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Household polluting energy use and overlapping water, sanitation and hygiene risks in Karangura, Kabarole District, Uganda: a cross-sectional environmental-health study

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Household polluting energy use and overlapping water, sanitation and hygiene risks in Karangura, Kabarole District, Uganda: a cross-sectional environmental-health study

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Abstract

Background

Environmental health in the home setting is influenced by inter-related exposures related to energy, water sources, sanitation and hygiene. Such exposures are common among rural households but are often assessed within independent sectoral programs. We describe polluting energy use and intersecting WASH risks in rural Karangura, Uganda, as well as their socioeconomic and geographic distributions.

Methods

We carried out a secondary analysis of 620 household survey data collected in the baseline assessment of the 2025 Karangura Child Focused Community Transformation intervention. Polluting energy for cooking was defined as kerosene or firewood/charcoal use, whereas polluting lighting included kerosene, firewood/charcoal or lack of a lighting source. WASH risk domains include higher-risk water source, absence of a private/personal sanitation facility and non-regular handwashing with soap. An exploratory five-domain environmental health burden score was created, and households having three or more risk domains were considered as having high burden. We compared risk indicators across asset tertiles and parishes as well as calculated adjusted prevalence ratios using modified Poisson regression with village-clustered robust standard errors.

Results

Out of 618 households with valid cooking-energy use information, 562 (90.9%) used kerosene or firewood/charcoal for cooking. Polluting lighting and no lighting was mentioned by 322 out of 602 households (53.5%). Overall, out of 620 households, 451 (72.7%) reported at least one higher-risk water source, 85 (13.7%) had no private/personal sanitation facilities and 314 (50.6%) had non-regular handwashing with soap. Five-domain information was available for 601 households out of which 370 (61.6%) experienced high multidomain environmental health burden. High burden was more frequent in the middle (69.7%) and lowest (64.6%) asset tertiles than in the highest (50.5%). Adjusting for other factors (n=599), households in the middle asset tertile (aPR 1.39, 95%CI 1.12-1.72) and in the lowest asset tertile (aPR 1.34, 95%CI 1.02-1.77) had high burden more frequently than households in the highest tertile. Households reporting orphanhood also had increased burden (aPR 1.43, 95% CI 1.27-1.60).

Conclusions

Polluting energy use and WASH risks were common in Karangura and frequently co-occurred. Findings suggest an integrated action on environment aimed at transition to clean energy sources along with provision of improved water supply, sanitation facilities and handwashing practices. Monitoring should take into account such risks differentiated by socioeconomic and geographic position rather than treat energy and WASH issues separately.

Keywords: household energy; household air pollution; water; sanitation; hygiene; environmental health; inequalities; rural Uganda; WASH

Background

Environmental health in the domestic setting is the result of exposures that take place within the same environment. Cooking, lighting, water collection and storage, utilization of sanitation and hygiene occur under a common physical and socio-economic environment. When sources of air pollution co-occur with WASH that is either unsafe or inaccessible to people, then families experience co-occurrence of respiratory, infectious and environmental health risks [1–4]. Co-existence of household risks is important to understand because of the way the sectors of energy, water, sanitation and hygiene are monitored and planned. Household air pollution is one of the major environmental health issues that affect people globally. The World Health Organization (WHO) estimates that 2.1 billion people still cook food using open fires and inefficient fuels or kerosene, and the largest gap occurs in low-and-middle-income countries [1]. According to WHO, electricity, solar, biogas, liquefied petroleum gas and other low-emitting fuel technologies are classified as clean household energy, whereas the organization recommends against the use of household kerosene due to its impacts on air quality and risks to safety [1,5]. Combustion of polluting household fuels produces fine particulates, carbon monoxide and other pollutants that harm health disproportionately affecting women and children who usually spend more time near kitchen area or fuel gathering sites [1,2].

The evidence from Uganda shows that household use of charcoal and wood is significant. Florkowski and Neupane report persistent use of charcoal and firewood in Ugandan urban households and the choice is related to family income level and other factors [6]. According to the analysis of the 2016 Uganda Demographic and Health Survey, the use of biomass fuels for cooking is nearly universal in the surveyed households, as well as the correlation of living standards and household energy use [7]. These results suggest that the transition to the cleaner household energy is related not only to technological aspect but also to the issue of equity and accessibility.

The exposures to water, sanitation and hygiene are an overlapping environmental health challenge as well. The Joint Monitoring Programme (JMP) of WHO and UNICEF continues to demonstrate huge disparities in safely managed drinking water, sanitation and hygiene worldwide [8]. In addition, there is strong socio-economic and geographic variation in the level of water and sanitation services in Uganda [9–12]. Importantly, the infrastructure category does not automatically mean that the service is safe or reliable. Households might use multiple water sources and change them during water shortages. The sanitation facilities might not be classified as safely managed according to the basic questionnaire. In this respect, the holistic household-level view is important. The same families that cannot afford cleaner fuels and lighting sources might also be affected by access barriers to reliable water supply, private toilets and soap. On the contrary, different risk domains might be characterized by different socio-economic patterns. The lumping of all environmental health disadvantage into a single sector would make it impossible to see both co-existence and differences. An multidomain descriptive approach will help to find out the domains where the risks converge while preserving individual indicators for specific interventions.

Karangura Sub-County is a rural setting in the western part of Uganda. The 2025 Child Focused Community Transformation (CFCT) baseline survey included both household energy exposures as well as water source use, drinking water treatment, sanitation, hygiene, socioeconomic and geographic indicators. This paper uses the data from the CFCT baseline survey to assess environmental health

conditions beyond WASH. The objectives of the study are to: (1) describe the polluting household energy use (cooking and lighting) along with WASH risks; (2) estimate the co-existence of risks in five environmental health domains; (3) analyze socio-economic and geographic inequalities in these conditions; (4) identify the implications for environmental health interventions and sustainable service provision.

Methods

Study design and reporting

This study is a cross-sectional secondary analysis of household data collected during the 2025 CFCT project baseline survey. The household interviews took place between 31 March to 22 April 2025. The current analysis uses the existing de-identified data and does not involve any recruitment or collection of new data from participants. Reporting of this study adheres to the recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [13].

Study setting

Karangura Sub-County is situated in Kabarole District in the western part of Uganda. The parent survey included five hills and households distributed over Kamabale, Kibwa and Nyakitokoli parishes. The sampling frame of the parent survey included approximately 3,492 households and the sample size of 620 households was geographically allocated.

Study population and sample

There were 620 records in the household dataset. All records were retained for indicators with valid information. Denominators differ slightly in some cases because of the information about cooking-energy available for 618 households and lighting-energy for 602 households. Information for all five environmental health domains was complete for 601 households. The adjusted multidomain model

included 599 households because of lack of geographic information in two records for variance estimation.

Data collection and quality assurance

Research assistants conducted the structured digital household survey with the ODK-based mobile data collection. The baseline survey used the skip logic and validation built into the questionnaire, daily data upload when it was possible and supervisor review of the submitted records. The questionnaire covered household demographics, asset list, cooking and lighting energy, water sources, drinking water treatment, sanitation, handwashing and other CFCT thematic indicators.

Household energy indicators

The household was asked about its main source of energy for cooking and lighting. The response options included electricity, biogas, processed gas, solar, kerosene, firewood/charcoal, no energy and others. Although the question was formulated as the main source, a small number of households had more than one response option. For the current analysis, the household was considered as using polluting cooking fuel if the response was kerosene or firewood/charcoal. Electricity, biogas, processed gas and solar were regarded as clean response options. “Other” responses were not classified as polluting or clean. This terminology corrects the preliminary analysis label “biomass cooking fuel” because the derived indicator includes kerosene, which is not biomass fuel. Nevertheless, WHO regards both kerosene and traditional solid fuel combustion as polluting household energy [1,5].

Polluting household energy for lighting or lack of the source was regarded as kerosene, firewood/charcoal or no energy source. Electricity, biogas, processed gas and solar were regarded as clean reported responses. The analysis did not include the measures of stove technology, ventilation, emission rate, cooking location, exposure duration or particulate concentration. Therefore, the energy indicators are the categories of fuel/source that households report.

Water, sanitation and hygiene indicators

The water-source categories correspond to the conservative classification used for Karangura papers series. Households reporting the use of unprotected springs/wells, public hand-dug wells, surface water, valley tanks/dams or vendor-supplied water were classified as using any higher-risk water source. Since households could use multiple sources, the indicator does not reflect the exclusive use of higher-risk water source.

The household sanitation was classified as private/personal in case of flush toilet or personal pit latrine in the household. Other categories formed the comparison group. The term “improved sanitation” is intentionally avoided because the questionnaire does not capture all JMP criteria for classification of service level including slab type, containment and excreta management. The frequency of handwashing with soap was measured with response options of “sometimes”, “rarely” or “never”. “Sometimes” and “often” responses were classified as regular.

Multidomain environmental health burden

The exploratory five-domain environmental health burden score was constructed in order to summarize the co-existence of environmental risks without double-counting WASH components. One point was assigned for each of the following indicators: polluting cooking fuel, polluting lighting fuel or lack of lighting, any higher-risk water source, lack of private/personal sanitation facility and non-regular handwashing with soap. The score was ranging from 0 to 5 where the value indicated the number of unfavorable household environmental health conditions. High multidomain burden for this analysis was defined as three or more of five domains. This score is not a validated clinical or service-quality index and used for descriptive purpose only.

Equity variables and covariates

Socio-economic position was represented by the simple household asset index derived from the baseline quality-of-life and production-asset items and divided into tertiles. It is the study-specific asset count index as opposed to the principal-components wealth index used in Demographic and Health Surveys. Parish variable was used to reflect geographic patterning of environmental risks. Additional covariates in the adjusted model were respondent sex, respondent age, household orphanhood and presence of household member with disability. Village was used as the clustering unit for standard errors adjustment.

Statistical analysis

Binary indicators were described with counts and percentages and the environmental health burden score was described with frequency distribution. Differences across asset tertiles and parishes were tested with Pearson chi-square tests. The adjusted prevalence ratios for high multidomain environmental health burden were estimated with modified Poisson regression with a log link and sandwich standard errors clustered by village [14,15]. The adjusted model included asset tertile, parish, respondent sex, respondent age, household orphanhood and household disability. Reference categories were the highest asset tertile, Kibwa Parish, male respondent, no household orphanhood and no household disability. The results are presented as adjusted prevalence ratios (aPRs), 95% confidence intervals (CIs) and two-sided p-values. The complete-case analysis was used for the multivariable model.

Results

Household energy and WASH conditions

A total of 620 household records constituted the baseline. The proportion of households using polluting cooking fuels was close to complete coverage, 562 out of 618 households (90.9%) reported

use of kerosene or firewood/charcoal. The proportion of households reporting use of polluting lighting fuel or no source for lighting was 322 out of 602 (53.5%). Environmental risks related to WASH were common as well. Any higher-risk water source was reported by 451 households (72.7%), lack of private/personal sanitation facility by 85 (13.7%) and non-regular handwashing with soap by 314 (50.6%) (Table 1; Figure 1).

Multidomain environmental health burden

Full information on the five environmental health domains was available for 601 households. Zero-scored households were not present. The proportion of households with one risk domain was 61 (10.1%), two domains – 170 (28.3%), three domains – 221 (36.8%), four domains – 116 (19.3%) and five domains – 33 (5.5%). Overall, 370 out of 601 households (61.6%) fulfilled the criteria of high multidomain burden and had at least three adverse domains (Table 2; Figure 2). The presence of no zero-score household in this sample does not mean the absence of environmental risk in all aspects, which were not measured by the index (five questionnaire-derived environmental domains) as well as the absence of exposures such as ventilation, ambient pollution, microbial water quality or sanitation containment.

Inequalities by socioeconomic factors

There were considerable differences in environmental-health status depending on the position of a household in the asset distribution (Table 3; Figure 3). Households in the lowest asset tertile had 64.6% with high multidomain burden compared to 69.7% in the middle tertile and 50.5% in the highest tertile ($p<0.001$). The use of polluting lighting showed strong socioeconomic gradient: it occurred in 59.6% of households in the lowest tertile and 60.7% in the middle tertile against 40.4% in the highest tertile ($p<0.001$). Lacking of a personal sanitation was more frequent in the lowest tertile (19.8%) than in the middle (13.0%) or highest tertile (8.3%; $p=0.003$). Also, non-regular handwashing was less common in the highest tertile (38.8%) than in the middle (51.7%) and lowest tertiles (61.4%; $p<0.001$).

Usage of polluting cooking fuel was different from the previous example. It was very high in each asset category and it was highest in the highest asset tertile (97.6%), second highest in the middle tertile (89.4%) and third highest in the lowest tertile (85.9%) ($p<0.001$). This non-standard gradient illustrates that position of a household on the asset ladder cannot predict every type of environmental-health exposure in the same way. Fuel availability, cooking practices, household size, needs in food preparation and energy stacking could determine the type of cooking fuel in addition to the level of wealth in the rural area.

Geographic differences

Differences between parishes were less pronounced than socioeconomic differences for the overall multidomain burden (Table 4; Figure 4). Prevalence of high multidomain burden was 65.4% in Kamabale, 57.4% in Kibwa and 61.6% in Nyakitokoli ($p=0.377$). The usage of polluting cooking fuel was not the same across parishes (ranged from 85.9% in Kibwa to 94.3% in Kamabale; $p=0.037$). Usage of higher-risk water source also varied geographically: from 66.2% in Kibwa to 77.0% in Nyakitokoli ($p=0.033$). Differences between parishes in terms of polluting lighting, sanitation and handwashing were not significant ($p>0.05$).

Adjusted association with high multidomain burden

In the adjusted modified Poisson regression, the number of observations was 599 households. The adjusted prevalence ratio (aPR) of high multidomain burden in the middle asset tertile compared to the highest was 1.39 (95% confidence interval (CI) 1.12-1.72; $p=0.003$) and in the lowest tertile was 1.34 (95% CI 1.02-1.77; $p=0.036$). Kamabale had a higher adjusted prevalence of high burden than Kibwa (aPR 1.23, 95% CI 1.00-1.50; $p=0.050$); while the estimate for Nyakitokoli was not statistically significant compared to Kibwa (aPR 1.13, 95% CI 0.93-1.36; $p=0.210$).

Households reporting orphanhood had higher adjusted prevalence of high multidomain burden than households without orphanhood (aPR 1.43, 95% CI 1.27–1.60; $p<0.001$). Household disability,

respondent sex and respondent age were not independently associated with high burden at $p<0.05$. These associations are descriptive and should not be interpreted causally because the study is cross-sectional and the burden score represents coexisting household conditions rather than a disease outcome (Table 5; Figure 5).

Discussion

Principal findings

This analysis demonstrates that household environmental-health disadvantage in rural Karangura exceeds the individual level of any WASH or energy indicator. Nine out of ten households reported a category of polluting cooking fuel, more than half reported a polluting lighting source or lack of lighting, three quarters reported at least one higher risk water source and almost half reported non-regular handwashing with soap. With the use of five risk domains, almost two thirds of households reported at least three adverse environmental-health conditions. The major inequality determinant was socioeconomic – a combination of multidomain environmental health disadvantage, polluting lighting, lack of private sanitation facilities and non-regular handwashing was much more frequent outside the highest asset tertile.

Household energy transition and environmental health

High prevalence of polluting cooking fuel use fits the wide range of evidence on heavy dependence on solid fuels and kerosene in rural and low resource settings in sub-Saharan Africa [1,2]. The guidance of WHO notes that successful household energy transition involves not only the substitution of one household energy source by another but the transition to cleaner fuels and technologies in all spheres of consumption (cooking, heating, lighting) [5,16]. The findings in Karangura confirm this point. If solar energy or electricity were used for lighting, the use of firewood/charcoal or kerosene for cooking prevailed.

Studies conducted in Uganda demonstrate that household energy use depends on affordability, education, location and fuel availability [6,7]. The unexpected finding of higher frequency of polluting cooking fuel use in the highest asset tertile should not be interpreted as higher exposure among rich households. Cooking fuel choice in rural households might be associated with energy stacking, increased food demand, access to bought charcoal, availability of certain fuels or inadequacy of the asset measure. The questionnaire did not include indicators of stove efficiency and emissions. Future research should distinguish between primary and secondary fuels, cooking location, stove type and ventilation and should include measurement of PM2.5 or carbon monoxide whenever possible.

Overlapping WASH and energy disadvantage

Overlapping environmental health risks have important practical implications. A household that reports a polluting lighting source is likely to suffer from lack of reliable water, soap or private sanitation facilities, thus competing interventions for scarce household resources. The 2025 JMP report and recent research on Uganda demonstrate persistent inequalities in water and sanitation among poor and underserved households [8,9]. Our asset-stratified results indicate the same trend for sanitation, handwashing and multidomain burden. Thus, integrated planning should not assume automatic gains in one sector as an indicator of household environmental-health security.

The burden score was developed from five distinct domains instead of the preliminary Paper 5 composite indicator. The preliminary master analysis included a "high WASH risk" indicator and then added again sanitation and drinking-water treatment to the environmental-health score, doubling the same components. It also regressed the composite outcome on variables that form the composite itself, generating mechanically strong associations. This revised analysis eliminates this circularity. The new burden score is simpler because each of the risk domains contributes once to it and the adjusted model includes socioeconomic, demographic and geographic predictors, not the components of the outcome itself.

Socioeconomic and geographic implications

The asset-based results suggest that environmental-health programmes should be pro-poor but not depend only on the targeting by wealth. The burden was elevated in both the middle and lowest asset tertiles relative to the highest tertile, while the pattern of cooking fuel use differed from those observed for lighting, sanitation or handwashing. Thus, environmental-health programmes should include household profiling to establish what kind of domains limit the household rather than assign it a single label of vulnerability.

Geographic differences are less evident in the overall burden score but are clear for water-source use and cooking-energy categories. These differences are important for planning services. Water intervention should be aligned with reliability and safety of the water sources, while clean energy programmes should take into account local access to electricity, LPG, biogas, improved stoves or other local solutions. Monitoring system at the district and community levels can include a small set of energy and WASH indicators to detect households or villages with multiple environmental-health problems.

Policy and programme implications

For Karangura an integrated response would include four elements. First, programmes for household energy transition should involve sustainable shift from kerosene and traditional solid-fuel combustion towards cleaner energy technologies affordable and maintainable in local conditions. Second, WASH programmes should increase access to reliable and safe water sources, quality of sanitation facilities and promote handwashing with soap. Third, equity monitoring should disaggregate energy and WASH indicators by household economic and geographic position. Fourth, further assessment of household environment should include measures of exposure such as stove and kitchen characteristics, PM2.5 or carbon monoxide, microbial water quality and sanitation containment to link questionnaire categories to exposure measures.

Strengths and limitations

This study has several strengths. It was based on a large sample of rural households with good geographic coverage and measured energy, water, sanitation, hygiene and socioeconomic conditions in the same households. The revised analysis does not classify kerosene as biomass, does not make unjustified JMP sanitation claims based on the questionnaire and includes the burden score in which each of the risk domains contributes once. Modified Poisson regression provides prevalence ratios and the model incorporates clustered standard errors to control for within-village correlation.

There are several limitations of the study. First, the cross-sectional design prevents causality inference. Second, energy and WASH indicators are self-reported. Third, the questionnaire does not include stove efficiency, ventilation, fuel quantity, cooking duration, kitchen location, PM2.5, carbon monoxide and personal exposure measures, thus the reported categories of polluting fuel are proxies for exposure. Fourth, there were multiple responses in a few energy records despite the wording "main source". Fifth, the water-source variables are not backed up by microbial testing and the sanitation variable lacks technical details for JMP classification. Sixth, the asset tertiles are based on a simple study-specific asset score and should not be equated to the nationally-standardized wealth index. Seventh, the five-domain burden score is exploratory, gives equal weight to each of the domains and is not a validated health-risk scale. Finally, the data were collected during a short period in March-April 2025 and seasonal variation in fuel use, water availability and hygiene conditions are not reflected in these data.

Conclusions

Overlapping environmental-health risks of the polluting energy use and WASH problems were common for households in rural Karangura. Almost all households used polluting cooking fuel, while polluting lighting sources, higher risk water-source use and non-regular handwashing were also widespread. Almost two thirds of households with complete data suffered from at least three out of

five adverse environmental-health domains, and this multidomain burden was especially frequent among households outside the highest asset tertile.

Thus, the planning of household environment should not remain separate for the household energy and WASH interventions. Cleaner cooking and lighting, reliable and safe water access, sanitation improvement and regular handwashing should be planned together, with socioeconomic and geographic disaggregation of the households to find households with multiple environmental-health deficits. Further longitudinal research should combine the household environmental-health indicators with the measures of air pollution, microbial water quality and sanitation performance to establish combinations of these risk factors associated with health burdens and possible benefit from integrated interventions.

List of abbreviations

aPR: adjusted prevalence ratio

CFCT: Child Focused Community Transformation

CI: confidence interval

HAP: household air pollution

JMP: WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene

KFHI: Korea Food for Hungry International

ODK: Open Data Kit

PM2.5: particulate matter with aerodynamic diameter ≤2.5 μm

PR: prevalence ratio

SDG: Sustainable Development Goal

STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

WASH: water, sanitation and hygiene

WHO: World Health Organization

Tables

Table 1. Household energy and WASH environmental-health indicators

Indicator	Denominator	Households, n	Percent
Polluting cooking fuel	618	562	90.9
Polluting lighting fuel or no lighting	602	322	53.5
Any higher-risk water source	620	451	72.7
No private/personal sanitation facility	620	85	13.7
Non-regular handwashing with soap	620	314	50.6
High multidomain environmental-health burden (≥3 of 5 domains)	601	370	61.6

Note: Polluting cooking fuel includes reported kerosene or firewood/charcoal. Polluting lighting includes kerosene, firewood/charcoal or no lighting source. Sanitation is described as private/personal rather than "improved" because the questionnaire did not capture all JMP service criteria.

Table 2. Distribution of the five-domain environmental-health burden score (N=601)

Risk domains present	Households, n	Percent
1	61	10.1
2	170	28.3
3	221	36.8
4	116	19.3
5	33	5.5

The five domains were polluting cooking fuel, polluting lighting fuel or no lighting, any higher-risk water source, absence of a private/personal sanitation facility, and non-regular handwashing with soap. High burden was defined as ≥3 domains.

Table 3. Environmental-health indicators by household asset tertile

Indicator	Lowest tertile, %	Middle tertile, %	Highest tertile, %	p value

Indicator	Lowest tertile, %	Middle tertile, %	Highest tertile, %	p value
Polluting cooking fuel	85.9	89.4	97.6	<0.001
Polluting lighting fuel or no lighting	59.6	60.7	40.4	<0.001
Any higher-risk water source	70.0	81.6	66.5	0.001
No private/personal sanitation facility	19.8	13.0	8.3	0.003
Non-regular handwashing with soap	61.4	51.7	38.8	<0.001
High multidomain environmental-health burden (≥3 of 5 domains)	64.6	69.7	50.5	<0.001

Pearson chi-square p values compare the distribution of each binary indicator across the three asset tertiles. Denominators vary slightly for energy indicators because of missing or "other" responses.

Table 4. Environmental-health indicators by parish

Indicator	Kamabale, %	Kibwa, %	Nyakitokoli, %	p value
Polluting cooking fuel	94.3	85.9	91.5	0.037
Polluting lighting fuel or no lighting	54.9	50.0	54.3	0.644
Any higher-risk water source	69.6	66.2	77.0	0.033
No private/personal sanitation facility	10.8	14.8	14.8	0.448
Non-regular handwashing with soap	55.7	53.5	47.2	0.164
High multidomain environmental-health burden (≥3 of 5 domains)	65.4	57.4	61.6	0.377

Table 5. Adjusted modified Poisson model for high multidomain environmental-health burden (N=599)

Variable	aPR	95% CI	p value
Middle vs highest asset tertile	1.39	1.12–1.72	0.003
Lowest vs highest asset tertile	1.34	1.02–1.77	0.036
Kamabale vs Kibwa parish	1.23	1.00–1.50	0.050
Nyakitokoli vs Kibwa parish	1.13	0.93–1.36	0.210
Female vs male respondent	1.06	0.92–1.23	0.429
Respondent age, per year	1.00	1.00–1.00	0.710
Household with orphan(s)	1.43	1.27–1.60	<0.001
Household with member with disability	1.11	0.94–1.30	0.206

Reference categories: highest asset tertile, Kibwa Parish, male respondent, no household orphanhood and no household disability. Standard errors were clustered by village.

Figures and figure legends

Figure 1. Household energy and WASH environmental-health risks in Karangura.

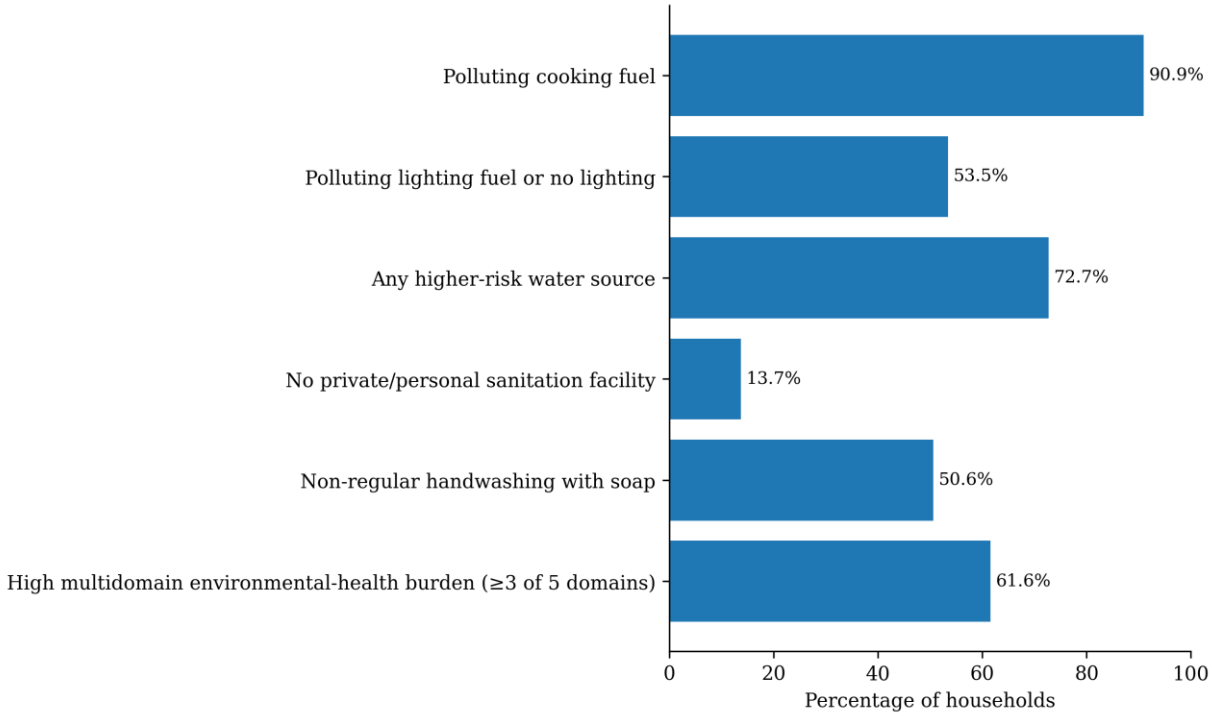


Figure 2. Distribution of the five-domain environmental-health burden score among 601 households with complete information.

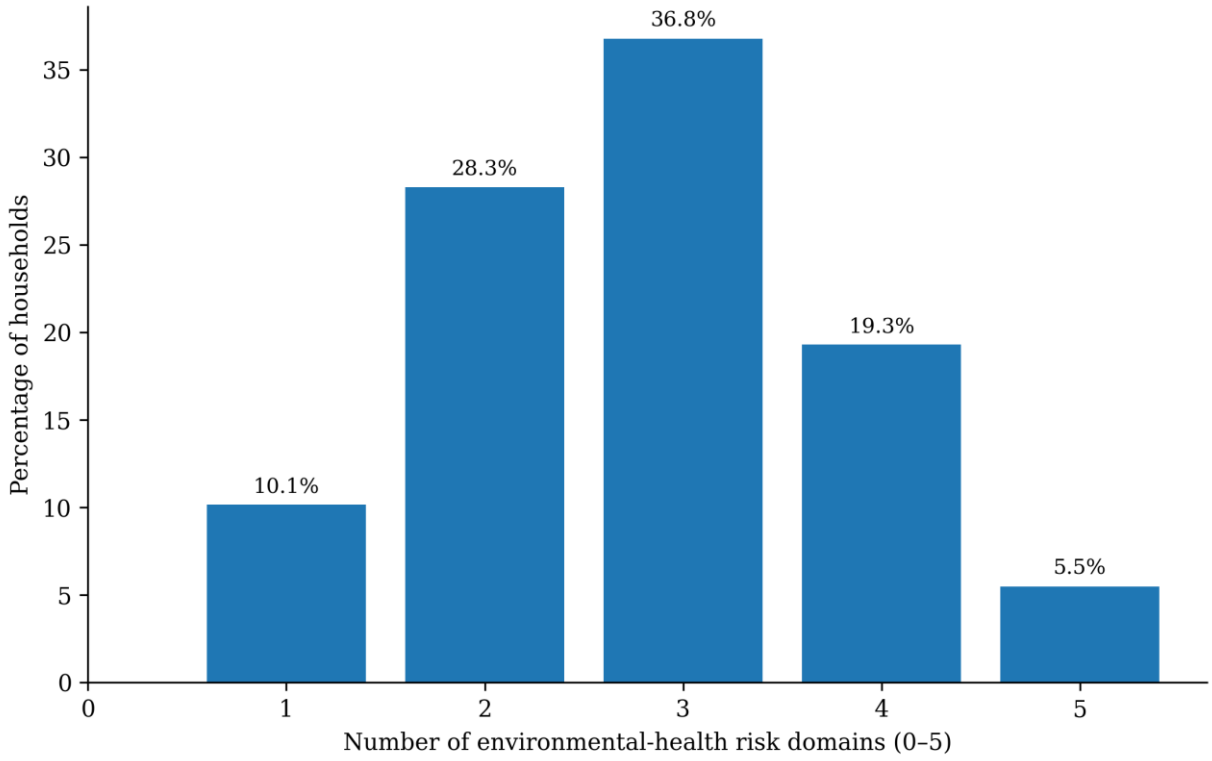


Figure 3. Household energy and WASH environmental-health indicators by asset tertile.

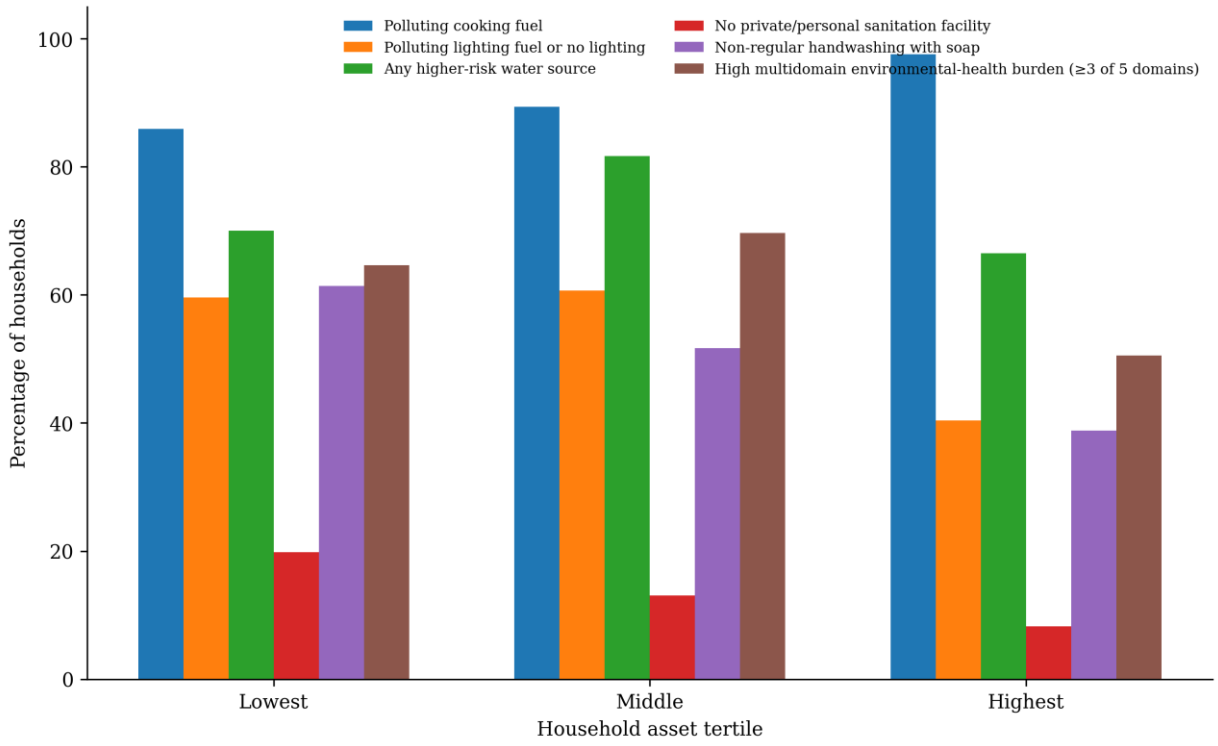


Figure 4. Household energy and WASH environmental-health indicators by parish.

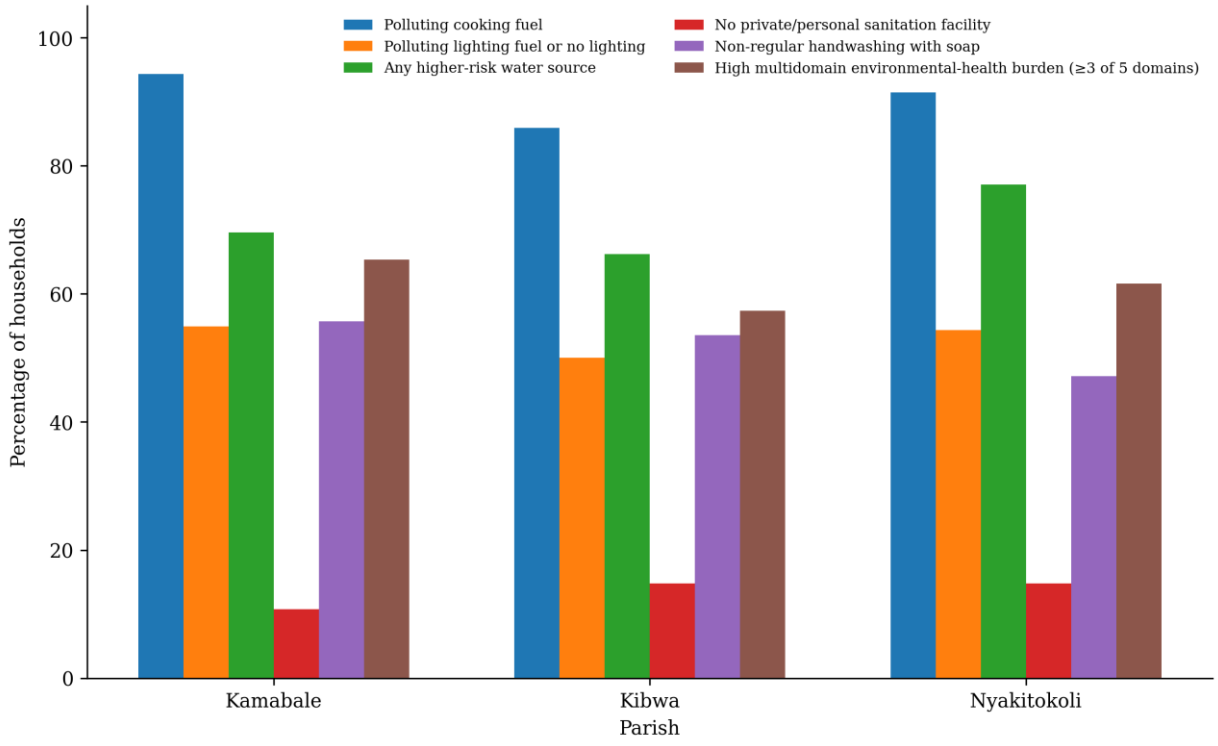
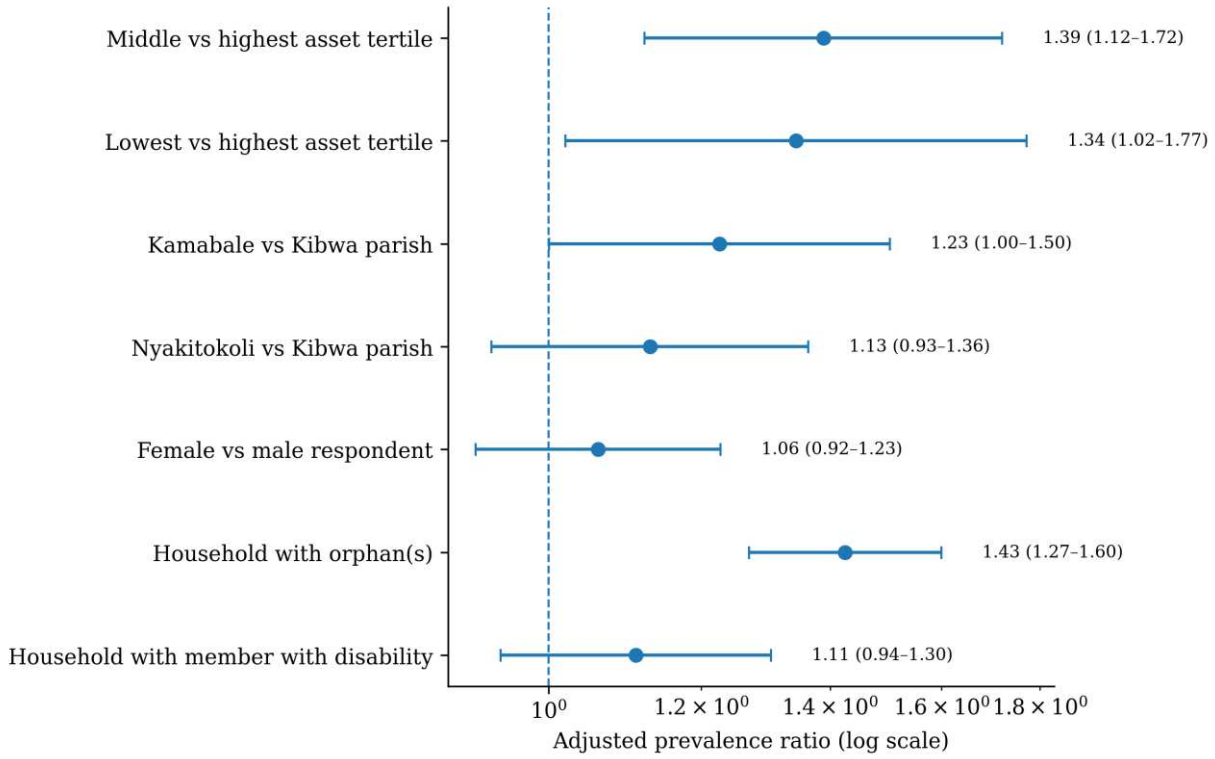


Figure 5. Adjusted prevalence ratios for high multidomain environmental-health burden. Modified Poisson estimates use village-clustered robust standard errors and adjust simultaneously for the displayed variables plus respondent age.



Declarations

Ethics approval and consent to participate

Clinical trial number: not applicable. Secondary analysis of anonymized household survey data was done using data obtained between 31st March to 22nd April 2025 in the Karangura CFCT baseline. This is because no new data was collected and there was no contact with any study participants in the current analysis. The baseline exercise was undertaken as part of the project's monitoring and evaluation activities and the protocols stipulated voluntary informed consent and confientiality safeguards.

Consent for publication

Not applicable. This manuscript reports aggregate, de-identified household data and contains no identifiable individual information, images or case details.

Availability of data and materials

The de-identified data and code used in the analyses for this paper are available from the corresponding author upon request, pending approval by the data custodian and relevant ethical and confidentiality policies.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SCO developed the manuscript concept, led the parent baseline methodology and project coordination, curated the analytical dataset, led the revised statistical analysis and visualization, and drafted the original manuscript. CKa, SK, DB, SO, and AN contributed to environmental-health framing, literature review, interpretation of household energy use and overlapping WASH risks, and critical revision of the manuscript. CA and UMW contributed to methodological development, interpretation of socioeconomic and geographic disparities, and critical revision of the manuscript. IS contributed to public-health analysis, WASH interpretation, literature review, and manuscript revision. PN and IRO contributed to epidemiological methodology, interpretation of analytical findings, and critical revision of the manuscript. SN contributed to methodological and health-systems analysis, supervision, and manuscript revision. HS and GN contributed to clinical and public-health interpretation and manuscript

revision. MH contributed to parent study implementation, field coordination, data quality assurance, and manuscript revision. RJO, MM, CKe, AT, and BK contributed to local programme interpretation, district health systems analysis, contextual validation, and critical revision of the manuscript. All authors reviewed and approved the final manuscript and agreed to be accountable for their respective contributions.

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Authors' information

The authors have multi-disciplinary background in public health, epidemiology, monitoring and evaluation, child health, district health systems, implementation science and community health programs in Uganda. This combination of skills shaped the analysis of findings on energy, WASH, environment, and equity.

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