.
year	Year	Temporal Control	Captures changes over time in climate, health, and socioeconomic conditions.	Reflects long-term environmental and climatic trends.	Temporal changes may influence food security and child nutrition outcomes.
x11	Health expenditure	Health & Sanitation	Reflects investment in healthcare services and public health programmes.	Supports adaptation to climate-related health challenges.	Improved healthcare reduces disease burden and malnutrition.
x5	Basic drinking water	Water Security	Measures access to safe drinking water.	Climate variability affects water availability and quality.	Poor water access increases infections that contribute to wasting.
x3	Freshwater withdrawals, total	Water Security	Indicates the availability and use of freshwater resources.	Climate change influences water supply and demand.	Water scarcity may reduce food production and household water access.
x6	Basic sanitation	Health & Sanitation	Measures access to improved sanitation facilities.	Extreme weather events can disrupt sanitation systems.	Poor sanitation increases exposure to infectious diseases linked to wasting.

x7	Forest area	Climate & Environmental	Represents ecosystem health and environmental sustainability.	Deforestation affects rainfall patterns and local climate regulation.	Reduced ecosystem services may affect food security and livelihoods.
x4	Agricultural water withdrawal	Water Security	Measures water use for agricultural production.	Climate change can increase irrigation demand.	Reduced agricultural output may decrease food availability.
x18	CO ₂ emissions (Total) excluding LULUCF	Climate & Environmental	Proxy for industrial activity and greenhouse gas emissions.	Major contributor to climate change.	Climate-related impacts on food and water systems may increase wasting.
x14	PM _{2.5} exposure (mean annual exposure)	Climate & Environmental	Measures exposure to fine particulate air pollution.	Climate conditions can affect pollutant levels and dispersion.	Increases respiratory illness and poor child health outcomes.
x15	Water productivity, total	Water Security	Measures economic output generated per unit of water used.	Efficient water use is important under climate stress.	Improved water efficiency may support food production and nutrition.
x17	CH ₄ emissions (Total) excluding LULUCF	Climate & Environmental	Reflects emissions from agriculture, livestock, and waste activities.	Methane contributes significantly to global warming.	Climate impacts on agriculture and food systems may increase wasting.
x9	Urban population	Socioeconomic	Measures the level of urbanization.	Climate-related migration can accelerate urban growth.	Urban poverty and food insecurity may affect child nutrition.
x8	GDP per capita	Socioeconomic	Indicator of economic development and living standards.	Wealthier economies are generally more resilient to climate shocks.	Higher income improves access to food, healthcare, and sanitation.
x2	Average precipitation	Climate & Environmental	Measures rainfall availability.	Direct indicator of climate variability and change.	Droughts and irregular rainfall can reduce crop yields and food security.

Declarations**Ethics approval and consent to participate**

Please note that ethical approval was not required for this study.

Consent for publication

Not applicable for that section

Clinical Trial Number

Not applicable

Availability of data and materials

The datasets generated by the survey research during and/or analyzed during the current study are available at <https://databank.worldbank.org/source/world-development-indicators#>

Competing interests

The authors declare that they have no conflict of interest.

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Authors' contributions

The authors, George Fosu Nimako, Adusei Bofa, Priscilla Felicia Tano, Christa Osei-Mensah and Georgina Afoakwah were responsible for the conception and design of the experiments, analysis, and interpretation of the data, and writing of the paper.

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