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The syndemic effects of food insecurity, water insecurity, and HIV on depressive symptomatology among Kenyan women

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ABSTRACT

Depression is a leading cause of disability worldwide and a major contributor to the overall global burden of disease, especially for women of childbearing age. Social science scholarship has demonstrated significant relationships between mental health, food insecurity (FI), water insecurity (WI), and HIV. Little is known, however, about the temporal relationships between food and water insecurity or the mechanisms through which these multiple stressors may operate or interact to impact depression. We therefore used syndemic theory to explore the complex relationships between FI, WI, and HIV on depressive symptomatology among Kenyan women of mixed HIV status (n=183, NCT02979418). We sought to 1) understand the temporal relationships between time-variant risk factors for depression, i.e. FI and WI, and 2) assess how these factors potentially interacted with HIV to impact depressive symptomatology. We first assessed the bidirectional relationship between WI and FI using a cross-lagged three-wave, two-variable panel model. Next, we modeled depressive symptomatology at 21 months as a linear function of the potentially syndemic interaction between FI, WI, and HIV status, adjusting for household wealth. WI had a predominant predictive effect on FI (Bayesian posterior predictive *p*-value=0.13); there was no reverse causality for the influence of FI on WI. The interaction effect of FI, WI, and HIV was significantly associated with greater depressive symptomatology (β=0.06) at 21 months postpartum. These data suggest that water insecurity may be an important determinant of food insecurity. Further, the co-occurrence of FI, WI, and HIV increases the likelihood of maternal depressive symptomatology, i.e. there is a syndemic relationship. These findings suggest that the role of household WI in other adverse health outcomes beyond mental well-being should be examined, and that interventions to improve mental health will be more effective if they also consider concurrent resource insecurities, regardless of HIV status.

1. Introduction

Depression is a leading cause of disability worldwide and a major contributor to the overall global burden of disease (World Health Organization, 2017). Depression is associated with numerous adverse outcomes in the general population, including an increased risk of cognitive impairment, cardio- and cerebrovascular diseases, and suicide (Lépine and Briley, 2011). As such, understanding the causes of poor mental health is an international priority given the high prevalence of depression and psycho-emotional distress in low- and middle-income countries (Kessler and Bromet, 2013), especially in sub-Saharan Africa (World Health Organization, 2017).

Women have a higher risk of depression than men, with women of childbearing age experiencing an even greater risk given the physical, hormonal, nutritional, and social changes associated with pregnancy, childbirth, and motherhood (Bloch et al., 2003; Brummelte; Galea, 2016; Gavin et al., 2005; Osok et al., 2018; World Health Organization, 2017). Depression during pregnancy and postpartum is of particular concern given its potential short- and long-term deleterious consequences for both mothers and their children, including insecure attachment, conduct and anxiety disorders, maladaptive social interactions, poor cognitive development, and poor physical health (Bernard-Bonnin et al., 2004; Lépine and Briley, 2011).

Some risk factors for depression among women of childbearing are well understood, including genetic vulnerabilities, adverse life events, lack of social support systems, and chronic stress and disease (Guintivano et al., 2018; Yim et al., 2015). There is also evidence of a bidirectional association between depression and HIV through biological, psychological, and social causal mechanisms (Arseniou et al., 2014; Nanni et al., 2015).

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Social science scholarship has demonstrated significant relationships between mental health and resource insecurity. For example, research in sub-Saharan Africa has found that there is demonstrable stress resulting from not having reliable access to preferred foods (Cole and Tembo, 2011; Hadley and Crooks, 2012; Sorsdahl et al., 2011; Tsai et al., 2012; Weaver and Hadley, 2009) and water in sufficient quantities or quality (Krumdieck et al., 2016; Stevenson et al., 2016, 2012a; Workman and Ureksoy, 2017). Inadequate nutrition has also been associated with depression among women of childbearing age (Bodnar and Wisner, 2005) and is a risk factor for perinatal depression (Ellsworth-Bowers and Corwin, 2012; Leung and Kaplan, 2009).

There is emergent evidence that resource insecurities have a bidirectional relationship with HIV and that the co-occurrence of these factors may undermine mental well-being. Previous work in Uganda and South Africa, for example, found that food insecurity was associated with depression among seropositive women (Tsai et al., 2016, 2012). In western Kenya, pregnant women of mixed HIV status reported that water insecurity had negative impacts on nutritional and psychosocial well-being (Collins et al., 2018; Krumdieck et al., 2016). Similarly, water insecurity, along with food insecurity and HIV, was associated with increased depression and anxiety symptomatology among women in Lesotho (Workman and Ureksoy, 2017).

Knowledge about the relationships between these multiple risk factors is critical for developing effective policies and programs that address the most salient determinants of depression. Yet little is known about the temporal relationships between food and water insecurity (Brewis et al., 2020; Young et al., 2019). Further, there is an acknowledged dearth of empirical data on the mechanisms through which these stressors may operate or interact (Brewis et al., 2020; Maxfield, 2019), although nascent evidence suggests food insecurity may be a pathway through which water insecurity negatively impacts mental health (Brewis et al., 2019). Understanding the causal relationships between these conditions is critical both for advancing theory and providing recommendations to reduce resource insecurities, ameliorate mental health, and possibly even improve HIV outcomes.

Syndemic theory offers a useful framework for exploring the complex relationships between resource insecurities, HIV, and depression. Syndemic theory posits that diseases cluster as a result of political-economic forces, such as poverty and inequality, and that co-occurring diseases and social forces interact to mutually exacerbate one another (Mendenhall et al., 2017; Singer, 1994; Singer et al., 2017; Singer and Clair, 2003). Although existing syndemic literature has cogently demonstrated that diseases such as depression concentrate among certain at-risk populations, Tsai and others argue that few studies have clearly demonstrated the exact relationship between examined co-factors (Tsai et al., 2017; Tsai and Burns, 2015; Tsai and Venkataramani, 2016). That is, previous studies have discussed synergism and interactions in a manner not borne out in the statistical models (Tsai and Burns, 2015). Indeed, the overwhelming reliance on cross-sectional data and superficial treatment of interaction effects has limited our understanding of syndemics (Tsai et al., 2017).

Given the paucity of longitudinal data on the complex relationships between resource insecurity, HIV, and depression, we used data from an observational study of food and water insecurity among Kenyan women living with and without HIV to empirically assess how these factors are related to each other as well as to depression. Specifically, our first objective was to understand the temporal relationship between time-variant risk factors for depression, i.e. food and water insecurity. We then aimed to assess how these factors potentially interacted with HIV to increase depressive symptomatology. In other words, our second objective was to test for syndemicity. We hypothesized that water insecurity would predict future food insecurity, and that there would be a syndemic relationship between the effects of food insecurity, water insecurity, and HIV on depressive symptomatology at 21 months postpartum.

2. Methods

2.1. Study design & setting

Data are from Pith Moromo [Luo for "enough feeding" (NCT02974972)], an observational longitudinal study whose primary goal was to assess the consequences of food insecurity and HIV on maternal and child health during the "first 1000 days" (i.e. the year prior to delivery and two years postpartum). Women were recruited from Family AIDS Care and Educational Services (FACES) clinics across seven rural, peri-urban, and rural areas (Kisumu, Macalder, Migori, Nyahera, Nyamaraga, Ongo, Rongo) in the former Nyanza region, Kenya between September 2014 and June 2015. FACES clinics deliver basic health services to all adults as well as integrated, comprehensive HIV treatment and prevention services.

Women were eligible to participate if they were within their first 7 months of pregnancy and intended to live in the catchment area until their infant(s) reached at least 9 months of age. Quota sampling was used in order to achieve equal numbers of pregnant women living with and without HIV by tertiles of food insecurity scores, as assessed using the nine-item Individual Food Insecurity Access Scale (low: 0–9, moderate: 10–18, severe: 19–27) (Natamba et al., 2015). Ultimately, 371 women were included at baseline. Participants still in the study at 9 months postpartum were enrolled into "Pii Ngima" [Luo for "water is life" (NCT02979418)] and surveyed through 21 months postpartum.

The Nyanza region was an appropriate study setting to test our hypotheses given the high prevalence of HIV, food and water insecurity, and depression. Homa Bay County had the highest adult HIV prevalence in Kenya (26%) in 2015 (National AIDS and STI Control Programme [NASCOP]). Further, the 2014 Kenya Demographic and Health Survey found that a greater proportion of individuals living in this region reported "poor" or "borderline" food consumption scores compared to all other regions in the country, and that 27% of the population obtained drinking water from an unimproved source (Kenya National Bureau of Statistics, 2015a). Psychosocial distress is also common throughout Kenya; an estimated 40% of individuals attending general medical facilities in the country report at least one mental health disorder (Ndetei et al., 2009).

2.2. Ethical approvals

Institutional Review Boards at Cornell University, Northwestern University, and Kenya Medical Research Institute approved study procedures. All participants provided written informed consent at enrollment.

2.3. Data collection

Survey data were collected by clinic-based study nurses using paper forms and tablet-based questionnaires. Participants were interviewed twice during pregnancy and seven times between delivery and 21 months, for a total of 9 clinical visits. Given that our objective was to test the temporal relationship between multiple risk factors for depression, we restricted our analysis to visits for which data on food and water insecurity were available, i.e. study visits at 15, 18, and 21 months postpartum. Any individual with data on one key variable (food insecurity, water insecurity, or depression) at 15, 18, and 21 months postpartum was included in the analytic sample (Fig. 1).

Depressive symptomatology was assessed at every odd visit using the Center for Epidemiological Studies-Depression (CES-D) scale (Radloff, 1977), a 20-item, Likert-format screening tool in which respondents are asked how often they experienced a particular symptom in the past week (range 0–60); higher scores indicate greater depressive symptomatology. This tool was selected because it has been validated for use among similar populations, including postpartum women in East Africa (Kilburn et al., 2016; Natamba et al., 2014). Given that the CES-D scale is

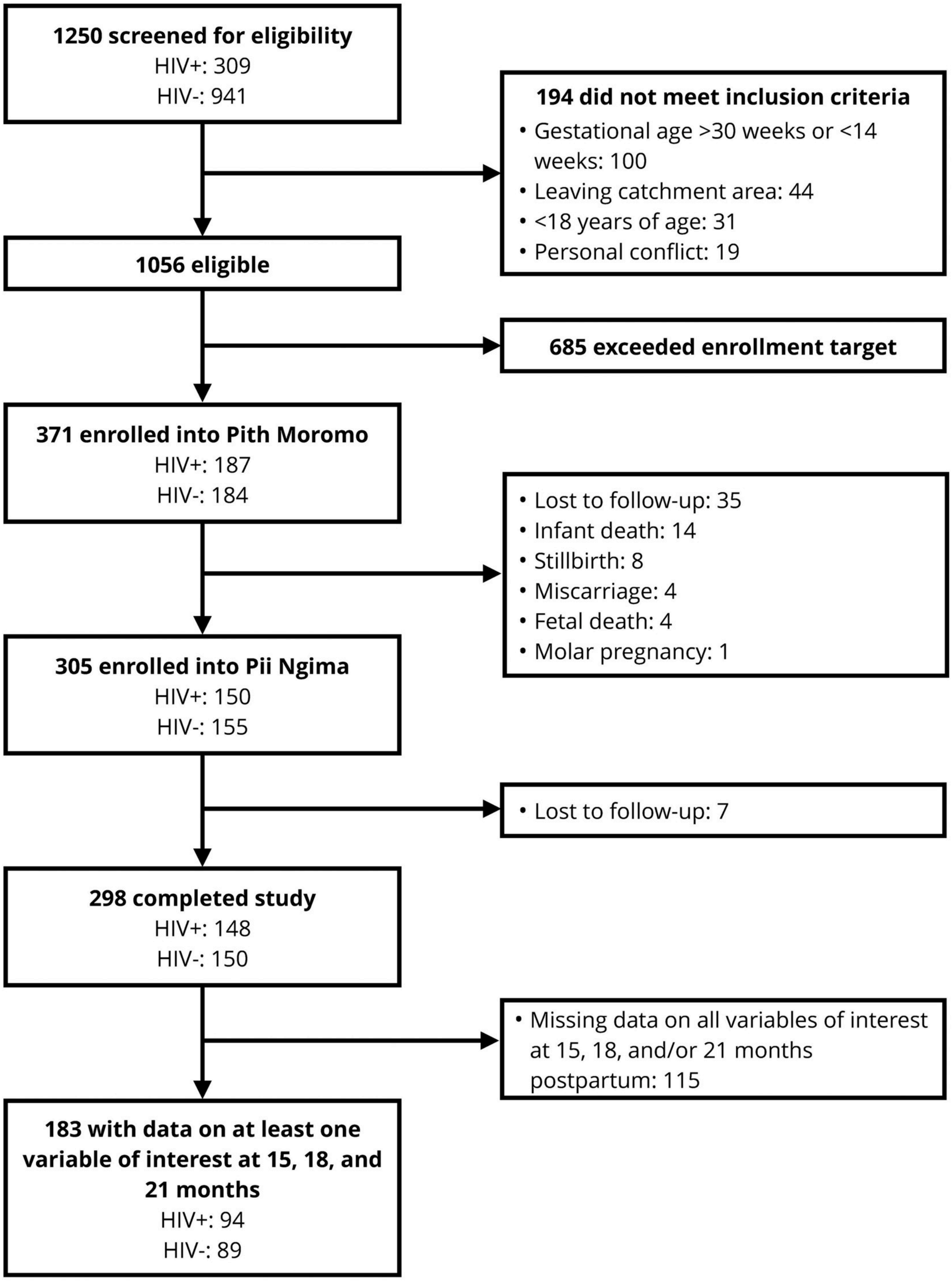

Fig. 1. Participant recruitment and attrition through the Pith Moromo and Pii Ngima studies.

not a clinical diagnostic tool, it cannot be used to classify individuals as depressed but can be used to quantify depressive symptomatology.

The Individual Food Insecurity Access Scale was used at every visit to measure food insecurity (Natamba et al., 2015). It is similar to the Household Food Insecurity Access Scale (Coates et al., 2007), except that participants are queried about their personal experiences with access to and use of food in the prior month, rather than those of the household; higher scores indicate greater food insecurity (range 0–27).

Water insecurity was measured starting at the 15-month visit using a 20-item household water insecurity scale that was developed and validated for this site (Boateng et al., 2018). It captures multiple dimensions of water insecurity in the prior month, including anxiety, insufficiency, opportunity cost, and quality. Higher scores indicate greater water insecurity (range 0–60).

HIV status of participants was recorded at baseline (approximately 7 months gestation) based on clinical records, and at subsequent clinic visits using the colloidal gold rapid test (Branson, 2000). Seroconversion occurred in four participants, although they were lost-to-follow-up by 15 months postpartum and hence were not eligible for inclusion in the analysis.

Time-invariant sociodemographic characteristics were included as potential confounders, including maternal age, education, marital status, household size, and household wealth. Household wealth was derived from a principal component analysis of self-reported household asset ownership at 9 months postpartum, using an adapted version of the Kenya Integrated Household Budget Survey Questionnaire (Kenya National Bureau of Statistics, 2015b). We retained the first principal component in its continuous form; higher asset scores indicate greater household wealth.

2.4. Statistical analysis

For analyses, we used sociodemographic data from baseline; food and water insecurity data from 15, 18, and 21 months postpartum; and depressive symptomatology data from 21 months postpartum. All analyses were completed using Stata 14.0 (StataCorp, College Station, TX, USA) or Mplus 8.0 (Los Angeles, CA: Muthén & Muthén).

We used univariate analysis to assess means and proportions for each variable. We then examined the bivariate relationships between potential confounders and key variables of interest (i.e. food insecurity, water insecurity, depression) at each time point using pairwise correlations for continuous variables and linear regressions for categorical variables. Potential confounders that were significant at $p < 0.2$ were included as controls in future models.

2.4.1. Assessing the relationship between food and water insecurity across time

To our first objective (i.e. assessing the temporal relationship between the time-variant risk factors for depression), we fit a cross-lagged three-wave, two-variable panel model, also known as the generalized method of moments (GMM) (Supplementary Figure 1). The models are crossed because they estimate relationships between variables (i.e. food and water insecurity) and lagged because they estimate relationships between variables across different time points (Kearney, 2017).

The assumptions for using a cross-lagged panel model were satisfied in three ways (Kearney, 2017). First, the measurement of each variable occurred at the same time. Second, the variables and their relationships remained stable across time. This means that food and water insecurity items measured their respective latent constructs, both on the same scale and with the same degree of precision over time, but with different amounts of error. Third, given that data were collected sequentially, temporal sequence was established.

To test model fitness, we used Bayesian posterior prediction model checking (PPMC), which is appropriate for modest sample sizes. The PPMC compares observed data with the posterior predictive distribution of replicated data generated using a predictive model that is sensitive to model misfit (Crespi and Boscardin, 2009; Gelman et al., 2013). For our Bayesian analysis, we used a Markov chain Monte Carlo (MCMC) numerical algorithm to estimate posterior distributions of model parameters and Gibbs sampler with 20,000 fixed iterations. A small *p*-value ($p < 0.05$) reflects poor model fit (Brown, 2014).

2.4.2. Assessing interactions between food insecurity, water insecurity, and HIV

To our second objective, i.e. testing the potential syndemicity of food insecurity, water insecurity, and HIV on maternal depressive symptomatology at 21 months, we developed multiple structural equation models. The three-month lag between the outcome of interest and independent variables is similar to lags in previous depression studies (e.g. Tsai et al., 2012).

We first regressed CES-D scores on food insecurity and water insecurity. We then regressed CES-D scores at 21 months as a linear function of the interaction between food and water insecurity at 18 months postpartum. To determine how HIV status contributed to the model, we also regressed CES-D scores on food insecurity, water insecurity, and HIV-positive status. Finally, to assess the potential syndemic relationship between these three factors, we regressed CES-D scores on the interaction between food insecurity, water insecurity, and HIV status (Fig. 2). All interactions were multiplicative (i.e. the product term between variables was used).

In order to obtain parsimonious models that appropriately accounted for potential confounders, we built each model in a forward stepwise manner, beginning with the strongest predictor and building up (Raudenbush and Bryk, 2002). Given that data on food or water insecurity were missing for some cases, we used the full information maximum likelihood (FIML) technique, a pragmatic missing data estimation approach for structural equation models, to produce unbiased parameter estimates and standard errors (Newsom, 2018).

3. Results

3.1. Sample characteristics

The final analytic sample included 183 women with data on at least one key variable (food insecurity, water insecurity, or depression) at 15, 18, and 21 months postpartum (Fig. 1). Mean maternal age at baseline was 25.5 ± 4.7 years, with a range of 18–38 years (Table 1). Slightly more than half (51.4%) of participants were living with HIV, and the majority had attained at least primary education (63.2%) and were married (92.9%). Mean household size was 7.5 ± 3.9 members, with a

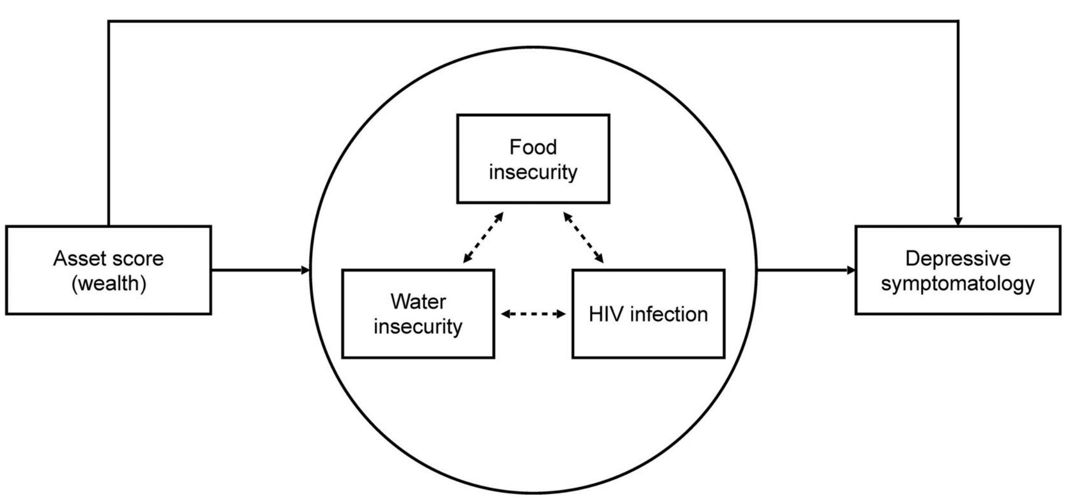

Fig. 2. A conceptual syndemic model showing the synergistic interaction between food insecurity, water insecurity, and HIV infection, and its effect on depressive symptomatology.

Table 1
Descriptive statistics of key time-variant and -invariant characteristics of Kenyan women included in the analytic sample.

Time-invariant variables	Univariate descriptives	
Maternal age (n = 182), mean (sd)	25.5 (4.7)	
HIV-positive (n = 183), %	51.4	
Education level (n = 171), %		
< secondary	63.2	
≥ secondary	36.8	
Married (n = 182), %	92.9	
Household size (n = 182), mean (sd)	7.5 (3.9)	
Asset index (n = 172), mean (sd)	0.18 (1.76)	
Time-variant variables	**Univariate descriptives**	**Cronbach's alpha**
15 months postpartum		
FI score (n = 116), mean (sd)	8.1 (5.0)	0.897
WI score (n = 162), mean (sd)	9.4 (12.6)	0.975
18 months postpartum		
FI score (n = 182), mean (sd)	7.7 (4.1)	0.872
WI score (n = 163), mean (sd)	8.3 (11.9)	0.975
21 months postpartum		
FI score (n = 182), mean (sd)	8.4 (5.0)	0.882
WI score (n = 164), mean (sd)	9.8 (12.7)	0.976
CES-D score (n = 183), mean (sd)	13.1 (7.7)	0.860

% = response proportions for categorical variable; sd = standard deviation; CES-D = Center for Epidemiological Studies-Depression Scale; FI = food insecurity using the Individual Food Insecurity Access scale (range: 0–27) (Natamba et al., 2015); WI = water insecurity using a 20-item scale validated for use in Kenya (range: 0–60) (Boateng et al., 2018).

range of 1–19.

Mean food and water insecurity scores ranged from 7.7 to 8.4 and 8.3 to 9.8 between 15 and 21 months postpartum, respectively. The mean CES-D score was 13.1 ± 7.7 at 21 months postpartum.

Women included in the analysis were similar across most characteristics compared to those who were excluded for not meeting analytic inclusion criteria (Supplementary Table 1). Those who were excluded, however, were younger, less wealthy, and had fewer household members.

3.2. Scale reliability

Cronbach's alpha for all scales ranged between 0.860 and 0.976, with little variation across time, indicating good to excellent internal consistency and stability (Table 1) (Nunnally, 1978).

3.3. Relationships between food and water insecurity across time

Our first objective was to understand the relationship between food and water insecurity. To do this, we created a three-wave, two-variable cross-lagged panel model with food and water insecurity at 15, 18, and 21 months postpartum, which had good fit, as indicated by a posterior predictive p-value that is greater than 0.05 (Table 2).

Both food and water insecurity predicted subsequent food and water insecurity (Table 2, Fig. 3). For instance, every point increase in food insecurity at 15 months was associated with a 0.47-point increase in food insecurity at 18 months. Similarly, a one-point increase in water insecurity at 15 months was associated with a 0.48-point increase in water insecurity at 18 months postpartum. To compare the magnitude of effects across food and water insecurity, we also report standardized coefficients (Table 2). For instance, each one standard deviation increase in food insecurity at 18 months was associated with 0.38-point standard deviation increase in food insecurity at 21 months.

There was a significant cross-lagged effect between water insecurity and future food insecurity; water insecurity at 18 months predicted food insecurity at 21 months postpartum (Table 2). Thus, every point increase in water insecurity at 18 months was associated with 0.12-point increase

Table 2
Three-wave, two-variable structural equation model of the relationship between food and water insecurity among postpartum women in Kenya (n = 183).

	β (PSD)	95% CI	Standardized Coefficient
Water insecurity at 18 months			
Water insecurity at 15 months	0.48 (0.07)	0.33, 0.63***	0.51
Food insecurity at 15 months	0.28 (0.20)	−0.10, 0.67	0.12
Water insecurity at 21 months			
Water insecurity at 18 months	0.69 (0.08)	0.54, 0.84***	0.63
Food insecurity at 18 months	0.19 (0.21)	−0.23, 0.60	0.06
Food insecurity at 18 months			
Water insecurity at 15 months	−0.00 (0.03)	−0.05, 0.05	−0.01
Food insecurity at 15 months	0.47 (0.07)	0.34, 0.60***	0.59
Food insecurity at 21 months			
Water insecurity at 18 months	0.12 (0.03)	0.06, 0.18***	0.28
Food insecurity at 18 months	0.46 (0.09)	0.30, 0.63***	0.38
Posterior predictive *p*-value	0.13		
Bayesian Information Criterion (BIC)	6497.84		

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; β represents the unstandardized amount of change in the outcome per unit change in the predictor; PSD = posterior standard deviation; 95% CI = 95% confidence interval; standardized coefficient represents the standardized amount of change in the outcome per standard deviation change in the predictor.

in food insecurity at 21 months postpartum. Notably, food insecurity exhibited no reverse causality on water insecurity (Fig. 3). In other words, although food and water insecurity co-occurred, they were not bidirectionally related. Instead, a predictive effect of lagged water insecurity on food insecurity was established.

3.4. Relationships between potential confounders variables of interest

Our second objective was to test for syndemic effects of food and water insecurity and HIV on maternal depressive symptomatology. To accomplish this, we first identified potential confounders that were significantly associated with depressive symptomatology, food insecurity, and water insecurity (Table 3).

Age was positively associated with household size and living with HIV. Living with HIV was positively associated with food insecurity at 15 and 21 months postpartum, water insecurity at 15 months postpartum, and depressive symptomatology at 21 months postpartum. Asset scores were negatively correlated with food insecurity at 15, 18, and 21 months; water at 18 and 21 months; and depressive symptomatology at 21 months. Neither maternal education nor marital status were associated with food insecurity, water insecurity, or depression at any time point in bivariate linear regressions (data not shown). As such, only asset index was included in subsequent models because all other potential confounders were not significantly associated ($p > 0.2$) with time-variant variables of interest.

3.5. Interactions between food insecurity, water insecurity, and HIV

We ran several multiple linear regression models of depressive symptomatology based on significant bivariate relationships. In the simplest model, which incorporated only food and water insecurity at 18 months, 7% of variation in depression scores was explained (Table 4, Model 1). When a synergistic interaction between food insecurity and water insecurity was considered, 9% was explained (Table 4, Model 2). The amount of variation in depression scores explained by the model remained at 9% when HIV was included (Table 4, Model 3).

We then regressed CES-D scores on a three-way interaction between food insecurity, water insecurity, and HIV-positive status, controlling for asset score (Table 4, Model 4). The three-way interaction was significant, such that holding all other factors constant, a 1-point increase in

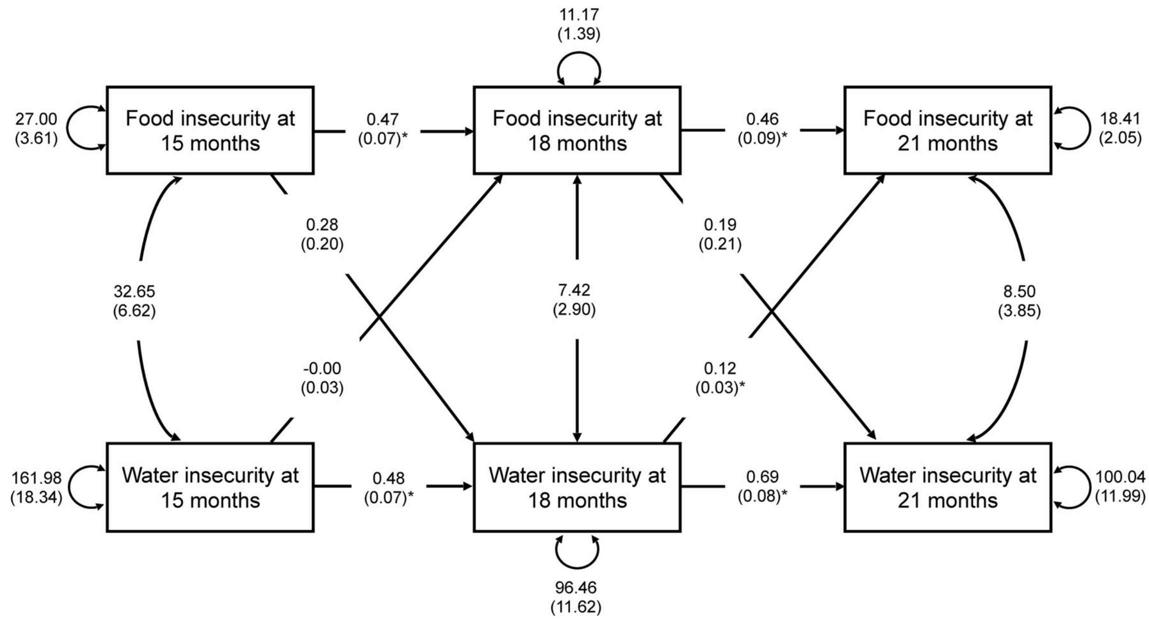

Fig. 3. Model results of a three-wave, two-variable cross-lagged panel model showing the bidirectional relationship between food and water insecurity at 15, 18, and 21 months postpartum for 183 participants, with covariance and unstandardized regression coefficients for both significant and non-significant effects.

Table 3
Pairwise correlation coefficients between sociodemographic characteristics and time-variant variables.

	Age	HIV+	Household size	Asset score	FI – 15 M	FI – 18 M	FI – 21 M	WI – 15 M	WI – 18 M	WI – 21 M	CES-D – 21 M
Age	1.000										
HIV+	0.270***	1.000									
Household size	0.303***	0.037	1.000								
Asset score	0.093	−0.042	−0.087	1.000							
FI – 15M	0.098	0.227*	0.126	−0.410***	1.000						
FI – 18M	0.036	0.137	0.096	−0.369***	0.582***	1.000					
FI – 21M	0.067	0.164*	−0.075	−0.353***	0.495***	0.478***	1.000				
WI – 15M	0.073	0.177*	0.052	−0.153	0.491***	0.290***	0.278***	1.000			
WI – 18M	0.061	0.120	−0.040	−0.174*	0.388***	0.382***	0.432***	0.597***	1.000		
WI – 21M	0.002	0.120	0.002	−0.212**	0.443***	0.284***	0.416***	0.570***	0.635***	1.000	
CES-D – 21M	−0.021	0.171*	−0.081	−0.214**	0.355***	0.210**	0.463***	0.039	0.128	0.031	1.000

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; CES-D = Center for Epidemiological Studies-Depression scale; FI = food insecurity; WI = water insecurity; 15 M = 15 months postpartum; 18 M = 18 months postpartum; 21 M = 21 months postpartum.

food or water insecurity, or living with HIV, was associated with a 0.06-point increase in depression scores. Given that the three-way interaction was multiplicative, this means that an individual living with HIV who has a food insecurity score of 10 and a water insecurity score of 10 is predicted to score 6.0 points higher on the depression scale than an individual with no HIV, food insecurity, or water insecurity. Additionally, 16% of the variation in CES-D scores was explained by this model, which is nearly double the variation explained in Model 3 (9%).

In sum, the co-occurrence of food insecurity, water insecurity, and HIV increases the likelihood of maternal depressive symptomatology. This significant multiplicative interaction is indicative of a syndemic relationship. Notably, the effects of food insecurity, water insecurity, and HIV on depressive symptomatology remained significant even when controlling for wealth.

4. Discussion

To our first objective, we found that food and water insecurity co-occur (Table 3), and that water insecurity predicts future food insecurity (Table 2, Fig. 3). Specifically, food and water insecurity at 15 and 18 months postpartum predicted subsequent food and water insecurity, respectively. Perhaps most interestingly, water insecurity at 18 months also predicted food insecurity at 21 months postpartum ($\beta = 0.12, p < 0.001$) (Table 2, Fig. 3). Water insecurity is thus predictive of food insecurity but not vice versa, that is, we did not find a bidirectional relationship between these two phenomena.

Prior work has demonstrated that food and water insecurity, at individual- and household-level(s), co-occur and may be causally related (Brewis et al., 2020; Wutich; Brewis, 2014; Young et al., 2019). These data represent the first opportunity, though, to empirically assess the temporal nature, directionality, and strength of relationships between food and water insecurity.

We found that greater household water insecurity at 18 months postpartum was associated with greater maternal food insecurity at 21 months postpartum (Table 2). Interestingly, we found no similar predictive relationship between water insecurity at 15 months postpartum and subsequent food insecurity. This discordance may be due, in part, to the fact that most 18-month interviews occurred during the rainy season, whereas the majority of 21-month interviews occurred during the harvest season. As such, our results align with previous theoretical work describing the linkages between food and water insecurity through agriculture; water insecurity during critical growing months may limit crop harvest and reduce food availability, thereby increasing food insecurity (Brewis et al., 2020; Ringler and Paulo, 2020).

Table 4

A lagged linear regression model showing the predictive effect of the interaction between food insecurity and water insecurity at 18 months, and HIV positive status on maternal depressive symptomatology at 21 months postpartum using a maximum likelihood estimator with robust standard errors (n = 183).[†]

	Model 1	Model 2	Model 3	Model 4
	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Asset score	−0.72 (−1.39, −0.04)*	−0.69 (−1.36, −0.03)*	−0.72 (−1.38, −0.05)*	−0.61 (−1.25, 0.04)
Food insecurity	0.26 (−0.04, 0.57)	0.07 (−0.29, 0.42)	0.23 (−0.07, 0.54)	0.48 (−0.06, 1.02)
Water insecurity	0.02 (−0.09, 0.12)	−0.29 (−0.59, 0.01)	0.01 (−0.09, 0.12)	−0.09 (−0.53, 0.36)
Food insecurity * water insecurity		0.03 (0.002, 0.06)*		−0.01 (−0.05, 0.04)
HIV positive			2.22 (0.06, 4.38)*	5.43 (0.18, 10.69)*
HIV positive * food insecurity				−0.67 (−1.34, 0.01)
HIV positive * water insecurity				−0.34 (−0.93, 0.25)
Food insecurity * water insecurity * HIV positive				0.06 (0.001, 0.11)*
Bayesian Information Criterion (BIC)	4257.45	5929.75	4546.11	9542.47
R-squared	0.07	0.09	0.09	0.16

[†] Sensitivity analyses using Bayesian estimation are available in Supplementary Table 2; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; all significance at 2-tailed p-value; 95% CI = 95% confidence interval; β represents the unstandardized amount of change in the outcome (CES-D scores) per unit change in the predictor.

The finding that household water insecurity is predictive of future individual food insecurity could have enormous policy implications. For example, the reduction of food insecurity is a Sustainable Development Goal (United Nations, 2019) and key objective for many governmental and non-governmental organizations. That water insecurity may be a distal cause of food insecurity means that the reduction of household water insecurity could become a development goal in and of itself, akin to how food insecurity is currently used. For example, if water insecurity precipitates food insecurity, it could be used as an indicator of eventual food insecurity, and would be useful for identifying vulnerable populations and targeting resources. Establishing causality between food and water insecurity in other settings will help us to evaluate the generalizability of this finding, although there is growing evidence of its plausibility (Brewis et al., 2020).

To our second objective, we found that water and food insecurity interacted multiplicatively to increase maternal depressive symptomatology (β = 0.03; $p < 0.05$) (Table 4, Model 2). Further, we established a syndemic interaction between food insecurity, water insecurity, and HIV, resulting in increased depressive symptomatology in this population (β = 0.06; $p < 0.05$) (Table 4, Model 4). That is, participants had higher CES-D scores if they experienced food insecurity, water insecurity, or HIV infection, and these stressors multiplicatively exacerbated the effects of each other. Consistent with previous studies, food insecurity (Tsai et al., 2016, 2012) and water insecurity (Brewis et al., 2019; Workman and Ureksoy, 2017) were found to be modifiable risk factors for depression, as was HIV (Bernard et al., 2017; Tsai et al., 2016, 2012). Our findings build on this work by demonstrating the importance of both non-communicable stressors, in this case, food and water insecurity, and communicable diseases, i.e. HIV, in shaping depression; the importance of both types of exposures is a major tenet of syndemic theory (Singer et al., 2017; Tsai et al., 2017; Tsai and Venkataramani, 2016).

These findings from our second objective also have practical and clinical relevance for improving mental health globally. For instance, our results demonstrate that concurrent food insecurity and water insecurity are a significant, but often overlooked, source of biopsychosocial stress for women with young children. Indeed, a review of mental health among women living with HIV revealed myriad correlates of depression (Kapetanovic et al., 2014), yet few studies have examined the role of resource insecurity on depressive symptomatology during the postpartum period. Further, it seems likely that these stressors would exacerbate depressive symptomatology in other groups (e.g. adult men, the elderly, and children, with and without HIV). For example, maternal food insecurity, water insecurity, and depression affects the health of children, both through vertical HIV transmission and in the critical early years of development (Van Rie et al., 2009; Young et al., 2014). Evidence of the deleterious consequences of water insecurity for depressive symptomatology suggests its role in other adverse health outcomes, including in chronic and infectious diseases, is worthy of examination. Lastly, these data suggest that interventions to improve mental health will be most effective if they consider concurrent resource insecurities, regardless of HIV status.

4.1. Strengths and limitations

This study contributes to our understandings of syndemic effects and resource insecurities in several ways. First, the relationships between food and water insecurity have only been examined cross-sectionally to date (Brewis et al., 2020, 2019; Maxfield, 2019; Stevenson et al., 2012b; Workman and Ureksoy, 2017). Our study builds on the observed associations by examining the contemporaneous relationship between food and water insecurity across time, and providing empirical evidence for the predictive effect of water insecurity on future food insecurity.

Second, the data and analyses presented here overcome several of the limitations identified in prior syndemic analyses, including imprecision in the definition and modeling of covariates that has resulted in the inability to demonstrate the specific mechanisms of purported syndemic interactions (Tsai and Burns, 2015; Tsai and Venkataramani, 2016). By using linear lagged models and explicitly testing for statistical interactions, we have provided clear evidence of a syndemic relationship between food insecurity, water insecurity, and HIV status on depressive symptomatology. The inclusion of women with and without HIV is a further strength of the study, given that most work to date on maternal depression is either among only those with or without HIV, such that the impacts of HIV cannot be assessed.

Despite these strengths, there are a few limitations that provide opportunities for future research. First, the fact that food insecurity was assessed at the individual level, while water insecurity was assessed at the household level, may underestimate the full multiplicative effect of the interaction if there is intrahousehold variation in experiences with water insecurity (Maxfield, 2019). Future studies may consider using variables measured at the same level. Further, depressive symptomatology was measured using a screener and not a diagnostic tool. Consequently, interpretation of our findings reflects experiences of women with depressive symptomatology and not those diagnosed with depression.

Our ability to generalize beyond this non-randomly selected cohort of women Kenyan is limited. Although it is plausible that these relationships exist in other populations, it will be important to explore them empirically in future studies. Additionally, future research should explore if the syndemic effect of these factors differentially influence children's and men's health.

Lastly, the size of our sample may have potentially underestimated the effects of food and water insecurity on depressive symptomatology in the GMM model. Future studies may need to examine this relationship using a larger sample. Larger samples with more time points would also enable the cross-lagged panel models to include fixed effects and thereby control for additional potential confounders.

5. Conclusion

In sum, we found that water insecurity had a predominant predictive effect on future food insecurity; water and food insecurity interacted multiplicatively to increase depressive symptomatology; and there is a synergistic interaction between water insecurity, food insecurity, and HIV on maternal depression. Concurrent attention to all of these exposures is necessary in order to reduce the burden of adverse mental health among some of the most vulnerable members of society.

Author contribution

Godfred Boateng led data analysis, helped design and create figures and tables, assisted with the writing of the original draft, and critically revised subsequent versions. Cassandra Workman assisted with the writing of the original draft, provided insights into data interpretation, and critically revised subsequent versions. Joshua Miller assisted with data analysis, was responsible for data curation, helped design and create figures and tables, and critically revised the manuscript. Maricianah Onono assisted with design of data collection, supervised data collection, assisted with interpretation of data, and critically revised the manuscript. Torsten Neilands assisted with data analysis and interpretation, and critically revised the manuscript. Sera Young conceived the study, acquired funding, designed data collection, helped supervise data collection, assisted with the writing of the original draft, and critically revised subsequent versions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2020.113043.

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