Assessing the Influence of Temperature and Precipitation Extremes on Women's Nutritional Status in Egypt and Jordan

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Abstract

Women in the Southwest Asian and North Africa (SWANA) region are increasingly vulnerable to the nutritional impacts of climate change. This study examines the relationship between climate extremes and women's nutritional status, focusing on body mass index (BMI) and hemoglobin levels among 110,213 women aged 15-49 in Egypt and Jordan. We employ fixed-effects regression models to analyze these effects using data from the Demographic and Health Surveys (DHS) and Climatic Research Unit-time series (CRU-TS). Higher temperatures, especially when combined with average or lower precipitation, are associated with reduced BMI and lower odds of obesity, particularly in urban areas. Conversely, hotter temperatures with average precipitation are linked to increased hemoglobin levels and reduced odds of anemia, with more substantial effects in rural areas. These findings underscore the need for targeted public health interventions and policies, emphasizing the importance of addressing urban-rural disparities and considering geographical contexts in shaping women's nutritional outcomes.

Introduction

The risk of climate change for health is greatest for vulnerable populations such as women, children, older adults, and those of lower socioeconomic status (Bezner Kerr et al., 2022; Duncan, 2006; Green et al., 2019; IPCC, 2023). In the Southwest Asian and North African (SWANA) region, also known as the Middle East and North Africa, climate change, in addition to ongoing social and political unrest, hinders poverty reduction and exacerbates food insecurity, with disproportionate impacts on women and girls (Al-Jawaldeh et al., 2022; Neira et al., 2023; Waha et al., 2017). Women have unique health needs, and face increased nutritional demands during critical life stages such as menstruation, pregnancy, and lactation (Sorensen et al., 2018; World Health Organization, 2017), rendering them one of the most vulnerable populations to climate change and related illnesses (Goh, 2012; Kuehn & McCormick, 2017; Secretary-General, 2022; Sellers, 2016; Sorensen et al., 2018). Researchers have been and continue to be engaged in examining the links between climate extremes and their effects on health and nutrition. Yet, engagement that specifically examines the risks to women is rare. Several researchers have considered the impacts of temperature and precipitation extremes on women’s nutrition and wellbeing using a wide-scale analysis (Gray & Thiede, 2024; Trentinaglia et al., 2021). Others have considered how climate extremes such as drought impact women in rural regions such as in Andrha Pradesh, India, or Fars Province, Iran (Lambrou & Nelson, 2010; Keshavarz et al., 2013). However, studies examining women’s nutrition on a regional scale using nationally representative data are infrequent. Furthermore, the lack of research, specifically in the SWANA region leaves a gap in understanding how one of the most at risk groups are affected by climate change.

To address this lacuna, this study investigates the impact of temperature and precipitation anomalies on two key nutrition indicators, body mass index (BMI) and hemoglobin levels, among 110,213 women across Egypt and Jordan. These countries are each positioned differently within the climate gradient of the SWANA region. Using the Demographic and Health Surveys

(DHS) and the Climatic Research Unit-time series (CRU-TS), we analyze how climate extremes experienced during a woman's life affect BMI, odds of obesity, hemoglobin level, and odds of anemia, examining these effects over two years to encompass more than two complete agricultural cycles. Additionally, we disaggregate these effects by rural and urban settings to better understand if the agricultural pathway mediates these impacts. By elucidating the role of climate extremes, we aim to deepen the understanding of their impact on women's nutrition within the SWANA region.

Background

Women's Nutrition and Extreme Climate Events

Climate change can impact women's nutritional outcomes through multiple pathways such as agriculture, food insecurity, and susceptibility to infectious diseases (Al-Jawaldeh et al., 2022; Bezner Kerr et al., 2022; Goh, 2012; Jobbins & Henley, 2015; Sorensen et al., 2018). For example, heat waves, drought, and extreme precipitation events directly affect food availability by increasing food prices and food insecurity and undermining the nutrition and livelihoods of millions (Bezner Kerr et al., 2022; Romanello et al., 2023).These compounding climate events can place immediate pressure on smallholder farmers and cause increased malnutrition in women and children in farming families (IPCC, 2023). Furthermore, these vulnerable populations are most at risk of diarrheal and vector-borne diseases exacerbated by climate change (Romanello et al., 2023; Sorensen et al., 2018). Thus, it is difficult to isolate one pathway to which women will become more malnourished with the changing climate, as many are interconnected and complex.

Micronutrient deficiencies are essential indicators of malnutrition in women, especially pregnant women and their children, linking lifelong effects on children's development and women's wellbeing (Sustainable Development Solutions Network, n.d). Micronutrient deficiencies such as iron deficiency are the leading cause of anemia in women globally, due to the life stages that women experience, such as menstruation and pregnancy (Christian, 2021; Kassebaum et al., 2014; World Health Organization, 2017). Most micronutrients, such as iron, are derived from food, primarily from plants and high-quality diets, of which women in low- and middle-income countries (LMIC) are often unable to fulfill their daily requirements and most susceptible to suffer from anemia (Christian, 2021; Kassebaum et al., 2014; Kinyoki et al., 2021). Iron-deficiency anemia (IDA) is illustrated by lower hemoglobin levels, which diminishes energy, leading to a severe lack of productivity, leaves women predisposed to infections, and can cause serious harm to pregnant mothers (Haas & Brownlie, 2001; Kassebaum et al., 2014). Furthermore, increasing risks include exposure to water-borne illnesses, which can increase diarrheal illness and further exacerbate women's nutritional absorption, causing them to be more at risk for anemia (World Health Organization, 2017). By the year 2030, there is projected to be an expected 250,000 further deaths a year from climate change-related malnutrition, malaria, and other heat-related illnesses (WHO, 2021). Thus, mitigation and alleviation for WRA in LMICs is critical.

Limited research has explored how exposure to climate extremes affects women's nutrition, with most studies focused on low-and middle-income settings, likely due to existing concerns about food insecurity. Large-scale evidence indicates that increasing temperatures are associated with an increased risk of being underweight among women of reproductive age groups across 59 LMICs (Gray & Thiede, 2024). Gray and Thiede (2024) suggest that warming temperatures will likely decrease crop yields, amplify infectious diseases, and diminish labor productivity, leading to significant health implications for vulnerable populations. In contrast, a study spanning 134 countries found that exposure to hot and cold temperatures significantly increased BMI for women (Trentinaglia et al., 2021). Trentinagalia et al. (2021) found a link between increased BMI and agricultural productivity, suggesting that higher agricultural productivity in LMICs generally leads to lower food prices and increased caloric intake, which can contribute to weight gain and obesity. Similarly, Huang and Hong (2024) found that a 1ºC increase in temperature results in 12.3% more adults with obesity globally. Notably, they find that the impact of warming on obesity is more pronounced in the Eastern Mediterranean and Asian region, highlighting the vulnerability to the SWANA region and need for research in this area (Huang & Hong, 2024). These contrasting findings underscore the need for further research and the complexity of climate change's impact on nutrition. The 2019 Lancet report highlights this complexity by drawing attention to the co-occurrence of three pandemics, climate change, undernutrition, and obesity, in what they term The Global Syndemic (Swinburn et al., 2019). The report emphasizes the need for integrated interventions and policies that address all three pandemics simultaneously, rather than treating them in isolation from each other (Swinburn et al., 2019).

Earlier evidence focused on a more narrow scale showed that drought exposure was associated with a reduction in BMI for women in Zimbabwe while men's BMI remained constant (Hoddinott & Kinsey, 2000). Although fewer small-scale studies directly address women's nutrition, several suggest that women consume less food during climate-related events (Beaumier & Ford, 2010; Goh, 2012; Keshavarz et al., 2013; Lambrou & Nelson, 2010; Sellers, 2016). These relationships have been examined in places such as Andhra Pradesh, India (Lambrou & Nelson, 2010), and in Fars Province, Iran (Keshavarz et al., 2013), where researchers found that women in farming families consumed less food than men and children during drought years, often going days without food altogether. However, very few studies have examined these relationships using nationally representative data, and there is a notable absence of research in the SWANA region. An example of this type of work looking at adult health in general was conducted using nationally representative data in China to examine how climate extremes impact nutrition (Mueller & Gray, 2018). Mueller and Gray (2018) found that extreme heat significantly increased the likelihood of underweight status among older adults in China, worsening their health outcomes. They suggest one possible mechanism: seniors may forego meals to cope with income shocks—a strategy also noted in the research discussed on women.

Climate Change and Food Insecurity the SWANA Region

SWANA is highly vulnerable to the impacts of climate change, and compared to other regions, crop yields were significantly impacted, resulting in decreased earnings for farmers and increased food security concerns (Aggarwal et al., 2019). Agriculture is a critical source of income and food for people across the SWANA region, with over 80% of agricultural land and 100% of pastoral land being rain-fed (Selvaraju, 2013). Given the high dependency on rain-fed farming, climate-driven factors such as extreme water scarcity (Barlow et al., 2016; Borgomeo et al., 2021), regionally increased warming and aridity (Tabari & Willems, 2018), rising sea levels (Waha et al., 2017), and the potential of climate-induced conflicts (Ash & Obradovich, 2020; Eklund et al., 2022) are expected to expose a significant proportion of the population, especially women, to food insecurity, poverty, and malnourishment (Al-Jawaldeh et al., 2022; Waha et al., 2017). The region already experiences an elevated prevalence of food insecurity and faces the double burden of nutrition, with both overnutrition/overweight and obesity and undernutrition (FAO et al., 2021; Jobbins & Henley, 2015). Obesity in the SWANA region is highly prevalent, with 27% of the adult population classified as obese, ranked second in the world after the Americas (FAO et al., 2021). Specifically, in Egypt, women are more than twice as likely to be obese compared to men (Alebshehy et al., 2016), and Egypt is the 10th country in the world with the highest proportion of adult women living with obesity (Worldobesity.org). The prevalence of anemia among women of reproductive ages (WRA) was recorded of the highest in Middle Eastern countries in 2018 compared to other low- and middle-income countries (LMICs) (Kinyoki et al., 2021). 35% of women of reproductive age experience anemia, and the region also faces significant challenges, with over fifty-five million people undernourished (FAO et al., 2021).

The SWANA region is witnessing a rise in severe droughts, devastating flooding events, and heat waves (Barlow et al., 2016; Hoell et al., 2024; Selvaraju, 2013; Waha et al., 2017). Jordan is among the most water-scarce nations globally. Its unique geographic location leaves it vulnerable to water poverty as its reserves are depleted, further exacerbated by its downstream location on the Yarmouk-Jordan River, which supplies Syria and Palestine, and the increased population from numerous refugee resettlement shocks in the region (Rajsekhar & Gorelick, 2017). In 1999 and 2000, Jordan experienced two droughts that impacted the livelihoods of 180,000 and 150,000 people, respectively, causing a major disruption to food-producing communities (EM-DAT, 2023). Anthropogenic climate change will only further degrade the limited water supplies in the region, potentially preventing countries like Jordan from growing food and leading to increased dependence on imports (Waha et al., 2017).

Water scarcity, dependence on imports, urbanization, and shifts towards western diets contribute to vulnerability and food insecurity in the SWANA region. Egypt, in particular, is the world's largest wheat importer, with the Egyptian diet heavily reliant on this staple (FAO et al., 2021; Jobbins & Henley, 2015). Due to socio-political factors, Egypt has faced several food supply crises, and climate change has the potential to disrupt further the flow of food in this region (FAO et al., 2021; Waha et al., 2017). These shifts exacerbate food insecurity, amplifying the burden of malnutrition, especially among women in the region (Al-Jawaldeh et al., 2022; Selvaraju, 2013). Over 77% of Egypt's population cannot afford a healthy diet (FAO et al., 2021). Both due to food insecurity and the changing climate, there is a significant challenge for women of reproductive ages (WRA) in the SWANA region to obtain enough iron and other crucial nutrients, further perpetuating the risks of anemia and illness (Smith et al., 2017; Verner, 2012). Our study on Egypt and Jordan is useful to examine the impacts of climate change in the SWANA region, considering the insights they provide on North Africa and the Levant. Using publicly available data from the Demographic and Health Surveys (DHS), these two countries have population-representative data over several years, making them amenable for our analysis on women’s nutritional status.

Women in the SWANA region are particularly susceptible to the effects of climate change due to the intersection of gender and societal norms. In patriarchal systems prevalent in SWANA and other areas alike, food distribution within households such as the ones mentioned above is influenced by the gendered perceptions of nutritional needs, further perpetuating women's vulnerability to climate change (Al-Jawaldeh et al., 2022; Goh, 2012; Lambrou & Nelson, 2010). Furthermore, those from lower socioeconomic backgrounds are particularly vulnerable to climate extremes' health and nutritional impacts. By 2030, climate change is projected to leave an additional 236 million women and girls hungry, doubling the number of anticipated men (131 million) (UN, 2024). Extreme climate events contribute to rising food prices, which can reduce dietary consumption and diversity, exacerbating the challenges economically disadvantaged women face (Bezner Kerr et al., 2022). In order to address how climate extremes might affect women's nutritional status in the SWANA region, this study examines the impacts of climate extremes on the nutritional outcomes of women across Egypt and Jordan. By analyzing nationally representative data and considering rural-urban disparities, this research aims to provide understandings into the region's multifaceted interactions between climate change, food security, and women's nutrition.

DATA AND METHODS

Data

To understand the relationship between women's nutritional status and climate, this study draws on nationally representative data from the Demographic and Health Surveys Program (DHS) accessed via the IPUMS database (Boyle et al., 2022) and links it to temperature and precipitation data. Using a multi-stage sampling cluster approach, the DHS collects nutrition and health data, and data on wellbeing of women of reproductive ages 15-49 and children under five. We use six rounds from Egypt, surveyed in 1992, 1995, 2000, 2005, 2008, and 2014, and four rounds from Jordan, surveyed in 2007, 2009, 2012, and 2017-18. Each round contains measures of height and weight for women and relevant contextual variables ranging from the individual to the community level. BMI is available for all rounds, while hemoglobin and anemia level, however, are not available in Egypt 1992, 1995, and 2008. The choice of BMI and hemoglobin as our main outcome variables is particularly useful in assessing nutritional status and health impacts. BMI provides insight into the prevalence of obesity or underweight status and other underlying health issues (Hall & Cole, 2006), and has been used in several papers linking environmental changes and health (Gray & Thiede, 2024; Hoddinott & Kinsey, 2000; Trentinaglia et al., 2021). Hemoglobin levels indicate the prevalence of anemia, a condition linked to nutritional deficiencies that can be exacerbated by climatic factors (Smith et al., 2017).

The individuals in our analytical sample consist of women between the ages of 15-49 at the time of the interview. We exclude women for whom we do not have their location because we cannot match them to our climate data. We also exclude women for whom we do not have data on either of our primary outcome variables. Our analytical sample size is 110,213 women (85,859 from Egypt and 24,354 from Jordan). For our anthropometric outcome variable, BMI, we had data on 110,073 women. BMI is calculated using the height and weight of women taken by the DHS personnel (Boyle et al., 2022). Women with a BMI above 30kg/m^2 are considered obese, and those with a BMI less than 18.5kg/m^2 are considered underweight. For our anthropometric outcome variable, hemoglobin, we had data on 44,795 women. A healthy hemoglobin level for women of reproductive age is generally about 12 to 15.5g/dl, and women with hemoglobin below 12g/dl are classified as anemic. DHS accounts for elevation, as hemoglobin gets steeper with elevation increase (Nestel, 2002). When DHS personnel collect blood spots to report hemoglobin levels, they also record location and elevation data, which is implemented in an adjustment formula, making measuring anemic outcomes in places with varying elevation reliable (Boyle et al., 2022). We generated our obesity measure by creating a binary variable, 'obese', defined as having a BMI greater than 30kg/m^2. We generated our anemia measure by creating a binary 'anemic' variable, defined using the *biofanemialvl* variable from DHS that classifies women as anemic if their hemoglobin levels are below or equal to 11.9g/dl.

Table 1 presents unweighted descriptive statistics for all variables in our analytical sample. This table includes our dependent variables (women's nutritional markers), our independent variables (climate-combined categories and continuous climate anomalies), and sociodemographic controls. The average BMI for the women in our sample is 28.78 kg/m^2, coupled with a relatively large standard deviation of 5.65. According to global health standards, a substantial portion of our sample falls into the overweight category (NIH, 2023). Thirty-seven percent of women were classified as obese (a BMI of 30 or higher), indicating a nutritional burden and the need for targeted nutrition interventions for this population. Globally, the prevalence of obesity is 16% in adults, and the prevalence of overweight is 44% in women (WHO, 2024). Furthermore, the average hemoglobin level in our sample is 12.29 g/dL, which is at the lower limit of the normal range for adult women, indicating a potential concern for anemia, especially considering the lowest observed value (4.110 g/dL) was significantly below the normal range. The prevalence of anemia in our sample is 35%, which is of critical concern for women of reproductive age and an alarming public health issue (World Health Organization, 2017). Globally, the prevalence of anemia is 24.3% across all ages; however, for WRA, the global prevalence of anemia is 33.7%, with high geographic variation (GBD 2021 Anaemia Collaborators, 2023). Combined, these descriptive results suggest a double burden of malnutrition in the region, with women in Egypt and Jordan facing both overnutrition and undernutrition. Additionally, 28% of women in our sample did not have an education, and 94% were married. We see an even distribution of women living in rural and urban regions, and about 47% of them were exposed to combined climate anomalies in the areas in which they lived.

Table 1
Descriptive statistics for the predictors and outcomes

Variables	N	Mean	SD	Min	Max
Women's health outcomes					
Body Mass Index	110,073	28.78	5.65	12.35	59.93
Hemoglobin	44,795	12.24	1.44	4.10	18.00
Obese	110,073	0.37	0.48	0.00	1.00
Anemic	44,800	0.35	0.48	0.00	1.00
Reproductive age groups					
15-19	110,213	0.04	0.19	0.00	1.00
20-24	110,213	0.15	0.35	0.00	1.00
25-29	110,213	0.21	0.41	0.00	1.00
30-34	110,213	0.18	0.39	0.00	1.00
35-39	110,213	0.17	0.37	0.00	1.00
40-44	110,213	0.14	0.35	0.00	1.00
45-49	110,213	0.12	0.33	0.00	1.00
Education level					
None	110,213	0.28	0.45	0.00	1.00
Primary	110,213	0.14	0.34	0.00	1.00

Secondary	110,213	0.44	0.50	0.00	1.00
Higher	110,213	0.15	0.35	0.00	1.00
Socioeconomic characteristics					
Marriage status	110,213	0.94	0.23	0.00	1.00
Children ever born	110,213	3.29	2.32	0.00	19.00
Pregnancy status	110,213	0.10	0.30	0.00	1.00
Rural	110,213	0.51	0.50	0.00	1.00
Improved toilet	110,205	0.96	0.19	0.00	1.00
Climate - anomalies					
12-month Rainfall anomaly	110,213	-0.19	0.99	-2.52	2.43
12-month Temperature anomaly	110,213	0.13	0.70	-1.83	1.40
24-month Rainfall anomaly	110,213	-0.21	0.90	-2.12	2.70
24-month Temperature anomaly	110,213	0.21	0.74	-1.58	1.65
Climate-combined anomalies (Temperature/precipitation)					
Normal/normal	110,213	0.55	0.50	0.00	1.00
Hot/wet	110,213	0.01	0.10	0.00	1.00
Hot/normal	110,213	0.14	0.34	0.00	1.00
Hot/dry	110,213	0.07	0.25	0.00	1.00
Normal/dry	110,213	0.13	0.33	0.00	1.00
Cold/normal	110,213	0.00	0.04	0.00	1.00
Cold/wet	110,213	0.00	0.06	0.00	1.00
Normal/wet	110,213	0.11	0.31	0.00	1.00

We measured climate exposure for each woman by extracting data from the Climatic Research Unit-time series (CRU-TS) database v4.06 on monthly mean temperature and precipitation totals (Harris et al., 2020). CRU-TS, a project of the University of East Anglia, is a high-resolution gridded dataset that utilizes monthly land station observations to create climate anomalies for several variables. This study uses temperature and precipitation values provided by CRU-TS. CRU-TS collects data from over 4,000 global weather stations and utilizes temporal and spatial interpolation methods to derive monthly means of the anomalies onto a 0.5º grid over the land surface while accounting for missing data and poor station coverage (Harris et al., 2020). CRU-TS data is widely used in research examining climate extremes and health (Gray & Thiede, 2024; McMahon & Gray, 2021; Mueller & Gray, 2018; Nicholas et al., 2021; Randell et al., 2020; Trentinaglia et al., 2021). While this data has not yet been utilized in research examining climate extremes and health in SWANA to our knowledge, it has been used in recent climatic studies in the region (Hoell et al., 2024; Zittis et al., 2022).

We extract a monthly time series at the governorate level in Egypt and Jordan because while DHS has GPS locations for households, they are unavailable for all Egypt and Jordan rounds. By using the governorate level, we maintained temporal resolution without sacrificing spatial resolution. These data were extracted as spatial means of temperature and precipitation anomalies within each governorate. Next, using the raw climate data, we created 12-month and 24-month running means in each governorate to capture the complete annual agricultural cycle and the preceding agricultural season. We then standardize these values into anomalies (z-scores) to capture the relative deviation from the historical climate. Standardized climate anomalies are preferred over raw climate data because they capture meaningful deviations from typical experiences and are better predictors of social outcomes (Gray & Wise, 2016).

For our analysis, we developed a categorization scheme for temperature and precipitation extremes using our 24-month running anomalies to create a nine-category measure. Temperature anomalies were divided into three groups: hot, for anomalies greater than one standard deviation above the mean, indicating warmer than usual temperatures; normal, for anomalies within one standard deviation of the mean, indicating typical temperatures; and cold, for anomalies more than one standard deviation below the mean, indicating colder than usual temperatures. Similarly, precipitation anomalies were categorized into three groups: wet, for anomalies greater than one standard deviation above the mean, indicating wetter than normal precipitation levels; normal, for anomalies within one standard deviation of the mean, indicating typical rainfall; and dry, for anomalies more than one standard deviation below the mean, indicating drier than normal precipitation levels. This categorization allows for a nuanced analysis of climate extremes and their potential impacts on women's nutritional outcomes in the SWANA region. These anomalies are then linked to the DHS sample based on location and interview date.

Analysis

We examine the effect of temperature and precipitation anomalies on BMI and hemoglobin using fixed-effects linear regression models. For the binary obesity and anemia variables, we employ fixed-effects logistic regression models. Our modeling approach incorporates DHS survey weights and adjusts for clustering at the governorate level to account for climate exposure and characteristics among women within each governorate. Additionally, we include a time trend (interview year) to control for any linear changes over time that might influence our results, such as changes in healthcare access. We also incorporate area-fixed effects to account for persistent characteristics of these regions that tend not to change over time, such as historical climate patterns or geographic features. These fixed effects control for linear changes and time-invariant factors at the governorate level, such as development, infrastructure, topography, and soil, that may be linked to climate change and women's nutritional outcomes. Using our combined climate anomalies in specification 1, 12-month continuous climate anomalies in specification 2, and 24-month continuous climate anomalies in specification 3, we model BMI and hemoglobin in a linear regression model, and obesity and anemia using logistic regression. We subsequently extend these analyses by adding interactions with our urban and rural measures to allow these characteristics to modify the effects of temperature and precipitation on BMI, hemoglobin, obesity, and anemia.

We hypothesize that exposure to extreme temperatures and precipitation will significantly affect the nutritional outcome of WRA in Egypt and Jordan. Furthermore, we expect these effects of temperature and precipitation on women's nutrition to be more pronounced for those living in rural areas than urban areas. To test our hypotheses, we incorporate linear and non-linear specifications of climate effects and interactions with our control variables. To account for additional factors known to affect women's nutrition, we include a set of control variables such as age, education level, marital status, pregnancy status, number of births, and household characteristics. These household characteristics include access to improved toilet infrastructure (e.g., flush toilets or non-flushing systems) and rural or urban status. There may be substantial variation in the definition of rural-urban status because the DHS program does not have a standardized definition. They adopt the definition from each country (Boyle et al., 2022). Egypt defines the following places as urban: the governorates of Cairo, Alexandria, Port-Said, the frontier governorates, district capitals, and the capitals of other governorates. Conversely, Jordan defines places with 5,000 or more inhabitants and each governorate's district and sub-district centers as urban (Boyle et al., 2022). These controls allow us to account for biological factors influencing women's anthropometry and the availability or lack thereof of resources that could contribute to nutritional change.

RESULTS

Table 2 displays the regression coefficients quantifying the effects of combined climate anomalies, 12-month continuous climate anomalies, 24-month continuous climate anomalies, and our control variables on BMI and hemoglobin levels in Egypt and Jordan for women of reproductive age. For specification 1, the climate effects are jointly significant for both outcomes. We find a significant positive association between exposure to normal/dry conditions and BMI and a significant positive association between the same conditions and hemoglobin. Exposure to hot/wet conditions is associated with a decrease in BMI, as is exposure to hot/dry conditions. In contrast, exposure to hot/normal conditions is associated with increased hemoglobin levels. Compared to normal conditions, exposure to hot/wet extremes is associated with a decrease in BMI by 2.10 units. In comparison, exposure to hot/dry conditions is associated with a reduction in BMI by 1.17 units. Conversely, exposure to average temperature and dry precipitation anomalies is associated with an increase in BMI by 0.47 units and hemoglobin by 0.31 units. We did not observe any significant relationship between exposure to colder temperature categories and BMI or hemoglobin levels among women. The climate effects for specifications 2 and 3 are jointly significant for hemoglobin but not BMI. We find a significant positive association between exposure to 12-month temperature anomalies and hemoglobin levels, as is exposure to 24-month temperature anomalies. For each unit increase in 12-month temperature anomalies, hemoglobin increases by 0.457 units; for each unit increase in 24-month temperature anomalies, hemoglobin increases by 0.454 units. We did not observe any significant relationship between precipitation anomalies and hemoglobin.

Table 2
BMI and hemoglobin on combined climate exposures and continuous 12- and 24-month anomalies. Table shows coefficients when outcomes are regressed on climate anomalies and sociodemographic covariates. Joint tests of significance for climate is listed below each model.

Variables	BMI	Hemoglobin
Climate-combined anomalies (Temperature/precipitation)		
Normal/normal (reference)	0.00	0.00

Normal/wet	0.23		0.25	+
Normal/dry	0.47	***	0.31	***
Hot/wet	-2.10	***	0.17	+
Hot/normal	-0.12		0.23	*
Hot/dry	-1.17	***	-0.11	
Cold/normal	0.62		n/a	
Cold/wet	-0.12		n/a	
Cold/dry	n/a		n/a	
Reproductive age groups				
15-19 (reference)	0.00		0.00	
20-24	0.91	***	0.03	
25-29	1.94	***	0.10	+
30-34	3.15	***	0.10	+
35-39	4.15	***	0.03	
40-44	5.37	***	0.10	*
45-49	6.01	***	0.16	*
Socioeconomic characteristics				
Marriage status	0.29	***	0.02	
Children ever born	0.14	***	-0.03	***
Pregnancy status	0.62	***	-0.77	***
Improved toiled	1.23	***	0.03	
Rural	-0.71	***	-0.02	
Education level				
None	0.00		0.00	
Primary	0.84	***	0.00	
Secondary	0.68	***	-0.02	
Higher	-0.10		0.01	
Joint test of climate effects	171.00	***	40.01	***
Climate-continuous anomalies				
12-mo precipitation anomaly	0.161		0.009	
12-mo temperature anomaly	0.002		0.457	***
Joint test of climate effects	2.01		19.27	***
24-mo precipitation anomaly	0.070		0.009	
24-mo temperature anomaly	-0.179		0.454	***
Joint test of climate effects	1.32		13.33	***
N	110,065		44,795	

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Region indicators and a time trend term are included in the model but not shown.

Table 3
BMI and hemoglobin on combined climate exposures and continuous climate anomalies decomposed by rural and urban settings. Table shows coefficients when outcomes are regressed on climate anomalies.

Variables	BMI (N = 110,065)				Hemoglobin (N = 44,795)			
Climate-combined anomalies (Temperature/precipitation)	Urban		Rural		Urban		Rural	
Normal/normal (reference)	0.0.500		0.00		0.00		0.00	
Normal/wet	0.23		0.25		0.28	+	0.27	+
Normal/dry	0.48	**	0.40	*	0.38	***	0.22	*
Hot/normal	-0.69	*	0.31		0.18	*	0.32	*
Hot/wet	-2.09	***	-2.09	***	0.22	*	0.22	*
Hot/dry	-1.38	***	-0.51		-0.10		-0.21	+
Cold/normal	0.60		0.67	*	n/a		n/a	
Cold/wet	-0.23		-0.14		n/a		n/a	
Joint test of interaction		5.74***				3.47***		
Climate-continuous anomalies								
12-mo precipitation anomaly	1.10		1.184	+	1.00		1.01	
12-mo temperature anomaly	0.60	+	1.35		1.54	***	1.62	***
Joint test of interaction		47.95***				0.56		
24-mo precipitation anomaly	1.16	*	0.97		0.99		1.03	
24-mo temperature anomaly	0.53	***	1.81		1.52	***	1.64	***
Joint test of interaction		21.0***				1.68		

+ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001.
Region indicators and a time trend term are included in the model but not shown.

We also test for interactions between climate exposures and urbanicity to provide insight into BMI and hemoglobin levels that vary by rural and urban regions (Table 3). Our joint significance tests indicate that the relationship between exposure to combined climate anomalies and BMI and hemoglobin is significantly modified by whether women live in an area classified as urban or rural. Specifically, while we observed a significant positive association between normal/dry conditions and BMI, the association is stronger among women living in urban areas. Similarly, a significant positive association between normal/dry conditions and hemoglobin levels is observed, with more substantial effects in urban areas. Exposure to hot/normal conditions is associated with decreased BMI among women in urban areas but not rural areas. Additionally, exposure to hot/dry conditions is associated with decreased BMI in urban areas rather than rural areas. We also find a significant positive association between hot/normal conditions and hemoglobin levels, with these relationships being more robust for the populations living in rural regions (an increase of 0.38 units) than those in urban areas (0.18 units). Finally, there are no significant effects of any cold temperature category on BMI except for a slight, non-significant increase in BMI under cold/normal conditions in rural areas (an increase of 0.67 units). These effects are weaker and not statistically significant in urban regions. For hemoglobin, cold temperature categories did not apply (n/a) to either urban or rural areas, indicating non-applicability for these conditions.

The joint test for interaction for specifications 2 and 3 is significant for BMI but not hemoglobin (Table 3). We find a significant positive association between exposure to 24-month precipitation anomalies and BMI among women in urban areas but not in rural areas, and a positive association between 24-month temperature anomalies and BMI in urban areas. For each unit increase in 24-month precipitation anomalies, BMI increases by 1.16 units in urban areas; for each unit increase in 24-month temperature anomalies, BMI increases by 0.53 units in urban areas. We did not observe any significant relationship between 12-month anomalies and BMI. Our findings highlight a complex relationship between climate exposures and health outcomes, which is further influenced by the urban or rural context of the population. Urban areas experience more pronounced changes in BMI in response to temperature and precipitation extremes compared to rural areas, emphasizing the need for tailored public health strategies that consider these differential impacts.

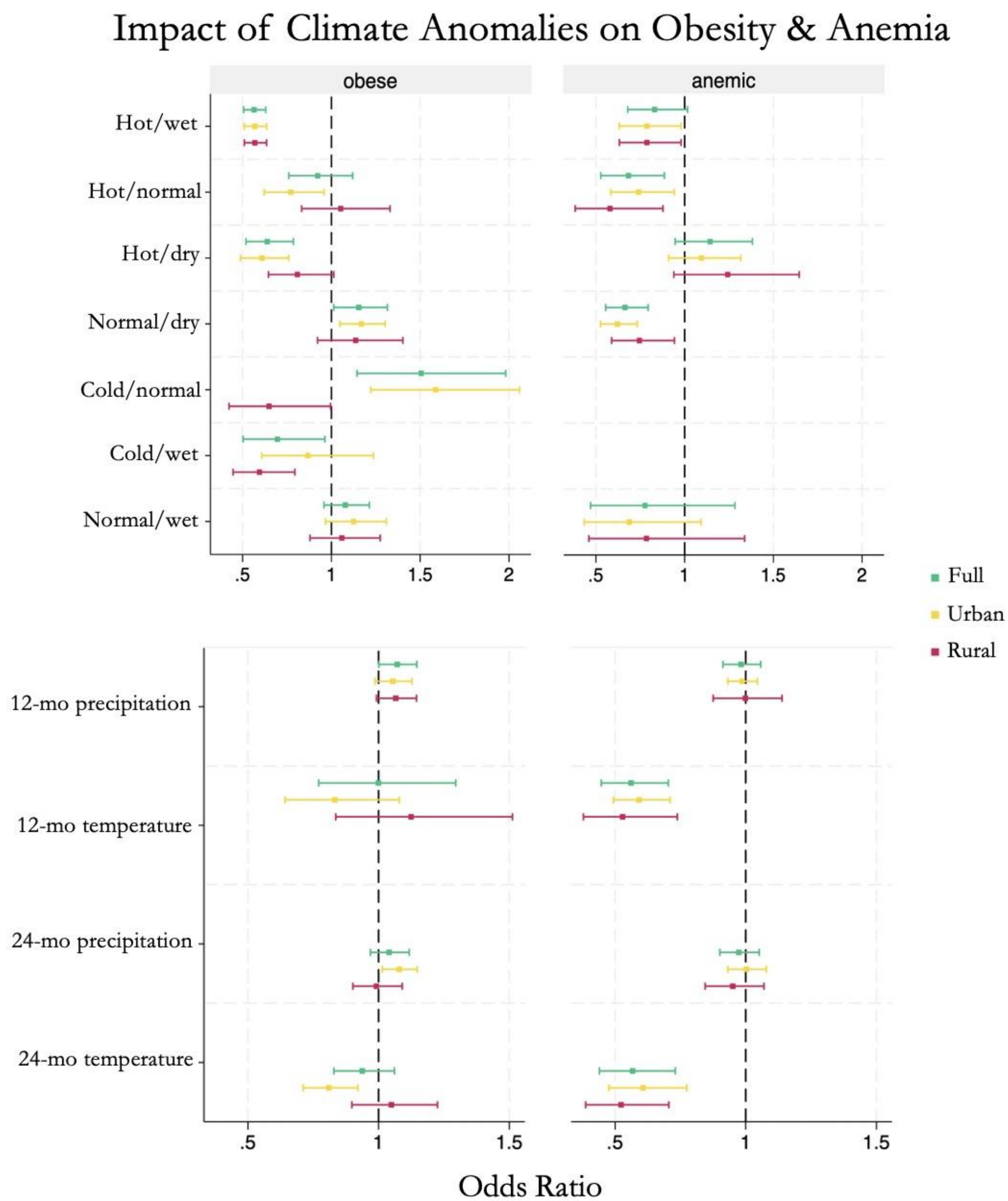

Figure 1: Impact of climate anomalies on obesity and anemia among women of reproductive age in Egypt and Jordan. The plots display odds ratios and 95% confidence intervals for different climate anomaly specifications, shown for the full sample and decomposed by rural and urban subsamples.

Next, we examine the impact of combined climate categories on our binary obesity and anemia outcomes using logistic regression models. Figure 1 presents results, showing the likelihood, expressed as odds ratios (OR), of being obese or anemic when women are exposed to climate anomalies for both the full sample and decomposed by rural and urban subsamples. For obesity, we observed significant associations with several combined climate categories (Specification 1). Women exposed to hot/wet conditions had significantly lower odds of being obese (OR= 0.564, P <0.001) in the full sample, with the exact effect sizes in both the urban and rural strata. Exposure to hot/normal conditions was associated with a significantly reduced likelihood of obesity (OR=0.771, P <0.05), only in urban areas. Similarly, women exposed to hot/dry conditions had significantly lower odds of being obese in urban areas (OR=0.639, P <0.001) but not in rural areas. The more substantial effect in the urban subsample may influence the significant effect observed in the full sample. Exposure to normal/dry conditions was associated with a slight but significantly higher likelihood of obesity (OR=1.168, P <0.01) in urban areas, potentially contributing to the significant effect in the full sample. Women exposed to cold/normal conditions had significantly higher odds of being obese in the full sample (OR=1.505, P <0.01), and urban areas (OR=1.586, P <0.001), whereas those in rural areas had significantly lower odds of obesity (OR=0.649, P <0.05). Lastly, exposure to cold/wet conditions was associated with a significantly reduced likelihood of obesity in rural areas (OR=0.595, P <0.001), which may be contributing to the significant effect in the full model (OR=0.696, P <0.05). For our continuous climate anomalies (specifications 2 and 3) on obesity, we find several significant relationships. Women exposed to 12-month precipitation anomalies had slightly higher odds of being obese only in the full sample (OR=1.071, P<0.05). No significant differences were observed for 12-month temperature anomalies across full, urban, and rural samples. Women exposed to 24-month precipitation anomalies had slightly higher odds of obesity in the urban subsample (OR=1.079, P<0.5). Exposure to 24-month temperature anomalies resulted in lower odds of obesity in the urban sample (OR=0.809, P<0.01).

For anemia, we identified several significant associations with various combined climate categories. Women exposed to hot/wet conditions had slightly lower odds of being anemic in the full sample (OR=0.831, P <0.1), with the same effect for the rural and urban subsamples (OR=0.787, P <0.05). Exposure to hot/normal conditions resulted in significantly lower odds of anemia in the full sample (OR=0.683, P <0.01), less pronounced in urban areas (OR=0.741, P <0.05) and more pronounced in rural areas (OR=0.580, P <0.01). Women exposed to normal/dry conditions had significantly lower odds of being anemic in all three models: full (OR=0.664, P <0.001), urban (OR=0.621, P <0.001), and rural (OR=0.745, P <0.05). For continuous climate anomalies on anemia, no significant differences in anemic odds were observed across full, urban, and rural samples for 12-month precipitation anomalies. However, women exposed to 24-month temperature anomalies had significantly lower odds of anemia in the full sample (OR=0.561, P<0.001), the urban sample (OR=0.592, P<0.001), and in the rural sample (OR=0.529, P<0.001). These findings underscore the nuanced relationships between climate anomalies and health outcomes among women in Egypt and Jordan with differential impacts observed across urban and rural areas. These highlight the importance of considering geographical context when developing public health strategies.

DISCUSSION

Our study aimed to determine whether temperature and precipitation anomalies affect women's nutrition in Egypt and Jordan. In particularly, our findings highlight the impact of higher temperatures on BMI and obesity odds. We discovered that higher temperatures, when combined with wet or dry precipitation levels, are associated with reduced BMI among WRA.

When examining the impact of these climate conditions on obesity, we find that higher temperatures, also when combined with wet or dry precipitation levels, decrease the odds of obesity. Furthermore, when stratifying by rural and urban areas, we found that higher temperatures combined with normal or dry precipitation levels are associated with a reduction in BMI in urban areas but not rural areas. This is consistent with our obesity models, where the same conditions decreased the odds of women being obese in urban areas, as confirmed by the significant reduction in obesity odds with 24-month temperature anomalies. Interestingly, our results show that urban women are more affected by temperature anomalies than their rural counterparts, possibly due to the urban heat island effect and differing access to resources. Additionally, when women are exposed to average temperatures and dry conditions, we find an association with increased BMI and hemoglobin levels, with a more substantial effect in urban areas. Similarly, under these conditions, women have higher odds of obesity and lower odds of anemia, both with a more robust effect in urban areas. An increased BMI is consistent with a higher chance of obesity; likewise, increased hemoglobin levels are consistent with lower chances of anemia. Moreover, when combined with average precipitation, hotter temperatures are associated with increased hemoglobin for WRA in Egypt and Jordan, with a larger effect in rural areas. This result is consistent with our anemia models, which predict that women have lower odds of being anemic under the same conditions, which has a more substantial effect in rural areas, as confirmed by the significant reduction in anemia odds with 24-month temperature anomalies.

Our results indicate that temperature is a significant determinant of women's body mass. In Egypt and Jordan, higher temperatures are linked to decreasing BMI and a lower likelihood of being obese for WRA. This result is consistent with Gray & Thiede's (2024) findings of women across LMICs exposed to increasing temperatures, which were at risk of being underweight. However, our findings contradict those of Trentinaglia et al. (2021), who found that increasing temperatures were linked to increasing BMI and obesity. This discrepancy could be due to the difference in scale as their study was done on a global scale while ours was a small regional study. Our finding which highlights a decrease in BMI likely reflects an intersection of reduced agricultural productivity, which limits access to nutritious food, and increased physiological stress due to extreme temperatures. Further, we found that in several cases of higher temperatures, the climate effects appeared larger on women that DHS labeled living in urban regions. While we expected rural areas to be most impacted due to the agricultural mechanism, which can affect women's health through multiple pathways, our results indicate that women in urban locations are not protected from climatic shocks.

The SWANA region is one of the most rapidly urbanizing areas of the world (Schäfer, 2013), and Egypt holds the largest and only mega-city in the region (Cairo). One of the main drivers of food insecurity by the year 2030 will be urbanization (Jobbins & Henley, 2015). Urbanization is increasing vulnerability to extreme heat, especially for at-risk populations, such as women in LMICs (Romanello et al., 2023). Notably, the urban heat island effect is amplifying heat extremes in cities (Ranasinghe et al., 2021). Furthermore, climate shocks such as extreme heat can impact food availability and prices. Specifically, the poorest groups in urban settings, such as female-headed households, tend to face malnutrition due to choosing calorie-rich but nutritiously poor food because of high prices (Bloem et al., 2010; FAO, 2008; FAO et al., 2021). And while we were focusing more on the agricultural and food production aspect, researchers have suggested that studies begin to focus their attention on the climate change impacts on the poorest and most vulnerable in urban areas (Jobbins & Henley, 2015). A limiting factor to this is that DHS uses a dichotomous rural/urban classification that lacks standardization and is defined independently by each country (Boyle et al., 2020). Thus, there may be distinct variations between what is categorized as urban in Egypt and Jordan. As urbanization increases, the distinctions between rural and urban areas shift. Thus, it would be beneficial to have a more continuous variable of urbanicity, such as using the DHS variable *popdensity*, which is not available for all rounds used in this study.

Increasing temperatures in some circumstances are linked to increasing hemoglobin and lower odds of anemia in women in Egypt and Jordan. In particular, hot/normal and 24-month continuous climate anomalies had a more pronounced effect in rural areas. Extreme heat conditions due to climate change put immense pressure on rural communities' food security, health, and livelihoods in regions like SWANA (Food and Agriculture Organization of the United Nations and United Nations Economic and Social Commission for Western Asia, 2021). Despite the consensus that climate change is expected to cause increased illness and decreases in the nutritional content of food and thus exacerbate diarrhea and anemia, we find a different trend for this case study (Bezner Kerr et al., 2022; Smith et al., 2017). While these results warrant further investigation, there has been some evidence that physically active people, such as athletes, who undergo heat training, experience increasing hemoglobin levels, and farmers who work outdoors did not exhibit a high anemia prevalence (Olivares et al., 2022; Rønnestad et al., 2021). Furthermore, we would have expected that extreme climate exposures like hot/dry would lead to decreasing hemoglobin and increased prevalence of anemia, but our results were null.

While we observed some associations between rainfall patterns and women's BMI and hemoglobin, the relationships were less consistent, suggesting a need for a more in-depth analysis to understand these associations fully. Our study revealed that average temperatures and dry conditions are associated with increased BMI, hemoglobin levels, odds of obesity, and decreasing odds of anemia. Interestingly, an increase in continuous precipitation anomalies was also sometimes associated with increasing BMI and odds of obesity. This inconsistency in our precipitation findings may be attributed to limitations in our data. The CRU-TS dataset has sparse station measurements in the SWANA region. Despite its advantage of interpolating missing values from multiple sources to provide continuous climate data, potential discrepancies in the data can arise based on how and where the original observations are collected, which can introduce variability. Because of interpolation, temperature data is generally more consistent over large areas than precipitation data. According to the IPCC, temperature variables have higher consistency than other variables, especially precipitation (Seneviratne et al., 2021). For example, Trentinaglia et al. (2021) examined the impacts of temperature and precipitation on obesity across 150 countries using CRU data. Their results indicated that the overall effect on BMI was primarily driven by temperature rather than precipitation. Future studies, especially in the SWANA region, could benefit from supplementing precipitation data with additional localized measurements or exploring alternative datasets that have shown success in similar climatic regions.

To our knowledge, this is the first analysis to quantitatively link women's nutrition in the SWANA region to temperature and precipitation extremes. However, other studies have noted that women in the area, particularly those of lower socioeconomic backgrounds are at the greatest risk of diminishing health and nutrition due to climate change impacts (FAO et al., 2021; Food and Agriculture Organization of the United Nations and United Nations Economic and Social Commission for Western Asia, 2021; Smith et al., 2017), suffer from gendered perceptions of nutritional needs perpetuating their risks to climate change impacts (Al-Jawaldeh et al., 2022; Food and Agriculture Organization of the United Nations and United Nations Economic and Social Commission for Western Asia, 2021), are burdened disporportionatly with domestic work and take on more agricultureal duties in challending climatic conditions, known as the feminization of agriculture (Jobbins & Henley, 2015; Keshavarz et al., 2013; Selvaraju, 2013; Verner, 2012), face a number of risks related to water instability (Borgomeo et al., 2021; Verner, 2012), and are more at risk of water and climate related gender-based violence (Borgomeo et al., 2021; FAO et al., 2021). These compounded stressors significantly increase their overall health risks, likely to contribute to higher rates of obesity and anemia. Therefore, addressing climate resilience and nutritional interventions in this region is crucial for mitigating the adverse health outcomes women face.

This study explores the complex relationships between climate anomalies and women's nutritional status in the SWANA region, shedding light on the critical impacts of temperature and precipitation extremes on health outcomes in Egypt and Jordan. While we do not specifically test differences in health outcomes between men and women, there is strong consensus that climate change, together with gender inequality, is one of the greatest challenges of our time, and women and girls are disproportionately vulnerable to the impacts of climate change (Bezner Kerr et al., 2022; Duncan, 2006; Secretary-General, 2022). Women in places like the SWANA region are particularly at risk because of existing social and political tensions and the fact that they make up a large proportion of displaced people (Jolof et al., 2022). In these situations, women experience high adversity and climate change is likely to critically challenge their livelihoods and well-being (Borgomeo et al., 2021). Addressing the challenges posed by climate change requires a concerted effort from governments, international organizations, and local communities to develop integrated and sustainable solutions. By focusing on the intersection of climate change and women's health, we can better tailor interventions to meet the unique needs of women in the SWANA region, ultimately reducing the burden of malnutrition and improving overall public health outcomes. While women are critical in implementing adaptive measures, they are underrepresented in climate policymaking (Secretary-General, 2022; Sellers, 2016; Sorensen et al., 2018). While women represent a large portion of those vulnerable to climate change, acknowledging that women are powerful agents of adaptation through their roles as community leaders, mothers, and educators, thus ensuring women become a part of the conversation, is critical to our future.

CONCLUSION

Our findings reveal that adverse climate conditions, particularly increased temperatures, are strongly associated with reduced body mass index among women of reproductive age in the SWANA region, with less pronounced effects on hemoglobin and anemia. The observed decrease in BMI underlines a significant nutritional stressor that could exacerbate health disparities and underweight status among women. This connection between extreme climate conditions and nutritional deficits underscores the urgent need for targeted public health interventions and policy measures. Implementing nutrition-specific programs that support women during critical periods such as pregnancy and lactation is essential to prevent micronutrient deficiencies and safeguard maternal and child health. Our study highlights the importance of further research into the nuanced impacts of climate change on different subpopulations. Notably, studies should explore the differential effects on rural versus urban populations, considering the distinct socioeconomic and environmental contexts influencing nutritional outcomes. By addressing these challenges with integrated and sustainable solutions, we can better support the health and well-being of women in the SWANA region and ultimately improve overall public health outcomes.

REFERENCES

Aggarwal, P., Vyas, S., Thornton, P., & Campbell, B. M. (2019). How much does climate change add to the challenge of feeding the planet this century? *Environmental Research Letters*, *14*(4), 043001. https://doi.org/10.1088/1748-9326/aafa3e

Alebshehy, R., Shuaib, N. M., & Mbako, J. D. (2016). Determinant Analysis of Obesity among Adult Females in Egypt. *The Egyptian Journal of Hospital Medicine*, *65*, 662–669. https://doi.org/10.12816/0033779

Al-Jawaldeh, A., Nabhani, M., Taktouk, M., & Nasreddine, L. (2022). Climate Change and Nutrition: Implications for the Eastern Mediterranean Region. *International Journal of Environmental Research and Public Health*, *19*(24), Article 24. https://doi.org/10.3390/ijerph192417086

Ash, K., & Obradovich, N. (2020). Climatic Stress, Internal Migration, and Syrian Civil War Onset. *Journal of Conflict Resolution*, *64*(1), 3–31. https://doi.org/10.1177/0022002719864140

Barlow, M., Zaitchik, B., Paz, S., Black, E., Evans, J., & Hoell, A. (2016). A Review of Drought in the Middle East and Southwest Asia. *Journal of Climate*, *29*(23), 8547–8574. https://doi.org/10.1175/JCLI-D-13-00692.1

Beaumier, M. C., & Ford, J. D. (2010). Food Insecurity among Inuit Women Exacerbated by Socio-economic Stresses and Climate Change. *Canadian Journal of Public Health*, *101*(3), 196–201. https://doi.org/10.1007/BF03404373

Bezner Kerr, R., T. Hasegawa, R. Lasco, I. Bhatt, D. Deryng, A. Farrell, H. Gurney-Smith, H. Ju, S. Lluch-Cota, F. Meza, G. Nelson, H. Neufeldt, and P. Thornton, 2022: Food, Fibre, and Other Ecosystem Products. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 713–906, doi:10.1017/9781009325844.007.

Bloem, M. W., Semba, R. D., & Kraemer, K. (2010). Castel Gandolfo Workshop: An Introduction to the Impact of Climate Change, the Economic Crisis, and the Increase in the Food Prices on Malnutrition. *The Journal of Nutrition*, *140*(1), 132S-135S. https://doi.org/10.3945/jn.109.112094

Borgomeo, E., Jägerskog, A., Zaveri, E., Russ, J., Khan, A., & Damania, R. (2021). *Ebb and Flow, Volume 2: Water in the Shadow of Conflict in the Middle East and North Africa*. The World Bank. https://doi.org/10.1596/978-1-4648-1746-5

Boyle, E. H., King, M., & Sobek, M. (2022). *IPUMS Demographic and Health Surveys: Version 9* (Version 9) [Dataset]. Minneapolis, MN: IPUMS and ICF. https://doi.org/10.18128/D080.V9

Christian, P. (2021). Anemia in women—An intractable problem that requires innovative solutions. *Nature Medicine*, *27*(10), Article 10. https://doi.org/10.1038/s41591-021-01514-3

Duncan, K. (2006). Global climate change, air pollution, and women's health. *Management of Natural Resources, Sustainable Development and Ecological Hazards*, *I*, 633–643. https://doi.org/10.2495/RAV060611

Eklund, L., Theisen, O. M., Baumann, M., Forø Tollefsen, A., Kuemmerle, T., & Østergaard Nielsen, J. (2022). Societal drought vulnerability and the Syrian climate-conflict nexus are better explained by agriculture than meteorology. *Communications Earth & Environment*, *3*(1), 85. https://doi.org/10.1038/s43247-022-00405-w

EM-DAT. (2023). *EM-DAT | The international disasters database*. https://www.emdat.be/

FAO. (2008). *High food prices and food insecurity: Threats and opportunities*. FAO.

FAO, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, & World Health Organization. (2021). *Near East and North Africa Regional Overview of Food Security and Nutrition 2020*. FAO. https://doi.org/10.4060/cb4902en

Food and Agriculture Organization of the United Nations and United Nations Economic and Social Commission for Western Asia. (2021). *Arab Food Security: Vulnerabilities and Pathways*.

GBD 2021 Anaemia Collaborators. (2023). Prevalence, years lived with disability, and trends in anaemia burden by severity and cause, 1990–2021: Findings from the Global Burden of Disease Study 2021. *The Lancet. Haematology*, *10*(9), e713. https://doi.org/10.1016/S2352-3026(23)00160-6

Goh, A. H. X. (2012). *A Literature Review of the Gender-Differentiated Impacts of Climate Change on Women's and Men's Assets and Well-Being in Developing Countries*. https://doi.org/10.2499/CAPRiWP106

Gray, C., & Thiede, B. C. (2024). Temperature anomalies undermine the health of reproductive-age women in low- and middle-income countries. *Proceedings of the National Academy of Sciences*, *121*(11). https://doi.org/e2311567121

Gray, C., & Wise, E. (2016). Country-specific effects of climate variability on human migration. *Climatic Change*, *135*(3), 555–568. https://doi.org/10.1007/s10584-015-1592-y

Green, H., Bailey, J., Schwarz, L., Vanos, J., Ebi, K., & Benmarhnia, T. (2019). Impact of heat on mortality and morbidity in low and middle income countries: A review of the epidemiological evidence and considerations for future research. *Environmental Research*, *171*, 80–91. https://doi.org/10.1016/j.envres.2019.01.010

Haas, J. D., & Brownlie, T., IV. (2001). Iron Deficiency and Reduced Work Capacity: A Critical Review of the Research to Determine a Causal Relationship. *The Journal of Nutrition*, *131*(2), 676S-690S. https://doi.org/10.1093/jn/131.2.676S

Hall, D. M. B., & Cole, T. J. (2006). What use is the BMI? *Archives of Disease in Childhood*, *91*(4), 283–286. https://doi.org/10.1136/adc.2005.077339

Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data*, *7*(1), Article 1. https://doi.org/10.1038/s41597-020-0453-3

Hoddinott, J., & Kinsey, B. (2000). Adult Health in the Time of Drought. *International Food Policy Research Institute*, *Food Consumption and Nutrition Division*(79).

Hoell, A., Robinson, R., Agel, L., Barlow, M., Breeden, M., Eischeid, J., McNally, A., Slinski, K., & Quan, X.-W. (2024). Changes to Middle East and Southwest Asia Compound Drought and Heat since 1999. *Journal of Climate*, *37*(1), 269–287. https://doi.org/10.1175/JCLI-D-23-0194.1

IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

Jobbins, G., & Henley, G. (2015). *Food in an uncertain future: The impacts of climate change on food security and nutrition in the Middle East and North Africa*. Overseas Development Institute (ODI) & World Food Programme.

Jolof, L., Rocca, P., Mazaheri, M., Okenwa Emegwa, L., & Carlsson, T. (2022). Experiences of armed conflicts and forced migration among women from countries in the Middle East, Balkans, and Africa: A systematic review of qualitative studies. *Conflict and Health*, *16*(1), 46. https://doi.org/10.1186/s13031-022-00481-x

Kassebaum, N. J., Jasrasaria, R., Naghavi, M., Wulf, S. K., Johns, N., Lozano, R., Regan, M., Weatherall, D., Chou, D. P., Eisele, T. P., Flaxman, S. R., Pullan, R. L., Brooker, S. J., & Murray, C. J. L. (2014). A systematic analysis of global anemia burden from 1990 to 2010. *Blood*, *123*(5), 615–624. https://doi.org/10.1182/blood-2013-06-508325

Keshavarz, M., Karami, E., & Vanclay, F. (2013). The social experience of drought in rural Iran. *Land Use Policy*, *30*(1), 120–129. https://doi.org/10.1016/j.landusepol.2012.03.003

Kinyoki, D., Osgood-Zimmerman, A. E., Bhattacharjee, N. V., Kassebaum, N. J., & Hay, S. I. (2021). Anemia prevalence in women of reproductive age in low- and middle-income countries between 2000 and 2018. *Nature Medicine*, *27*(10), Article 10. https://doi.org/10.1038/s41591-021-01498-0

Kuehn, L., & McCormick, S. (2017). Heat Exposure and Maternal Health in the Face of Climate Change. *International Journal of Environmental Research and Public Health*, *14*(8), 853. https://doi.org/10.3390/ijerph14080853

Lambrou, Y., & Nelson, S. (2010). FOOD SECURITY IN ANDHRA PRADESH, INDIA. *Food and Agricultural Organization of the United Nations*.

McMahon, K., & Gray, C. (2021). Climate change, social vulnerability and child nutrition in South Asia. *Global Environmental Change*, *71*, 102414. https://doi.org/10.1016/j.gloenvcha.2021.102414

Mueller, V., & Gray, C. (2018). Heat and adult health in China. *Population and Environment*, *40*(1), 1–26. https://doi.org/10.1007/s11111-018-0294-6

Neira, M., Erguler, K., Ahmady-Birgani, H., AL-Hmoud, N. D., Fears, R., Gogos, C., Hobbhahn, N., Koliou, M., Kostrikis, L. G., Lelieveld, J., Majeed, A., Paz, S., Rudich, Y., Saad-Hussein, A., Shaheen, M., Tobias, A., & Christophides, G. (2023). Climate change and human health in the Eastern Mediterranean and Middle East: Literature review, research priorities and policy suggestions. *Environmental Research*, *216*, 114537. https://doi.org/10.1016/j.envres.2022.114537

Nestel, P. (2002). *Adjusting Hemoglobin Values in Program Surveys*. INACG.

Nicholas, K., Campbell, L., Paul, E., Skeltis, G., Wang, W., & Gray, C. (2021). Climate anomalies and childhood growth in Peru. *Population and Environment*, *43*(1), 39–60. https://doi.org/10.1007/s11111-021-00376-8

NIH. (2023). *Assessing Your Weight and Health Risk*. https://www.nhlbi.nih.gov/health/educational/lose_wt/risk.htm

Olivares, L. V., Engle-Stone, R., Arnold, C. D., Langer, C. E., & Schenker, M. B. (2022). Anemia, Weight Status, and Fatigue Among Farmworkers in California: A Cross-Sectional Study. *Journal of Occupational & Environmental Medicine*, *64*(8), e459–e466. https://doi.org/10.1097/JOM.0000000000002578

Rajsekhar, D., & Gorelick, S. M. (2017). Increasing drought in Jordan: Climate change and cascading Syrian land-use impacts on reducing transboundary flow. *Science Advances*, *3*(8), e1700581. https://doi.org/10.1126/sciadv.1700581

Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz Carrascal, J. Sillmann, M.B. Sylla, C. Tebaldi, W. Wang, and R. Zaaboul, 2021: Climate Change Information for Regional Impact and for Risk Assessment. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1767–1926, doi:10.1017/9781009157896.014.

Randell, H., Gray, C., & Grace, K. (2020). Stunted from the start: Early life weather conditions and child undernutrition in Ethiopia. *Social Science & Medicine*, *261*, 113234. https://doi.org/10.1016/j.socscimed.2020.113234

Romanello, M., Napoli, C. D., Green, C., Kennard, H., Lampard, P., Scamman, D., Walawender, M., Ali, Z., Ameli, N., Ayeb-Karlsson, S., Beggs, P. J., Belesova, K., Berrang Ford, L., Bowen, K., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J., Cross, T. J.,

… Costello, A. (2023). The 2023 report of the Lancet Countdown on health and climate change: The imperative for a health-centred response in a world facing irreversible harms. *The Lancet*, *402*(10419), 2346–2394. https://doi.org/10.1016/S0140-6736(23)01859-7

Rønnestad, B. R., Hamarsland, H., Hansen, J., Holen, E., Montero, D., Whist, J. E., & Lundby, C. (2021). Five weeks of heat training increases haemoglobin mass in elite cyclists. *Experimental Physiology*, *106*(1), 316–327. https://doi.org/10.1113/EP088544

Schäfer, K. (2013, March). *Urbanization and Urban Risks in the Arab Region*. 1st Arab Region Conference for Disaster Risk Reduction, Aqaba - Jordan.

Secretary-General, U. (2022). *Achieving gender equality and the empowerment of all women and girls in the context of climate change, environmental and disaster risk reduction policies and programmes :* https://digitallibrary.un.org/record/3956348

Sellers, S. (2016). *Gender and Climate Change: A Closer Look at Existing Evidence*. Global Gender and Climate Alliance.

Selvaraju, R. Implications of climate change for agriculture and food security in the Western Asia and Northern Africa region. In Climate Change and Food Security in West Asia and North Africa; Springer: Dordrecht, The Netherlands, 2013; pp. 27–51.

Seneviratne, S.I., X. Zhang, M. Adnan, W. Badi, C. Dereczynski, A. Di Luca, S. Ghosh, I. Iskandar, J. Kossin, S. Lewis, F. Otto, I. Pinto, M. Satoh, S.M. Vicente-Serrano, M. Wehner, and B. Zhou, 2021: Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N.

Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi:10.1017/9781009157896.013.

Smith, M. R., Golden, C. D., & Myers, S. S. (2017). Potential rise in iron deficiency due to future anthropogenic carbon dioxide emissions. *GeoHealth*, *1*(6), 248–257. https://doi.org/10.1002/2016GH000018

Sorensen, C., Murray, V., Lemery, J., & Balbus, J. (2018). Climate change and women's health: Impacts and policy directions. *PLOS Medicine*, *15*(7), e1002603. https://doi.org/10.1371/journal.pmed.1002603

Sustainable Development Solutions Network. Indicators and a Monitoring Framework. Goal 02. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture. https://indicators.report/goals/ goal-2/ 23.

Tabari, H., & Willems, P. (2018). More prolonged droughts by the end of the century in the Middle East. *Environmental Research Letters*, *13*(10), 104005. https://doi.org/10.1088/1748-9326/aae09c

Trentinaglia, M. T., Parolini, M., Donzelli, F., & Olper, A. (2021). Climate change and obesity: A global analysis. *Global Food Security*, *29*, 100539. https://doi.org/10.1016/j.gfs.2021.100539

UN. (2024, March 8). *1 in every 10 women in the world lives in extreme poverty*. UN Women – Headquarters. https://www.unwomen.org/en/news-stories/press-release/2024/03/1-in-every-10-women-in-the-world-lives-in-extreme-poverty

Verner, D. (2012). *Adaptation to a Changing Climate in the Arab Countries: A Case for Adaptation Governance and Leadership in Building Climate Resilience*. World Bank Publications.

Waha, K., Krummenauer, L., Adams, S., Aich, V., Baarsch, F., Coumou, D., Fader, M., Hoff, H., Jobbins, G., Marcus, R., Mengel, M., Otto, I., Perrette, M., Rocha, M., Robinson, A., & Schleussner, C.-F. (2017). Climate change impacts in the Middle East and Northern Africa (MENA) region and their implications for vulnerable population groups. *Regional Environmental Change*, *17*(6), 1623–1638.

WHO. (2021). *Climate change and health*. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

World Health Organization. (2017). *Nutritional anaemias: Tools for effective prevention and control*. World Health Organization. https://iris.who.int/handle/10665/259425 World Health Organization. (2024, March 1). *Obesity and overweight*. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

Zittis, G., Almazroui, M., Alpert, P., Ciais, P., Cramer, W., Dahdal, Y., Fnais, M., Francis, D., Hadjinicolaou, P., Howari, F., Jrrar, A., Kaskaoutis, D. G., Kulmala, M., Lazoglou, G., Mihalopoulos, N., Lin, X., Rudich, Y., Sciare, J., Stenchikov, G., … Lelieveld, J. (2022). Climate Change and Weather Extremes in the Eastern Mediterranean and Middle East. *Reviews of Geophysics*, *60*(3), e2021RG000762. https://doi.org/10.1029/2021RG000762