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Ambient temperature and intake of sugar-sweetened beverages among women across 16 countries in sub-Saharan Africa: a cross-sectional analysis

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Abstract

Background

While a growing body of evidence associates high ambient temperatures with an increased risk of sugar-sweetened beverage consumption, this relationship remains understudied in sub-Saharan Africa population. Our study aimed to quantify the association between ambient temperature and consumption of sugar-sweetened beverages (SSBs) among women in sub-Saharan Africa.

Methods

We conducted a secondary analysis of data from 16 countries in sub—Saharan African to assess the association between ambient temperature and the prevalence of SSB consumption among women aged 15—49 years. The study utilized geocoded Demographic and Health Survey (DHS) data on women's feeding practices; spatially linked to remote sensed maximum daily 2—meter air temperature. We used modified Poisson regression with natural cubic splines, controlling for potential confounders, to estimate the association between ambient temperature and the prevalence of SSB consumption. We also examined whether these relationships differed by age group, number of children, marital status, fridge ownership, place of residence (rural or urban), wealth quintile and education level.

Findings

Of the 300,314 women, 22.2% (95%CI [21.8—22.6]) reported drinking at least one kind of SSB a day preceding the DHS interview. Overall, mean daily temperature at the 90th percentile was associated with a 24% higher prevalence of consuming SSBs (aPR = 1.24, 95% CI [1.13—1.36], $p < 0.001$) compared to the minimum prevalence temperature percentile (temperature at which prevalence was lowest). These associations varied substantially across countries, ranging from 12% in Ethiopia (aPR = 1.12, 95% CI [0.94—1.35], $p = 0.201$) to 44% in Senegal (aPR = 1.44, 95% CI [1.19—1.73], $p < 0.001$). Associations between heat exposure and SSB intake were more pronounced among women living in urban areas and in higher wealth quintiles, however, there was no evidence of effect modification (interaction effect p-value > 0.05).

Interpretation

Our analysis demonstrated substantial regional heterogeneity in the association between ambient temperature and intake of SSBs among women in sub—Saharan Africa. This evidence has important implications in planning heat—related nutritional interventions.

Introduction

Sugar—sweetened beverages (SSBs) refer to drinks that contain added sugars or other caloric sweeteners including carbonated and non—carbonated drinks, fruit juice concentrates, milk shakes, sweetened tea and coffee, and energy drinks[1]. Globally, the consumption of added sugar particularly

through desserts and SSBs, is associated with increased risk of cardio-metabolic diseases, including obesity, type 2 diabetes and cardiovascular diseases[2–4]. The burden varies substantially across regions and socio—demographic groups[3]. Notably, low and middle income countries are increasingly facing a double burden of disease: persistent under malnutrition and infectious diseases alongside a rising prevalence of cardio-metabolic diseases, driven in part by rapid urbanization and climate change—induced shifts toward unhealthy dietary practices[5–8].

Global estimates indicate regional disparity in SSB consumption with highest prevalence observed in high—income Western countries[9,10]. Nevertheless, emerging evidence shows that the prevalence of SSB intake is increasing most rapidly in sub—Saharan Africa[10]. Furthermore, patterns by socio—demographic factors differ substantially across settings: in high—income countries, the burden is greater among rural and lower socio—economic groups, whereas in developing countries urban and more economically empowered groups are at increased vulnerability[10–12].

Growing evidence demonstrates the role of climate change in the increasing prevalence of SSB consumption through rising temperatures[11,13]. For example, higher ambient temperatures may increase the need for hydration because of increased water loss through sweeting[14]. Other plausible direct mechanisms include targeted marketing during hot weather and perceived palatability of cold, sugary drinks may drive consumer preferences for SSBs instead of plain water. Climate induced food insecurity may also affect availability, variety and nutritional quality of unprocessed whole staple foods[15,16]. Although, sub—Saharan Africa has experienced a disproportionately sharp rise in SSBs consumption relative to global trends between 1990 and 2018[10], the influence of changing climatic conditions on this dietary shift remains unexamined. Current regional literature examines the associations between hot beverage consumption and esophageal cancer risk or the burden of SSB—associated cardio—metabolic diseases[2,17,18], leaving the potential dietary consequences of ambient heat exposure largely unexplored. To our knowledge, this is the first study to examine whether high ambient temperatures are associated with an increase SSB intake in African populations. To address this empirical gap, we quantified the association between ambient temperature and SSB intake among women of reproductive age using multi—country Demographic and Health Survey (DHS) data from 16 sub-Saharan African nations and maximum daily 2 —meter air temperature from European Center for Medium-Range Weather Forecasts ERA5-Land reanalysis[19,20].

Methods

Study design, population and data sources.

This cross-sectional study was based on individual-level data on feeding practices among women from 16 DHS datasets in Africa[20]. The Demographic and Health Surveys (DHS) are nationally representative surveys conducted routinely (about every 5 years) by government agencies in LMIC with support from the U.S Agency for International Development (USAID)[21]. DHS uses standardized questionnaires and

sampling methods to collect comprehensive information on country-specific demographics and health data, including nutrition, accidents, domestic violence, mental health, and women empowerment among others[20].

The study population consisted of all women aged 15–49 across 16 sub-Saharan Africa countries (Table 1). The analysis was restricted to countries that had included GPS information, women's dietary practices and other important covariates that would facilitate heat-exposure analysis. Detailed description of these datasets is found in the appendix p4.

Table 1

Survey weighted prevalence estimates of SSB intake among women during the day or night preceding the DHS interview across 16 sub-Saharan Africa countries and the distribution of daily maximum temperatures (Tmax) across survey clusters by country. Mean daily Tmax represents the average of the cluster-specific mean, reported as mean (standard deviation [SD]). Median daily Tmax represents the average of the cluster-specific median, reported as median (interquartile range [IQR]). Daily minimum and maximum Tmax represents daily temperatures observed within each cluster over the study period, summarized across clusters within each country.

Country	**Women (weighted)**	**Mean Daily Tmax, mean (SD) (°C)**	**Median Daily Tmax, median (IQR) (°C)**	**Minimum Daily Tmax (°C)**	**Maximum Daily Tmax (°C)**	**SSB prevalence, % (95% CI)**
Angola	14,717	29.0 (3.1)	28.9 (27.1–30.7)	27.0	30.3	38.3 (36.3–40.4)
Burkina Faso	17,659	32.8 (2.9)	32.7 (30.6–34.9)	31.8	33.9	20.4 (19.3–21.7)
Congo DR	27,583	29.1 (3.1)	29.2 (27.1–31.1)	28.0	30.3	12.8 (11.7–14.1)
Côte d'Ivoire	14,877	31.5 (2.0)	31.4 (29.9–33.0)	30.8	32.1	25.7 (23.9–27.5)
Ethiopia	21,395	25.9 (4.4)	25.7 (22.3–28.9)	25.0	26.9	9.3 (8.3–10.4)
Ghana	15,014	32.6 (2.0)	33.0 (30.9–34.4)	31.9	33.0	26.1 (24.9–27.4)
Kenya	32,156	27.2 (4.1)	26.7 (24.0-29.9)	26.4	27.8	12.4 (11.5–13.2)
Lesotho	6,413	24.0 (3.2)	23.8 (21.8–25.9)	22.5	25.5	32.9 (30.8–35.1)
Malawi	20,849	25.4 (2.3)	25.4 (23.8–27.0)	24.7	26.2	9.2 (8.6–9.8)
Mali	17,347	34.2 (2.9)	34.4 (32.6–36.1)	33.0	35.1	25.7 (24.0-27.5)
Mozambique	13,183	29.4 (3.3)	29.6 (27.2–	28.0	31.1	15.1 (14.1–16.3)

Country	Women (weighted)	Mean Daily Tmax, mean (SD) (°C)	Median Daily Tmax, median (IQR) (°C)	Minimum Daily Tmax (°C)	Maximum Daily Tmax (°C)	SSB prevalence, % (95% CI)
			31.8)			
Nigeria	39,050	35.2 (3.2)	35.2 (33.0-37.3)	34.5	35.7	39.0 (37.9–40.1)
Rwanda	14,283	24.0 (2.0)	23.8 (22.5–25.4)	23.0	24.8	12.0 (11.2–12.9)
Senegal	16,583	36.4 (3.4)	36.6 (34.2–38.8)	34.8	37.3	43.7 (41.1–46.4)
Tanzania	15,254	27.0 (2.4)	27.1 (25.5–28.6)	26.3	27.4	15.1 (13.9–16.3)
Zambia	13,951	26.7 (2.8)	26.7 (24.8–28.5)	25.5	27.9	17.0 (15.9–18.3)
Overall	**300,314**	**29.8 (5.0)**	**29.7 (26.1–33.7)**	**28.4**	**30.2**	**22.2 (21.8–22.6)**

Exposure

The primary exposure was maximum daily 2m air temperature on the day before the DHS survey interview (lag 0), one day and two days preceding the survey (lag 1 and lag 2) to account for delayed effects. For sensitivity analysis, we used mean daily temperature as alternative heat exposure. In addition, we adjusted for relative mean daily relative humidity. The ambient 2m air temperatures variables and relative humidity were obtained from the European Center for Medium-Range Weather Forecasts ERA5-Land reanalysis[19]. ERA5 has been rigorously validated and is widely recognized as a reliable data source for studies on environmental epidemiology, particularly for assessing the effects of heat exposure on health[22,23]. Since relative humidity was not directly available in ERA5-Land products, we derived it using humidity-related variables, which include 2m air temperature and dew point temperature (appendix p2). Temperature and humidity variables were resampled using bilinear interpolation to align with the DHS geocoded residential cluster and exported at resolution of 500m using Google Earth Engine API[24]. Each of these variables was extracted at the DHS survey cluster location by calculating the mean value within a 5 km buffer for rural clusters and a 2 km buffer for urban

clusters, reflecting the standard spatial displacement applied to protect survey respondents' confidentiality[25].

Outcome

The primary outcome was the consumption of sugar-sweetened beverages (SSBs), a binary variable equal to 1 if a woman reported to have consumed any sugar-sweetened beverage the day or night preceding DHS interview day and 0 otherwise. To assess the association between ambient temperature and SSB consumption, we restricted our analysis to sugar sweetened carbonated drinks including soda/energy drinks and sugar-sweetened fruit juices that are often consumed chilled when temperature is high[11]. In our analysis, we used the description 'sugar-sweetened juices' to refer to fruit juice and fruit flavored drinks. The outcome variable was derived from DHS's minimum dietary diversity module, developed by Food Agricultural Organization (FAO) for measuring women's nutritional adequacy[26].

Statistical analysis

We assessed the association between ambient temperature and the consumption of SSBs using two stage modelling approach[27]. In the first stage, a modified Poisson regression model was used to establish region specific associations of SSB consumption and maximum daily 2m air temperature. We modelled possible non-linear and delayed-exposure response relationships between temperature and consumption of SSBs using distributed lag non-linear models (DLNMs) with a maximum lag of up to two days. We used natural cubic splines with two internal knots placed at 50th and 90th percentiles. Natural cubic splines are the most common choice for temperature —health studies[28,29]. To ensure we have enough data for this stage[30,31], we first grouped first level administrative regions into former DHS geographies. Where needed, we further aggregated regions with similar climatic characteristics to attain minimum case count of 200 (appendix p 5–8).

In the second stage, a multivariable multi-level meta-regression was used to obtain pooled estimates using region specific coefficients from the first stage[27]. To explain regional heterogeneity in associations, we included regional mean maximum temperature and regional maximum temperature range in the second stage. Confounders in first stage and meta-predictors in second stage were checked for multi-collinearity using variance inflation factors (VIF). We used best linear unbiased predictions (BLUPs) from the meta-regression model to obtain robust regional estimates for regions with small populations by borrowing information from neighboring regions[32,33]. Heterogeneity in multivariable regression model was assessed using I^2 statistic. To assess potential modification effect, we performed stratified analyses by age, education level, wealth index, pregnancy, fridge ownership, marital status and place of residence. We tested difference between group levels in regression models using Wald tests, with p values below 0.05 deemed statistically significant.

Several sensitivity analyses were conducted to evaluate the robustness of our findings. First, we used mean daily temperature as an alternative temperature definition to assess these associations. Secondly, we fitted natural cubic splines with knot placements at 10th and 90th, 33rd and 66th, and linear model. Since higher humidity may impair human body's ability to cool itself through sweat[34], we adjusted for relative daily average humidity of the day preceding the survey in the main model. Finally, because we could not distinguish natural fruit juice from fruit drinks with added sugars, we conducted separate analyses for sugar-sweetened carbonated beverages and fruit juices.

All models were adjusted for socio-demographic factors including place of residence, wealth index, age, highest level of education and number of living children, marital status and fridge ownership (appendix p3). Estimates for cumulative effects (lag 0–2) from exposure response curves were reported as adjusted prevalence ratios (aPR) at the 90th percentile relative to the minimum prevalence temperature percentile (MPT) alongside their 95% confidence intervals (95%CI). Statistical analyses were two-sided, with p-values < 0.05 deemed statistically significant, and were performed using R software version 4.3.3 (https://www.r-project.org/), the packages dlnm and mixmeta. All statistical analyses accounted for the complex survey design. Missingness was below 0.1% across all variables; therefore, no multiple imputation for missing data was performed.

Results

Our analysis included 300,314 women across 115 sub-national regions in 16 sub-Sharan Africa Countries. The pooled prevalence of SSB consumption was 22.2% (21.8–22.6) with the highest prevalence observed in Senegal at 43.7% (41.1–46.4), followed by Nigeria at 39.0% (37.9–40.1) and lowest in Malawi at 9.2% (8.6–9.8). Across the study countries, the average maximum daily temperature was 29.8^{o}C (SD 5.0) and country level means ranging from 24.0^{o} C (SD 3.2) in Lesotho to 36.4^{o} C (SD 3.4) in Senegal. Figure 1 shows the geographical variation of average daily maximum temperature at various DHS sampling locations.

There was significant variation in SSB consumption prevalence at subnational level across all the countries as shown in the **appendix p8-10** (Rao-Scott F test p-value < 0.001). Additionally, the SSB consumption prevalence among urban-residing women was more than twofold higher than that among women residing in rural areas, (32.3% [31.6–32.9]) vs (14.7% [14.3–15.2]). Similar patterns were observed among women in the middle or higher wealth groups as compared to those in lower wealth index group (appendix p11).

We found evidence of positive association between maximum daily temperature and the prevalence of consuming sugar-sweetened beverages (Fig. 2 and Fig. 3). Overall, we estimated that the 90th (33.1^{o} C) mean daily temperature percentile was associated with 24% (adjusted prevalence ratio [aPR] = 1.24; 95% CI, 1.13–1.36; p < 0.001) higher prevalence of consuming SSBs as compared to the MPT (24.5^{o} C). Nationally, there was substantial heterogeneity in the association of maximum temperature on SSB

intake ranging from 12% (aPR = 1.12; 95% CI, 0.94–1.34; p = 0.201) in Ethiopia to 44% (aPR = 1.44; 95% CI, 1.19–1.73; p < 0.001) in Senegal as shown in Fig. 4.

Our analysis revealed differential effects of heat across the lag periods (appendix p 17). The strongest effects were observed for cumulative effects, followed by weaker but significant effects on same day as exposure (lag 0) and one day before exposure (lag 1). The effects were not significant two days before exposure (lag 2).

Sociodemographic characteristics did not significantly modify the temperature–SSBs consumption associations except for household size, where women with smaller family sizes were more vulnerable to SSB consumption (aPR = 1.25; 95% CI, 1.15–1.36; p < 0.001, p-for interaction = 0.010). Regarding wealth, significant positive associations were observed only among women in middle or higher wealth groups (aPR = 1.24; 95% CI, 1.13–1.35; p < 0.001).

Our results remained robust across multiple sensitivity specifications, including mean daily temperature and varied spline knot configurations (appendix p 18–22).

Discussion

Overall, we found a positive association between ambient temperature and intake of sugar-sweetened beverages among women in sub-Saharan Africa. These findings were robust across sensitivity analyses. That is, although point estimates shifted marginally under alternative exposure metrics including varying spline knot specifications, relative humidity adjustment, and beverage subgroup disaggregations, none of these model specifications altered the direction of the effect estimates substantially in the pooled regression analyses. However, subgroup analyses revealed marked country-level heterogeneity in the observed associations. The magnitude—and in some instances, the exposure level—of the temperature effect varied across geographic regions, likely reflecting differences in regional dietary patterns.

Given that temperatures across much of Africa are projected to exceed 3^{o} C above the temperature recorded in the period 1981—2010 by 2070-2100[35], these findings have important implications particularly for sub—Saharan Africa, which bears disproportionate health burden of climate change[22,36,37]. Specifically, these insights could inform targeted nutritional policies to mitigate the compounding impacts of rising temperatures on maternal health in a region facing a rapidly growing burden of cardio metabolic diseases, including obesity and cardiovascular conditions[2,3,11,22,38].

In contrast to findings from high countries[11], stronger associations were observed among women with lean families or higher economic status, suggesting a greater burden of risk in these population groups. These findings are supported by earlier studies reporting higher prevalence of SSBs among women in urban settings and higher socio-economic status in sub—Saharan Africa[10]. This pattern is especially concerning given that these groups are associated with the rising burden of obesity, diabetes and

cardiovascular diseases in sub —Saharan Africa[3,39]. Taken together, these findings underscore the urgent need for heat stress related nutrition policies targeting these socio-demographic groups.

Various underlying direct and indirect mechanisms are hypothesized to underlie the observed associations. Psychological and physiological triggers for cold beverages, perceived palatability and hot-weather marketing promotions may directly drive the consumption[11]. Lack of trust in piped water in most urban setting in sub-Saharan African countries may lead consumers to default to SSBs, including sports drinks that are perceived to be healthy and safe alternatives[16]. Furthermore, because of high taxes on bottled water, consumers may prefer bottled sugar sweetened beverages, which they may perceive as offering additional nutritional benefits. Indirect pathways include drought and chain supply that may negatively affect access to a variety of food options[6,40].

This study had some limitations. The use of weather reanalysis data may not fully capture heat exposure particularly the indoor context. Secondly, despite adjusting for large set of confounders there was still substantial unexplained heterogeneity (69.3%). Third, because our analysis was focused on sugar-sweetened beverages, which are often consumed, chilled when temperatures are high, other SSBs such iced tea and iced coffee, that may also be consumed during hot weather were excluded. However, these beverages are generally less common and their exclusion may therefore have introduced minimal bias. In addition, based on the available data, we could not distinguish between hot and iced tea or coffee. Data limitations also prevented us from quantifying the amount sugar per SSB servings as well as frequency. Finally, because of the cross-sectional nature of the study, the observed associations should be interpreted cautiously and not as evidence of causation. Nonetheless, this study is the first and largest to rigorously examine the association between ambient temperature and consumption of sugar-sweetened beverages in Africa providing critical insights on the potential intersection of nutrition and climate change.

In conclusion, our analysis provides important empirical evidence on the impact of heat on women's dietary practices in sub-Saharan Africa. Increased consumption of SSBs with rising temperatures in sub-Saharan Africa is a particularly pressing issue given the region's high vulnerability to climate change impacts[41,42]. These findings underscore the need for sub-Saharan African countries to integrate environmental heat adaptation interventions with health and nutrition policies in order to curb the rising prevalence of obesity, diabetes and cardiovascular diseases. Warning labels alongside educational policies encouraging healthy eating behaviors targeted at vulnerable groups such as those in urban residence or with greater purchasing power could help mitigate these effects[43]. Additionally, providing free, cold, and safe drinking water in urban centers may discourage consumption of sugar-sweetened beverages, which are sometimes perceived as safe and healthy options[16]. Fiscal measures such as taxes on sugar-sweetened beverages may offer additional policy iniative[44,45].

Declarations

Contributions

GB: Led the study conceptualization, conducted data analysis and interpretation, and drafted the original manuscript. Also reviewed and edited subsequent versions. **PM**: Contributed to conceptualization, performed data analysis and interpretation, supervised the study, and reviewed and edited the manuscript. **GB**: Serves as the guarantor of the study, takes full responsibility for the final work, had full access to the data, and made the decision to publish. All authors approved the manuscript for submission.

Declaration of interests.

Authors declare no competing interests

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No funding was received for these analyses, writing, or publication. The corresponding author had full access to the dataset and had final responsibility for the decision to submit the manuscript for publication. The DHS had no role in data analysis, interpretation of results, or manuscript writing.

Data availability

The DHS data used in this study is available at https://dhsprogram.com/data/available-datasets.cfm and can be freely accessed by registered users. ERA5 reanalysis 2m air temperature data is freely accessible via https://cds.climate.copernicus.eu/

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Figures

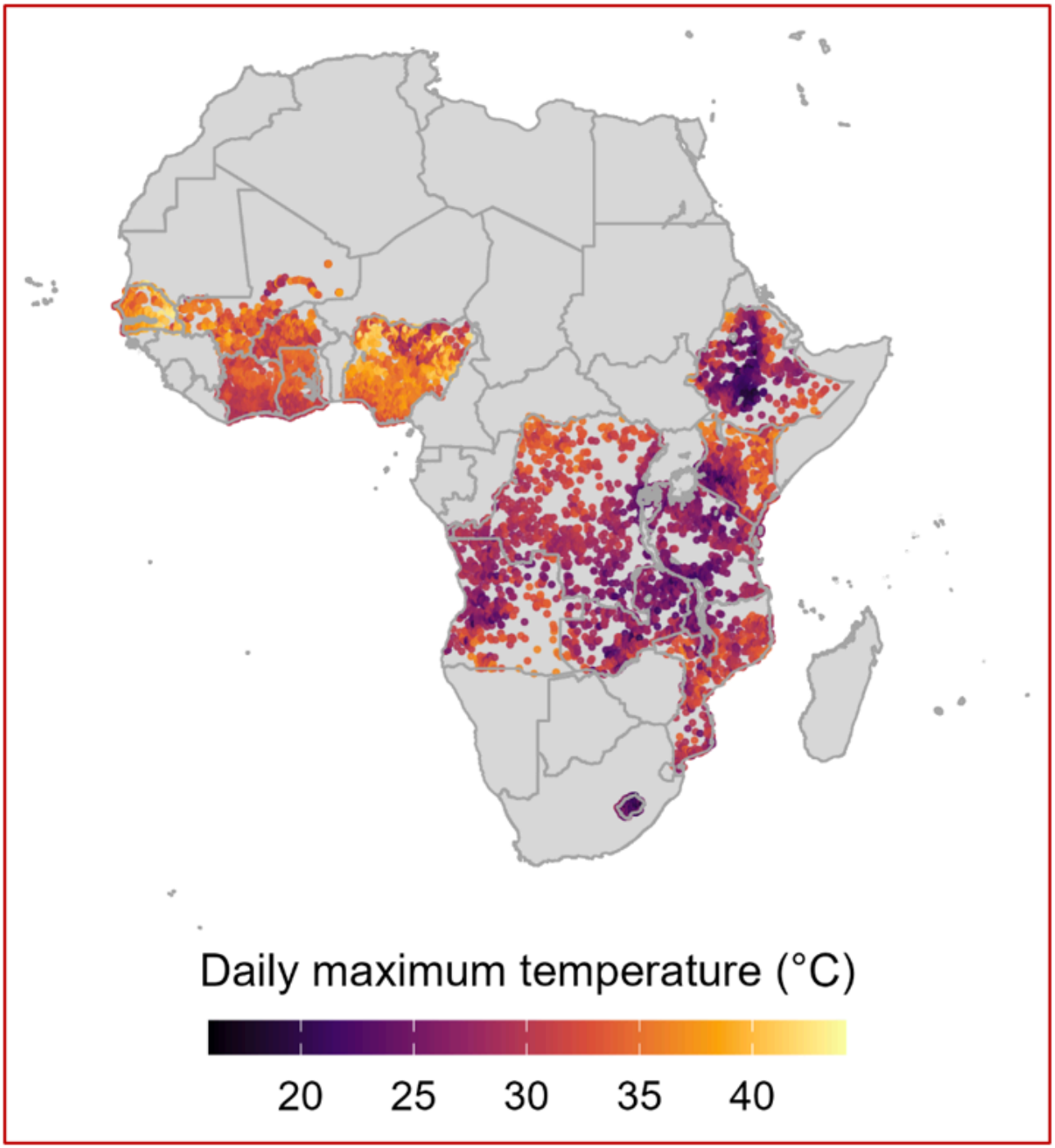


Figure 1

Spatial distribution of maximum daily 2m air temperature at DHS survey locations

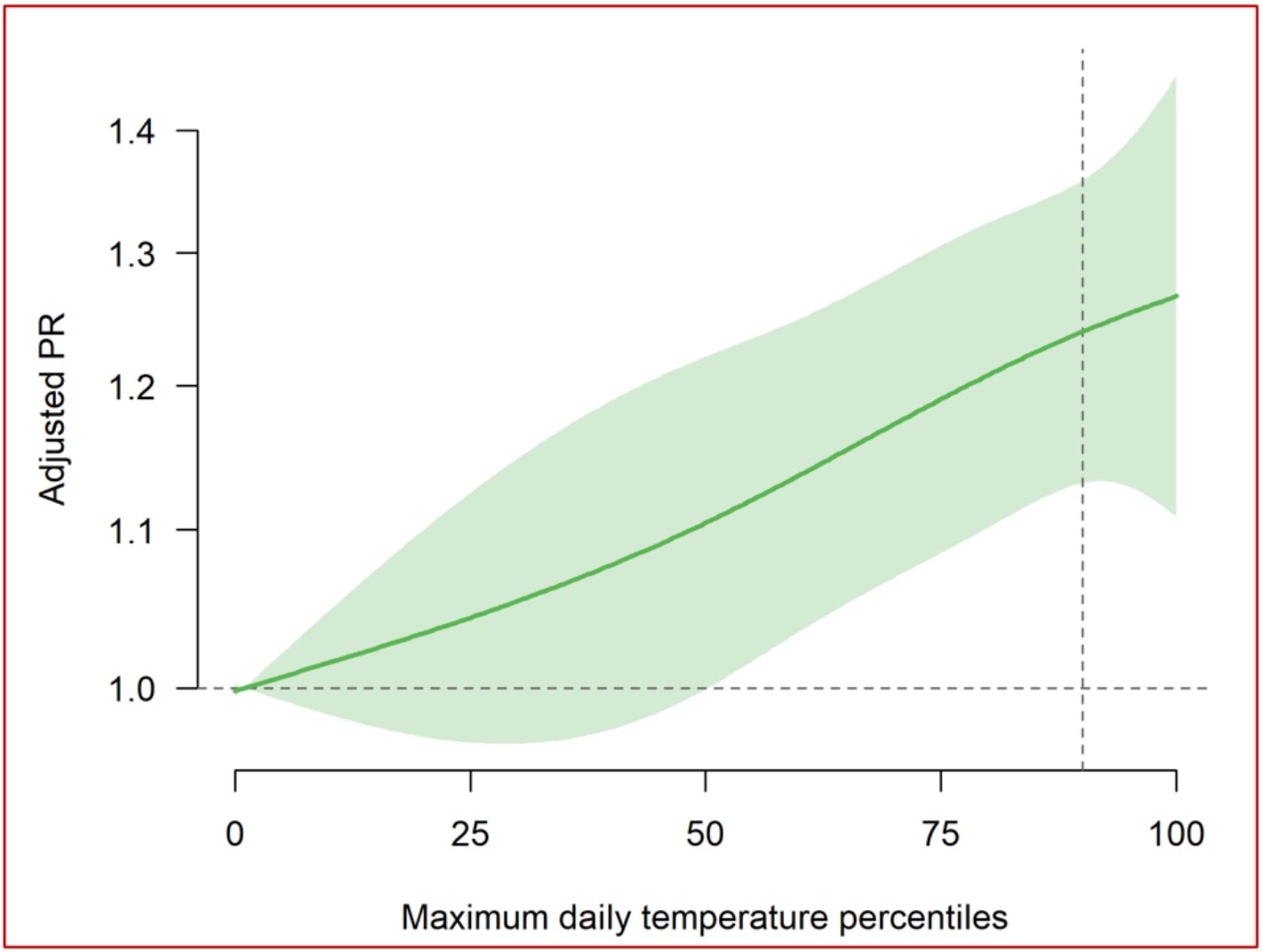


Figure 2

Pooled exposure response curve for the cumulative adjusted prevalence ratio (lag 0-2) associated with SSBs consumption among women aged 15 —49 years in sub-Saharan Africa. The dashed vertical grey line represent the 90th maximum temperature percentile.

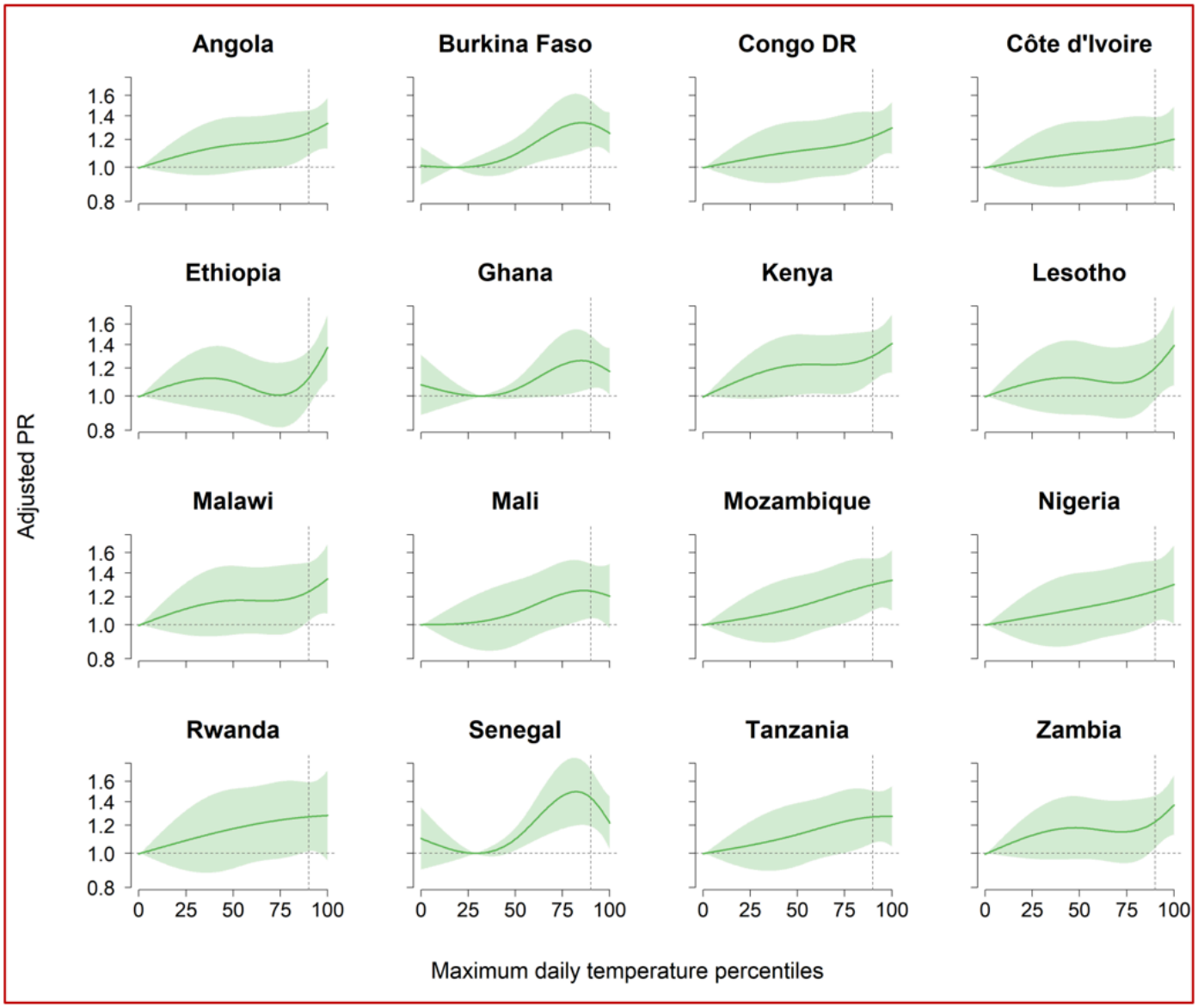


Figure 3

Country level exposure response curves for cumulative adjusted prevalence ratio (lag 0-2) associated with SSBs consumption among women aged 15 —49 years in sub-Saharan Africa. The dashed vertical grey line represent the 90th maximum temperature percentile.

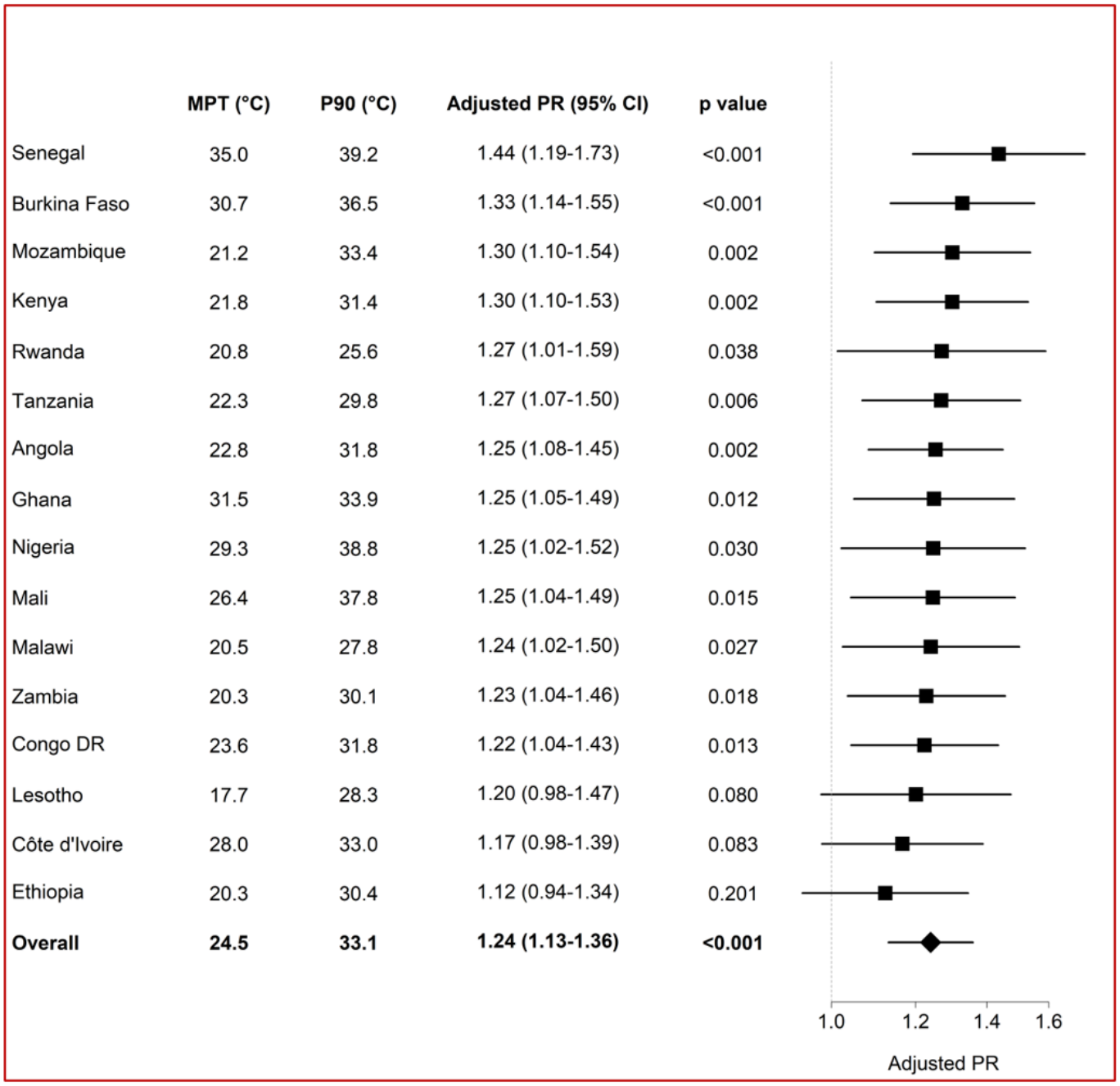


Figure 4

Associations between ambient temperature and consumption sugar-sweetened beverages among women across 16 Sub-Saharan African Countries.

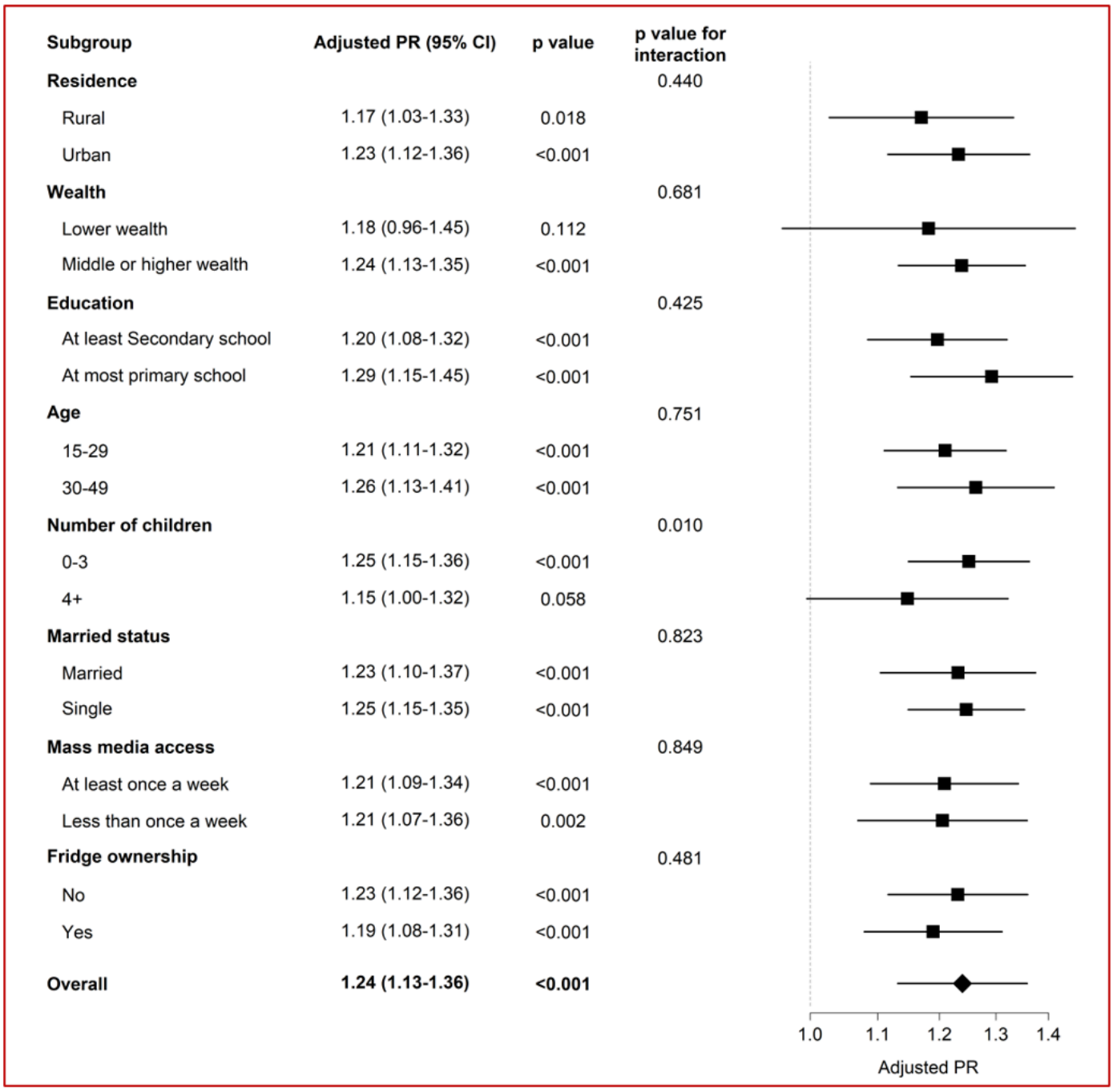


Figure 5

Findings from subgroup analyses showing adjusted prevalence ratio (aPR) of consuming sweetened sugar beverage among women across 16 sub-Sharan countries.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- appendix.docx