



Mobility ideation due to water problems during historic 2022 drought associated with livestock wealth, water and food insecurity, and fingernail cortisol concentration in northern Kenya

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ARTICLE INFO

Handling editor: Susan J. Elliott

Keywords:

Climate change
Water
Stress
Drought
Mobility ideation
Cortisol
Mental health
Pastoralism

ABSTRACT

Climate change is triggering environmental mobility through chronic water problems and punctuated events. Thinking about moving locations, or “mobility ideation”, is the precursor to migration intentionality and actual migration. Drawing on the embodiment construct, this study examines how the worst drought in recent history in the Horn of Africa affected water-related mobility ideation and, in turn, fingernail cortisol concentration (FCC), a chronic stress biomarker, among Daasanach semi-nomadic pastoralists in northern Kenya. To address these questions, we primarily draw on survey, anthropometric, water quality, and biomarker data among 175 adults living in seven communities in 2022. We used mixed-effects ordered logistic regression to test how livestock wealth, water insecurity, food insecurity, and anxiety/depression symptom scores were associated with household mobility ideation. We then used generalized linear models to test the association between mobility ideation on FCC. Thinking about moving at least once due to water problems increased from pre-drought in 2019 (55%) to during the drought in 2022 (92%), while actual mobility declined. Livestock wealth, while associated with actual mobility in the prior year, was protective against increased mobility ideation, while water insecurity, food insecurity, and anxiety/depression symptoms were associated with greater odds of thinking of leaving in 2022. Compared to adults who did not consider moving, those who considered moving rarely, sometimes, and often had FCC levels 18.1% higher (95% CI, 1.01–1.38; $p = 0.039$), 19.4% higher (1.01–1.41; $p = 0.040$), and 32.3% higher (1.01–1.73; $p = 0.039$), respectively, with results consistent in sensitivity analyses. Extreme climatic events in water scarce regions may increase mobility ideation through worsened experiential indicators of well-being and resource insecurity. Mobility ideation may capture measures of adversity suffered by pastoralists and signify climate distress. This research broadens understanding of how droughts get under the skin by leading to resource insecurity and triggering thoughts of moving, which increases chronic stress.

1. Introduction

People's lived experiences are increasingly affected by climate

change as precipitation becomes more variable alongside increasing risk of droughts (Pörtner et al., 2022). Extreme climatic events like drought have dire implications for human biology and health by increasing water

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<https://doi.org/10.1016/j.socscimed.2024.117280>

Received 13 December 2023; Received in revised form 9 August 2024; Accepted 27 August 2024

Available online 31 August 2024

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and food insecurity and hurting livelihoods (Connolly-Boutin and Smit, 2016; Rosinger, 2023a). Water scarcity not only increases risk of dehydration and water-borne diseases, but creates psychosocial stress – characterized as “suffering for water” (Ennis-McMillan, 2001).

When water-related problems worsen, one major adaptive response is migration (Wutich and Brewis, 2014). Climate change is triggering environmental mobility across countries and migration within countries through chronic water problems and punctuated events like flooding and drought (Stoler et al., 2021a). Droughts in marginal environments can change exposures, create increased competition for resources, and affect livelihoods, which can lead to migration (Gray and Mueller, 2012; Holdaway et al., 2013; Moore and Wesselbaum, 2023).

Thinking about moving locations, a condition reframed as “mobility ideation” (Stoler J et al. Under review), is the precursor to migration intentionality and actual migration (Black et al., 2011; Goldsmith and Beegle, 1962; Hunter et al., 2015; Sell and DeJong, 1978). Mobility ideation implicitly acknowledges dissatisfaction with the current situation and likely increases one’s psychosocial stress. While much in the literature has examined the stress associated with relocation, little work has examined stress associated with the pre-move period (Adger et al., 2021) or imagining relocation prior to the move itself (Koikkalainen and Kyle, 2016). We know even less about how mobility ideation—specifically in response to resource constraints such as water scarcity—is related to indicators of well-being and stress biomarkers.

The embodiment construct is a useful way to study how factors related to climate change, like water insecurity, can become incorporated into our bodies (Brewis et al., 2020; Krieger, 2005; Rosinger, 2023b). This construct highlights how multiple aspects of the environment can shape people’s bodies and population health disparities. Bodies serve as a window into people’s exposures, lived experiences, and health (Krieger, 2005). Embodiment helps unmask these pathways using biomarkers as ways to substantiate people’s stated accounts or uncover relationships people are unable to convey. In the case of climate change, uncertainty working through water and food insecurity can increase lack of control over circumstances and lead to increased psychosocial distress, which can then lead to increased allostatic load and cortisol (Crews et al., 2019).

Prior work in the Bolivian Amazon studied the embodiment of the water environment and demonstrated that inequity in access to improved water sources along with water-related injury were associated with higher hair cortisol levels (Rosinger et al., 2021b). Fingernail cortisol concentration (FCC) is an emerging non-invasive biomarker to assess chronic stress which allows retrospective analyses of stressful situations 3–4 months prior or work with populations for whom collecting hair samples is culturally inappropriate (Phillips et al., 2021). For example, this method was used to examine how traumatic experiences among refugees during forced migration were associated with FCC in Serbia (Jankovic-Rankovic et al., 2020). Therefore, one way to study how mobility ideation related to water during drought are affecting human biology and becoming embodied or “getting under the skin” is by examining a biomarker of stress, i.e., cortisol (Adams et al., 2020; Rosinger and Young, 2020).

1.1. Droughts, pastoralism, and stress

Pastoralism and mobility are among humanity’s oldest adaptive strategies to marginal environments (Ndiema et al., 2010; Tugjamba et al., 2023). Given the environments they inhabit, pastoralists are experienced with dealing with drought and environmental variability (Galvin, 2009). As livestock are paramount to pastoralists’ wealth, livelihoods, and nutrition, adaptive strategies to mitigate the effects of drought are localized yet broadly shared (Tugjamba et al., 2023). Short-term strategies include pasture management and stock migration, herd splitting, reliance on social networks for herd management and stock replacement, slaughter of stock, use of alternative food sources, and the sale of livestock; longer-term strategies include stock

diversification, education for children, and alternative employment (Gebre, 2012; Opiyo et al., 2015). Temporary migration with livestock to underused, distant pasture can reduce stress faced by pastoralists (Butt et al., 2009); and it is often wealthier pastoralists who move more frequently (Galvin, 2009).

Yet, socioeconomic changes along with climate variability make it harder to rely on previously successful adaptive strategies (Tugjamba et al., 2023). Extreme and more frequent drought leads to livestock mortality with worse droughts leading to greater losses (Nkedianye et al., 2011). During drought suffered by pastoralists in Namibia, food insecurity increased while dietary diversity decreased as access to milk and meat declined (Prall and Scelza, 2023). Similarly, drought in northern Kenya, as measured through vegetation cover, was associated with greater probability of malnourishment among children (Bauer and Mburu, 2017).

If adaptive strategies to drought in arid and semi-arid environments are unsuccessful or if livestock die, this can lead to stressful experiences for pastoralists and stimulate lifestyle transitions toward more market integration (Kirui et al., 2022). Prior research in northern Kenya found that Turkana nomadic pastoralists experiencing drought had significantly higher urinary cortisol levels than settled Turkana who were measured post-drought, suggesting some effect of the drought on circulating cortisol levels (Lukas et al., 2005). However, it is hard to tease apart whether the difference in acute cortisol was due to drought versus the difference in timepoints and livelihood strategies.

1.2. 2022 Greater Horn of Africa drought

Analyses using the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data indicate that rainfall deficits experienced in the Greater Horn of Africa during their long rainy season of March–May 2022 were the most severe on record over the last 70 years (NASA Earth Observatory, 2022). The World Health Organization (WHO) and United Nations (UN) issued several reports highlighting this drought and in May 2022 declared it a Grade 3 emergency (which requires a major/maximal response by the WHO), noting 46 million people were suffering from severe food and water insecurity (World Health Organization, 2023).

In northern Kenya, the drought began in late 2020 and peaked following the failed long rainy season in March–May 2022. This fourth consecutive failed rainy season (taking into account their dual rainy season) resulted in the deaths of hundreds of thousands of livestock and acute food insecurity for an estimated 5.4 million people (World Health Organization, 2023). While surveillance data at the county level demonstrated the magnitude of the drought on well-being, little work to date has provided an examination of how people’s lived experiences and well-being were affected by this historic drought.

Therefore, this study examines how the 2022 extreme drought was embodied among Daasanach pastoralists by examining the pathways from drought to mobility ideation to a biomarker of chronic stress. Drawing on the embodiment construct, we conceptualize that extreme drought negatively affects livelihoods and wealth, which can stimulate varying degrees of water and food insecurity and depression/anxiety (and their self-reinforcing feedbacks). These experiences can thereby trigger thoughts of moving due to water problems and may become embodied in chronic stress (Fig. 1). We test this through two aims: First, we examine how mobility ideation changed from before to during the drought, and whether livestock wealth, water insecurity, food insecurity, and depression/anxiety symptoms were associated with frequency of mobility ideation in 2022 in contrast with actual mobility. Second, we test whether more frequent mobility ideation was associated with higher FCC during this extreme drought adjusting for resource insecurities and other factors that may affect stress.

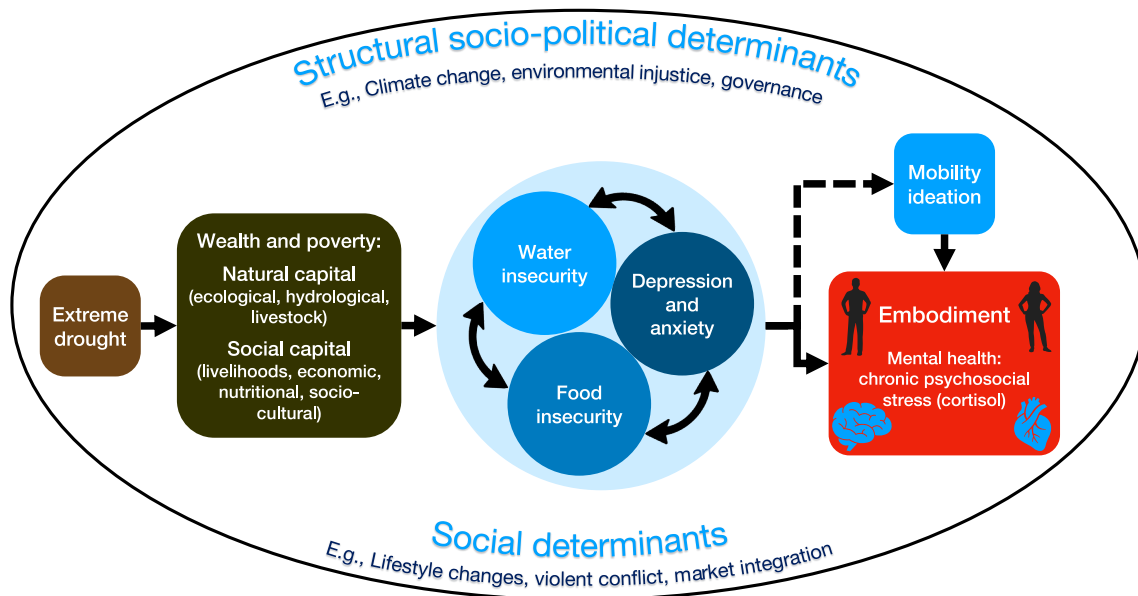


Fig. 1. Conceptual diagram illustrating the pathway between extreme drought and embodiment of chronic stress.

2. Methods

2.1. Field site

Approximately 19,000 Daasanach semi-nomadic pastoralists live in the hot, semi-arid northern Kenya desert across 26 villages around the northeastern margin of Lake Turkana just south of the Ethiopian border (Kenya National Bureau of Statistics, 2019). Like other eastern African pastoralist groups, Daasanach traditionally rely on milk from cattle, goats, and other livestock as a major caloric and hydration source (Kiura, 2005). Daasanach living in Kenya are more reliant on these traditional pastoral forms of subsistence than those who reside in the Omo River Basin of southern Ethiopia (Almagor, 1978) and have greater access to market and agricultural goods, although access to market goods has increased in recent years in the main town of Illeret, Marsabit, Kenya (Swanson et al., 2023).

Even during non-drought years, water and food insecurity are major sources of concern among Daasanach (Bethancourt et al., 2023; Gebre, 2012). These resource insecurities are worsened by increased climate variability in the region (MoALF, 2017). Daasanach traditionally manage their herds in response to their dual rainy season. The big rains (April–May) termed *ish hirai* or “fresh pastures” trigger movement of stock towards distant pastures to access broad availability of forage and water. Rapid stock movement helps ensure against overgrazing and degradation of pastures. By June, pastures begin to dry and a period referred to as *morgotch* or “mixed” leads to distribution of camps to be more constrained by water access and stock are moved off these points to access patches of available forage. Between July–September, a dry period referred to as *shante*, Daasanach further restrict herd movement and the distribution of camps as water access is limited to Lake Turkana, rock pools, the lower elevations where hand dug wells in dry rivers can still access water, and built wells. A similar process of dispersion and contraction then follows the short rains (Almagor, 1978). External political (governmental boundaries), social, economic, and environmental factors all affect Daasanach ability to migrate (Sagawa, 2010).

Data for this paper come from the Daasanach Human Biology Project, which is a longitudinal study measuring long-term perspectives on water insecurity, food insecurity, mobility, stress, energy expenditure, and nutrition (Bethancourt et al., 2023; Ford et al., 2023; Rosinger et al., 2021a; Swanson et al., 2023). This project carried out a first study wave in June–July 2019 and a second wave in June–July 2022. Household

surveys inquired about household-level and individual-level questions related to water, food, sociodemographics, nutrition, and health with up to two household heads (male and female) and up to two children (see (Bethancourt et al., 2023; Rosinger et al., 2021a) for additional details). The surveys were followed by anthropometric, biomarker, and environmental measurements.

In 2019 and 2022, we enrolled adults in seven communities at different distances to the main market town of Illeret to have variation in access to market goods and water sources. Three communities were in and around Illeret, three communities were 4–9 km away from Illeret, and one community was 20 km away. The initial 2019 survey used a random sampling design of every third household (Bethancourt et al., 2021). In 2022, we attempted to re-contact the 2019 sample and re-enroll them. We collected data from 175 adults with full survey and anthropometric data (114 of whom were enrolled in 2019 and 61 new adults enrolling neighbors of the absent households). In 2022, we implemented fingernail sample collection and 156 of 175 adults had samples collected. Additionally, in 2023 we conducted a group interview with 3 informants (2 male, 1 female) to discuss and freelist reasons why Daasanach move. Once they exhausted the reasons, they conducted a consensus exercise to rank the reasons in order of frequency and importance.

This research was conducted following the Declaration of Helsinki and was approved by the Institutional Review Board of Pennsylvania State University (STUDY00009589) and the Kenyan Medical Research Institute (SERU 3739). Permission was also obtained from the Director of Health in the county government of Marsabit, Kenya and from community leaders in all the communities sampled. All participants provided written and verbal informed consent.

2.2. Outcome (aim 1) and predictor (aim 2): Household mobility ideation

To assess mobility ideation in relation to the water situation (hereafter mobility ideation), we used a survey item developed by the Household Water Insecurity Experiences Research Coordination Network (HWISE-RCN) which was not part of the HWISE-12 scale (Young et al., 2019). Each adult in the household was asked, “In the past 4 weeks, how frequently have you thought of moving dwellings because of the water situation?” Potential responses were pre-binned using locally defined terms for “never” (defined as 0 times), “rarely” (or 1–2 times), “sometimes” (or 3–10 times), and “often/always” (or 11+ times),

like other HWISE questions. The never category was used as the reference group for this ordinal measure in analyses. This question differs from migration intentions (Adger et al., 2021) because it asks specifically about thinking about moving to understand rumination and ideation rather than whether the person is planning to move in the future. It also specifies that the thoughts of moving are due to water, which may be connected to other problems e.g., declining livestock due to water or pasture scarcity, but not due to other reasons Daasanach move, like for marriage.

2.3. Predictor: Wealth

While livestock (particularly cattle) play a primary role in status and wealth for Daasanach, these relationships are complex. Livestock are the bank account of pastoralists as Daasanach refer to them as “four-legged wealth”. Beyond relying on them as an economic reserve, for status, and use in ceremonies and rituals as well as hide for multiple uses, livestock are paramount to nutritional and hydration needs of pastoralists through milk, meat, and blood. During the survey we inquired about all livestock each adult owned including the number of cows, goats, sheep, camels, donkeys, and other livestock. The number of livestock was multiplied by the yearly local value of each animal and summed to calculate livestock wealth (in Kenyan Shillings [KSH]). Livestock wealth could be both a stressor during a drought or a reserve to cope with drought.

2.4. Predictor: Household water insecurity (HWISE)

Household water insecurity was measured using the 12-question household water insecurity experiences (HWISE) scale and was asked of each adult separately. The HWISE scale was validated in low- and middle-income countries (Young et al., 2019), and has been used in this site previously (Bethancourt et al., 2023; Ford et al., 2023). The HWISE items describe the frequency of different water-related experiences (e.g., worrying about one’s water situation) that occurred over the past four weeks. A score of 0, 1, 2, or 3 was given to answers of never (0 times), rarely (1–2 times), sometimes (3–10 times), or often/always (11+ times), with a maximum score of 36.

2.5. Predictor: Household food insecurity (HFIAS)

Household food insecurity was assessed using the 9-item Household Food Insecurity Access Scale (HFIAS) (Bethancourt et al., 2023; Coates et al., 2007) and was asked to each adult separately. This scale addresses the frequency in the previous four weeks with which any household member experienced nine different dimensions of food insecurity, including anxiety and uncertainty of food access, inadequacy of food quality, insufficient food intake, and hunger. Like the HWISE scale, a score of 0, 1, 2, or 3 was given to answers of never, rarely, sometimes, or often/always, respectively, for a maximum score of 27.

2.6. Predictor: Depression/anxiety (PHQ-9)

We assessed depression and anxiety symptoms for each adult using the patient health questionnaire-9 (PHQ-9), validated and adapted to eastern African settings (Brewis et al., 2021) by replacing the question around suicide with two questions about “being unable to control worrying” and “feeling nervous”. Each question is given a score of 0, 1, 2, or 3 to answers of “not at all”, “several days”, “more than half the days”, or “nearly everyday”, with a maximum score of 30.

2.7. Outcome (aim 2): Fingernail cortisol concentration (FCC)

Our prior ethnographic work indicated hair collection for measurement of cortisol was not culturally acceptable or feasible. Therefore, we implemented a fingernail collection protocol. The fingernail samples captured the exposure period of ~February–March of 2022, which was

the height of the drought before the fourth failed rainy season. We collected fingernails from all household heads following the protocol specified by Davison (Davison et al., 2020), such that participants were willing to provide a sample, sufficient nail growth existed in at least 1 finger, and fingernails were cut to the fingernail bed on all 10 fingers if possible. Fingernails were analyzed for cortisol concentration at the Biomarker Core Laboratory at Pennsylvania State University using a Salimetrics Assay Diluent and assayed in duplicate following the manufacturer’s instructions (see additional description in supplemental materials). Intra- and inter-assay coefficients of variation for the samples were 10.0% and 7.6%, respectively. We used the average concentration in analyses and excluded one outlier that was >11 SD beyond the highest value in the sample, consistent with other studies of FCC (Chen et al., 2023).

2.8. Covariates

Age (in years), sex (male, female), and body mass index (BMI) (kg/m^2) calculated by measured height on a Seca stadiometer and weight on a Tanita scale were included as covariates because they are individual factors that affect cortisol levels which may also affect people’s ability to move or consider moving (Gettler et al., 2021; Jankovic-Rankovic et al., 2020; Phillips et al., 2021). Household size was defined as the number of family members who live under the same roof as additional individuals require additional water and food resources, but may be able to provide additional assistance for tending to livestock or fetching firewood or water. For the mobility ideation models, we adjust for the number of times the adult reported moving (for more than a week at a time) in the prior year as prior mobility may predict future mobility but is also different from thinking about moving. We adjusted for a well-known driver of psychosocial stress, one’s perceived social relative ranking in a community as it related to status, wealth, education, and livestock ownership for Daasanach, with the MacArthur Scale of Subjective Social Status (Giatti et al., 2012). We also adjusted for water-related environmental factors which may affect one’s stress or resilience to drought. We controlled for the amount of drinking water the household had stored at home (in liters) and the number of water fetching trips the household takes each week. Participants provided information about the household’s main drinking water source—Daasanach frequently dig new hand-dug wells for drinking and use older wells (that are nearby) for giving water to livestock or will water livestock from the same well while fetching water. We measured water salinity of the drinking water source using a YSI ProDSS Multi-Parameter Water Quality Meter and accompanying sensors, as described elsewhere (Rosinger et al., 2021a).

2.9. Statistical analyses

All analyses were computed using Stata V15.1 (College Station, TX). We first examined how the frequency of mobility ideation changed pre-drought in 2019 to during the peak of the drought in 2022. Second, we assessed bivariate boxplots of FCC, water insecurity, food insecurity, and anxiety/depression by categories of mobility ideation. We assessed normality of the FCC data using graphical methods, which demonstrated FCC was slightly right skewed (Fig. S1).

For aim 1, we used mixed-effects ordered logit regression to test the association between drivers of mobility ideation with observations nested within households and within their communities to account for clustering for these survey outcomes. As lack of wealth can lead to resource insecurities and considering moving, we tested how livestock wealth and then successive experiential measures of well-being, including water insecurity, food insecurity, and PHQ-9 scores, were associated with the odds of moving into a category of greater household mobility ideation controlling for covariates specified above. We then re-estimated this with all four predictors in the same model. As mobility is a dynamic process, we also tested how the number of moves changed over time and estimated a multiple linear regression model with the outcome

variable mobility in the prior year in relation to livestock wealth and the other predictors to contrast how drivers of mobility differ from mobility ideation.

For aim 2, we used generalized linear models with a log-link function and a gamma distribution (which models right skewed outcome data), following prior work with FCC data (Herane-Vives et al., 2018), to test the association between mobility ideation on FCC. We report the exponentiated coefficients to help with interpretability of the data; the coefficients signify the percent change in FCC based on the predictor variables. We use robust standard errors clustered at the community level for FCC models. We estimate the association first with no covariates, then adjusting for biological factors that may affect FCC, including age, sex, and BMI. We then additionally adjust for household factors that may increase stress or protect against it, including amount of drinking water stored at home per 10 L, drinking water salinity (per 100 mg/L), weekly water fetching trips (per 3 trips), the MacArthur ladder (with each unit being one step lower in perceived rank), household size, and livestock wealth (natural log-transformed +1 due to the skewed distribution). Finally, we adjust for depression/anxiety symptoms and the depression/anxiety variable squared, since there is a curvilinear association with dampened stress response to heightened depression (Fig. S2), water insecurity, and food insecurity.

To understand potential bias associated with 12 fingernail samples that had any unground sample remaining (see supplemental materials), we performed a sensitivity analysis by re-estimating the FCC models excluding these samples using the same GLM models among the remaining 143 adults.

As a robustness analysis, we examined how mobility ideation categories related to high FCC (those with the highest chronic stress). We operationalized high FCC as the top tertile compared to the bottom two tertiles based on prior work which demonstrated elevated CVD risk due to elevated FCC for the top tertile among adults (Izawa et al., 2019). We re-estimated the FCC models using mixed-effects logistic regressions with the same nesting strategy. To visualize the predicted probability of having high cortisol across the range of covariates, we used the margins command post logistic regression (Williams, 2012). We set statistical significance at $p < 0.05$.

3. Results

Descriptive characteristics of the full sample in 2022, FCC sample, and stratified by mobility ideation categories are presented in Table 1. Among the full sample, 43.5% of participants were male with a mean age of 42 years and mean BMI of 18.2 kg/m². No significant differences existed in participant characteristics between the full and FCC samples.

3.1. Mobility ideation

Mobility ideation increased from 2019 to 2022 (Fig. 2A–B). Pre-drought in 2019, 45% of adults said they never considered moving because of the water situation. During the height of the drought in 2022, only 8% reported never considering moving while 35% of adults reported considering moving 1–2 times, 35% considered moving 3–10 times, and 22% considered moving 11 or more times. In contrast, the mean number of moves in the prior year declined from 4.2 (SE = 0.38) in 2019 to 3.3 (SE = 0.27) in 2022.

The group informant interview yielded 18 potential major reasons for moving (or considering moving) for more than a week (Table S1). The consensus ranking placed water-related issues as four of the top six reasons, including looking for pasture (#1), lack of water (i.e., sources dried up) (#3), climate change/flooding (#5), and moving closer to food aid by the Ethiopian border (#6). These descriptions demonstrate the importance of climate and water to mobility for Daasanach semi-nomadic pastoralists.

Unadjusted box plots demonstrate that mobility ideation was associated with significantly higher trends in FCC, water insecurity, food insecurity, and depression/anxiety score across categories (Fig. 3A–D).

Ordered logistic regression models demonstrate that greater livestock wealth was protective against mobility ideation (OR = 0.72; 95% CI: 0.57–0.91; $p = 0.006$), while each additional point in water insecurity (OR = 1.40; 95% CI: 1.14–1.71; $p = 0.001$), food insecurity (OR = 1.43; 95% CI: 1.16–1.76; $p < 0.001$), and depression/anxiety symptoms (OR = 1.23; 95% CI: 1.14–1.32; $p = 0.001$) were significantly associated with higher odds of moving into a category of greater mobility ideation (Table S2, Models 1.1–1.4; Fig. 4). When all four predictors were included in the same model, the effect sizes were slightly attenuated but remained significant for livestock wealth (OR = 0.78; 95% CI: 0.67–0.91; $p = 0.001$), water insecurity (OR = 1.29; 95% CI: 1.05–1.58; $p = 0.013$) and food insecurity (OR = 1.20; 95% CI: 1.02–1.42; $p = 0.027$) while depression/anxiety symptoms was no longer significant ($p = 0.15$) (Table S2, Model 1.5; Fig. 4). The number of moves the adult took in the prior year was associated with greater odds of mobility ideation (OR = 1.21; 95% CI: 1.07–1.37; $p = 0.002$). In contrast, results from the multiple linear regression models show that as livestock wealth increased so did the number of moves participants reported, whereas water and food insecurity and depression/anxiety were unrelated to mobility (Table S3). Compared to the poorest quartile, those in the richest quartile reported 3.8 (SE = 1.1; $p = 0.013$) more moves in the prior year (Table S3; Fig. S3).

Adults who reported not considering leaving in 2022 resided in 3 of 7 communities – most from a community 4 km away from Illeret. In 2020,

Table 1
Demographic characteristics for the sample and stratified by mobility ideation due to water problems.

	Full sample	FCC sample	Mobility ideation due to water problems			
	(n = 175)	(n = 155)	Never (n = 11)	Rarely (n = 56)	Sometimes (n = 54)	Often (n = 34)
	Mean or % (SD)	Mean or % (SD)	Mean or % (SD)	Mean or % (SD)	Mean or % (SD)	Mean or % (SD)
Male (%)	43.5%	45.8%	72.7%	48.2%	42.6%	38.2%
Age (years)	42.0 (15.9)	43.1 (15.9)	44.6 (13.5)	45.0 (15.2)	41.2 (14.6)	42.6 (19.7)
BMI (kg/m ²)	18.2 (2.9)	18.3 (3.0)	20.7 (5.6)	18.0 (2.9)	18.2 (2.3)	18.1 (2.9)
FCC (pg/mg)	–	8.25 (3.97)	7.06 (1.45)	8.46 (4.26)	7.91 (3.55)	8.85 (4.60)
Stored home drinking water (L)	17.4 (17.0)	18.6 (17.5)	28.2 (33.1)	16.2 (14.1)	20.6 (14.9)	16.5 (18.9)
Drinking water salinity (mg/L)	315 (81)	318 (79)	338 (79)	313 (66)	320 (88)	316 (86)
Weekly water fetching trips	15.7 (4.3)	15.6 (4.5)	15.9 (4.5)	16.1 (3.5)	15.1 (4.5)	15.6 (5.7)
SES ladder*	8.1 (1.6)	8.1 (1.7)	7.8 (1.5)	7.9 (1.7)	8.3 (1.5)	8.2 (1.9)
HH size	6.9 (2.7)	6.9 (2.7)	6.1 (3.4)	7.4 (2.3)	7.0 (2.7)	6.4 (3.0)
Livestock wealth (KSH)	56356 (62731)	54869 (58083)	46295 (45089)	65696 (66587)	49490 (54337)	48352 (51786)
Times moved in prior year	3.4 (3.7)	3.3 (3.7)	3.3 (4.1)	2.7 (3.0)	3.7 (4.2)	3.8 (3.9)
Depression/anxiety (PHQ-9)	14.7 (4.7)	14.8 (4.7)	13.1 (4.7)	13.4 (3.7)	15.5 (4.2)	16.4 (6.1)
Water insecurity (HWISE)	22.6 (5.3)	22.9 (5.3)	18.9 (5.6)	21.6 (4.6)	22.7 (4.2)	26.9 (5.6)
Food insecurity (HFIAS)	17.7 (4.1)	17.8 (4.0)	16.7 (6.4)	16.1 (3.8)	18.5 (2.6)	19.7 (4.3)

Note: FCC: Fingernail cortisol concentration; HH: household. KSH (Kenyan Shillings).

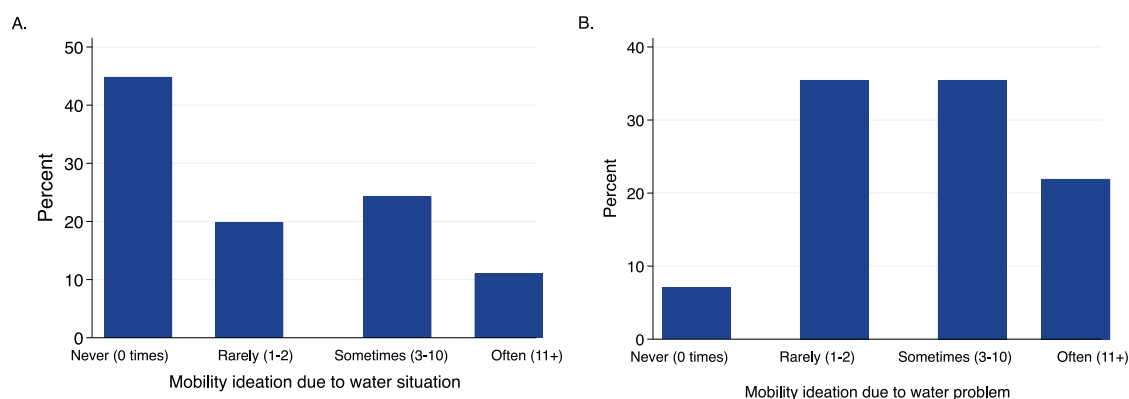


Fig. 2. Change in mobility ideation from (a) pre-drought (2019) to (b) the height of the severe drought (2022) among Daasanach adults. Notes: $n = 242$ adults in 133 households in 2019; $n = 175$ adults in 127 households in 2022.

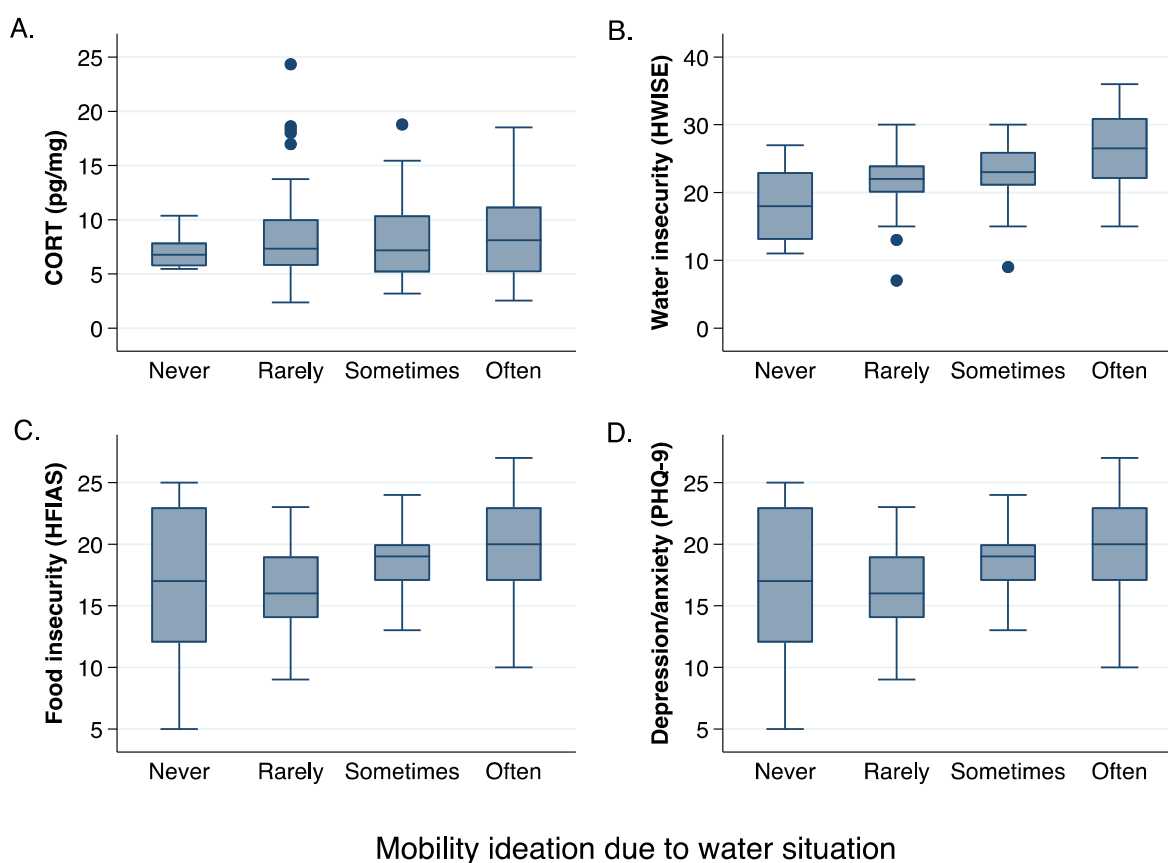


Fig. 3. Unadjusted boxplots of mobility ideation due to water situation in 2022 among Daasanach adults and A) fingernail cortisol concentration (CORT), B) water insecurity, C) food insecurity, and D) depression/anxiety symptom scores.

that community had a solar-powered shallow well constructed near their community that pipes water to four taps. In 2022, this well was functional and of sufficient quality (tested negative for pathogenic bacteria). Likely as a result, this community had the lowest water insecurity (Fig. S4).

3.2. Fingernail cortisol concentration

The mean FCC in the sample was 8.2 pg/mg (Range: 2.4–24.2; 3.9 SD) (Table 1; Fig. S1). Across unadjusted and adjusted models, adults who reported thinking about moving rarely, sometimes, and often all had sequentially higher FCC than those who never considered moving

(Fig. 5; Table S4, Models 3.1–3.4). In the fully adjusted model (Model 3.4), compared to adults who never considered moving, those who considered moving rarely (1–2 times), sometimes (3–10 times), and often (11+ times) had FCC levels 18.1% higher (95% CI: 1.01–1.38; $p = 0.039$), 19.4% higher (95% CI: 1.01–1.41; $p = 0.040$), and 32.3% higher (95% CI: 1.01–1.73; $p = 0.039$), respectively. These coefficients translate into increases of 1.28, 1.37, and 2.28 pg/mg for each successive category of mobility ideation.

When including livestock wealth, water insecurity, and food insecurity in the models, none of these factors were independently associated with FCC levels (Table S4). Other factors that were associated with higher FCC were BMI, drinking water salinity, number of water fetching

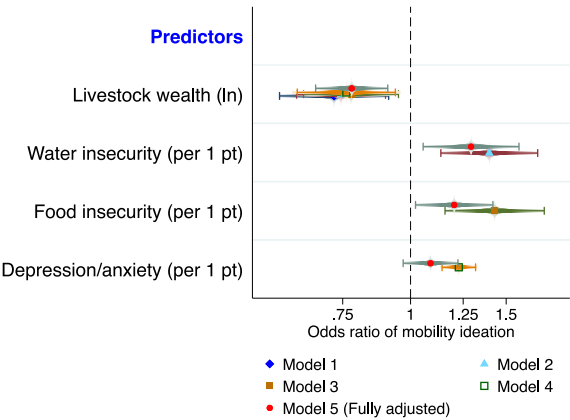


Fig. 4. Forest plot of odds ratios and 95% confidence intervals of predictors of mobility ideation due to water problems from mixed-effects ordered logistic regression models. Notes: n = 175; full model results shown in Table S1.

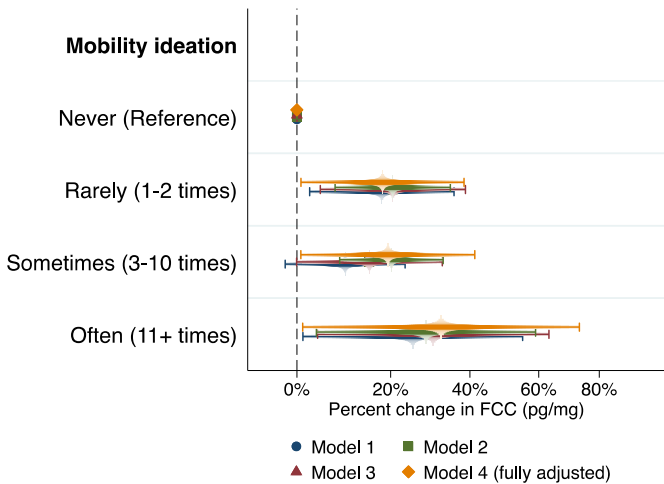


Fig. 5. Percent change in fingernail cortisol concentration by mobility ideation frequency among Daasanach adults. Notes: n = 155; full model presented in Table S4.

trips, lower perceived social standing, and depression/anxiety symptoms. The amount of water a household had stored was associated with lower FCC.

The sensitivity analyses with the restricted sample indicate results (coefficients and statistical significance) consistent with the fully adjusted model among the full FCC sample (Table S5, Models 4.1–4.4).

The robustness analyses indicate consistent results with significantly higher odds of being in the top tertile of FCC if one considered leaving at any frequency (Table S6, Models 5.1–5.5). Adults who considered moving rarely, sometimes, and frequently had 5.5 (95% CI: 1.82–16.7; $p = 0.002$), 6.4 (95% CI: 2.42–17.0; $p < 0.001$), and 12.3 (95% CI: 2.94–51.7; $p = 0.002$) times the odds of having high FCC compared to those who never considered moving, respectively (Table S6, Model 5.4). Adjusting for the range of covariates in this model, the probability of being in the top tertile of FCC was significantly lower among adults who reported never considering moving (9.1%, 95% CI: 2.5–15.6) compared to adults who rarely (33.9%; 95% CI: 23.9–43.9), sometimes (31.5%; 95% CI: 21.1–41.9), and often thought about moving (44.1%; 95% CI: 27.9–60.3; $p < 0.001$) (Fig. 6).

4. Discussion

This paper aimed to understand how extreme drought gets embodied

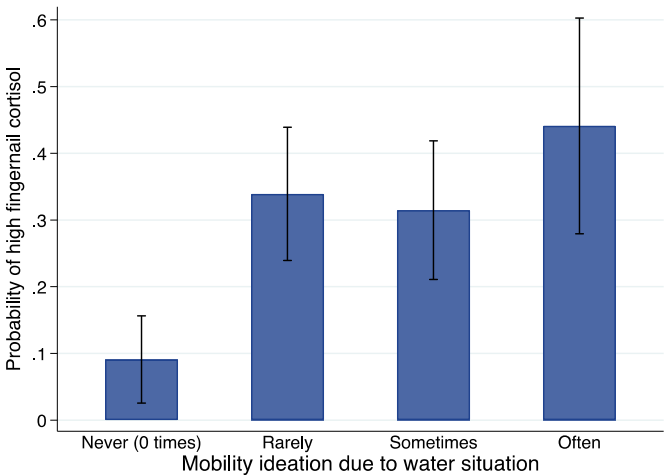


Fig. 6. Predicted probability of high fingernail cortisol concentration and 95% confidence intervals by mobility ideation frequency among Daasanach adults. Note: High cortisol defined as top tertile. Figure adjusted for the range of covariates in Supplemental Table 6, Model 4.

by examining the relationships between experiential resource insecurities and water-related mobility ideation and, in turn, chronic stress. To our first aim, we find that mobility ideation increased significantly from 2019 pre-drought to the height of the drought in 2022, while actual mobility declined as livestock died and food aid available in towns became more important. Livestock wealth was strongly protective against thinking about moving, while greater water and food insecurity were associated with greater frequency of mobility ideation. In contrast, livestock wealth, but not water and food insecurity, was associated with more reported moves in the prior year which demonstrates that associations between drivers of mobility are different from mobility ideation, which captures rumination. To our second aim, adults who reported considering moving dwellings at greater frequencies because of the water situation had sequentially higher FCC and greater odds of high cortisol levels. These results suggest that rumination about leaving due to the extreme drought was embodied in chronic stress.

Pastoralists across regions are traditionally nomadic and move in response to changes in resources (Ndiema et al., 2010). This key adaptive strategy of moving to have better access to food and water, however, is being impeded by climate change and lifestyle transitions as movement is restricted (Galvin, 2009; Tugiamba et al., 2023; Wafula et al., 2022). Thinking about moving differs from actual mobility, which can reduce stress from drought (Butt et al., 2009). For the neighboring Turkana pastoralists in Kenya, stress was conceptualized as “thinking too much” and worrying about moving and hunger were associated with higher cortisol (Pike and Williams, 2006). These concerns were shared as major stressors by Daasanach semi-nomadic pastoralists who highlighted that water-, food-, and climate-related issues were the top reasons people thought about moving.

The extreme drought through four failed rainy seasons caused severe disruption in water access and pasture, which depleted herd sizes, management, and ability to practice adaptive strategies to drought for Daasanach. Lower wealth and livestock ownership [compared to 2019 (Bethancourt et al., 2023)] alongside resource insecurity appeared to be prime stimulating factors for mobility ideation. As the drought led to widespread livestock losses for Daasanach, those who still had more livestock had significantly lower reports of thinking about leaving but were more likely to report temporary moves. Having greater number of livestock is critical for food security as well as status and prestige.

Our study found that 92% of adults considered moving at least once due to water problems in northern Kenya during the extreme drought in 2022. This number was strikingly higher than three years earlier when 55% of adults considered moving at least once. One cross-cultural study

in 29 sites in low- and middle-income countries asked the same question and, while not among pastoralists, found that 21.8% of adults considered moving at least once in the prior month (Stoler et al., 2021b). Prior work found the search for pasture and water resources were primary drivers of pastoralists migrating away from communities to cities, like Nairobi, Kenya, and that pastoralists face diverse, disruptive challenges in that transition which may exacerbate stress (Wafula et al., 2022).

As climate variability increases, adaptive strategies can become less effective (Galvin, 2009; Tugjamba et al., 2023; Wafula et al., 2022). Daasanach report that during drought, livestock, particularly goats and sheep, can subsist on fallen leaves and branches cut from shrubs and trees. Across seasons, Daasanach diets have traditionally shifted from wet season reliance on milk to greater consumption of blood and meat in the dry season (Kiura, 2005). Surplus milk during the wet season is often processed into *ghee* for storage and later consumption. As conditions for forage deteriorate and animal well-being declines, surplus livestock are slaughtered. They then must turn to alternative food sources like fishing. We observed during the 2022 drought after the loss of stock, large numbers of Daasanach settled along Lake Turkana to prepare dried fish, which became less stigmatized. Additionally, Daasanach sold some remaining livestock, particularly goats, in nearby settlements and across the Ethiopian border to support food purchase and other costs (e.g., school fees). But these experiences were described by Daasanach as stressful.

Prior work has found that wealthier pastoralists, i.e., those with more livestock are more likely to move as they have more resources to carry out those moves and face increased pressure by having larger herds, whereas poorer families or those whose livestock died during drought have less of a choice in settling near towns (Galvin, 2009). Our study found that livestock wealth played two different roles in these relationships: consistent with the literature, it was associated with more moves in the prior year, but was protective against mobility ideation. We highlight the nuance in this dynamic process as mobility ideation is likely capturing a sense of dissatisfaction and greater rumination whereas mobility captures livestock pressure along with capabilities.

Further, greater water and food insecurity, which are indicators of adversity, were associated with mobility ideation, but not actual mobility. Those Daasanach who are most likely to think about moving have a suite of significantly different experiences as they are more likely to be poorer, less food and water secure, and perceive themselves as lower status. Consistent with other studies in Sub-Saharan Africa and among pastoralists (Adams et al., 2020; Bisung and Elliott, 2018; Mushavi et al., 2020; Pike and Williams, 2006), these results demonstrate how damaging poverty and these lived experiences – exacerbated by the drought – can be to mental health. Thus, they underscore the interconnections between these experiences of resource insecurity and embodiment. It is likely the rumination surrounding resource insecurity and climate distress associated with mobility ideation driving higher FCC levels.

The mental health consequences of adversity and resource insecurity are increasingly recognized (Wutich et al., 2020), yet the role of climate change and extreme climatic events are critical to examine in driving those experiences to uncover the toll on human biology. The embodiment construct helps unmask these processes. While in the fully adjusted model water and food insecurity and wealth were unassociated independently with FCC, the drought likely working through depleted wealth and livestock triggered conditions of heightened resource insecurity and anxiety/depression symptoms which increased mobility ideation and were embodied in higher stress (Fig. 1). Yet, water insecurity (Wutich et al., 2022), food insecurity (Maynard et al., 2019), and depression/anxiety have been reported as key concerns for migrants. Thus, it is possible these indicators of well-being and mental health are both causes and consequences of mobility ideation.

Despite experience with climate variability (Galvin, 2009), stress from drought can be severe for pastoralists as uncertainty exists surrounding future rainfall, remaining livestock, and food access.

Long-term stressors such as those linked to extreme drought, can lead to hyper- or hypo-responsiveness – where individuals experience continued stress or habituation due to cognitive acceptance of the drought not going away – thus leading to dampened cortisol response (Crews et al., 2019). We observed some evidence of this with a quadratic relationship between depression/anxiety symptoms and FCC (Fig. S2). Daasanach FCC values were higher than those recorded among Afghanistan and other Middle-Eastern and Northern African refugees who were forced to resettle in Serbia, who had mean of 3 pg/mg compared to 8.2 pg/mg in this study (Jankovic-Rankovic et al., 2020); and also higher than adults (4.4 pg/mg) in the BaYaka forager community in the Congo Basin (Gettler et al., 2021).

Our participant observations, surveys, and group interviews with Daasanach informants substantiate the ties between mobility ideation and resource insecurity. While there are a variety of reasons to move, they indicate that water is often central to mobility as they move to find pasture for livestock and more reliable access to water sources. They also discussed how climate-related factors can drive mobility, like water scarcity and flooding, desire to be closer to drought-related food aid, and to lower risk of conflict with neighboring tribes—often exacerbated by water scarcity, similar to other pastoralists (Wafula et al., 2022). Further, Daasanach note that thinking about moving is stressful as there is more to worry about in terms of potential things that could go wrong during the move.

This paper adds to the emerging literature on embodiment related to environmental resource insecurity by intersecting it with extreme climatic events such as severe drought (Adams et al., 2022; Rosinger, 2023a, 2023b; Rosinger et al., 2021b; Rosinger and Young, 2020). Here, mobility ideation may be an indicator of climate distress from the drought. This study can help inform how future climate refugees may be negatively affected by the resulting elevated stress from thinking about moving even if a move does not occur. While environmental displacement and relocation is stressful, individuals who are not displaced also suffer from environmental and development projects such as dams through worsened well-being (Owuor et al., 2023). Our effect sizes of 18–32% increased FCC among those who think about moving because of water problems have implications for human biology as chronically elevated cortisol is harmful for cardiovascular, cognitive, and immune health (Sapolsky, 2005).

4.1. Water interventions to mitigate stress

The standpipe construction by a non-governmental organization – implemented by PACIDA in collaboration with the community with funding from federal ministry for economic cooperation & development [BMZ] and Malteaser International – in 2020 prior to the drought reduced that community's water insecurity and frequency of water-linked mobility ideation. This likely led to lower stress, although our study was not designed to specifically test this. This structural intervention highlights how important proper water access is for reducing water insecurity and associated psychosocial distress during extreme drought.

4.2. Limitations

Because we only collected FCC measures during the 2022 survey wave, we cannot infer directionality or causality. It is possible that those with higher chronic stress are more likely to consider moving while it is also possible that thinking about moving increases stress. Thus, there are social feedback systems during drought between perceiving water problems which cascade into other problems like food insecurity and death of livestock, which increase stress and make one more likely to think about moving, which exacerbates stress. Future work should examine FCC at multiple timepoints in relation to extreme climatic events to assess impact of drought on chronic stress. The cortisol analytic sample size of 155 for adults is on the larger side for assessment of FCC as

sample sizes range from 10 to 245 participants (mean 79) across 15 adult studies reported in a recent systematic review (Phillips et al., 2021). The smaller number of observations in the never category decreases statistical power, but results are robust to multiple specifications. While we do not have precise data on individual livestock losses, compared to 2019, mean herd sizes plummeted in 2022 (Bethancourt et al., 2023). Further, our models indicated that lower relative standing (which could reflect livestock losses) on the MacArthur Scale was associated with higher FCC. Finally, we did not have information on individual variation in growth rate of nails that may affect small differences in the window of exposure for the accumulation of cortisol into the keratin (Phillips et al., 2021).

5. Conclusion

This study found that thinking about moving due to water problems increased from pre-drought to during the historic 2022 drought in the Horn of Africa, while actual mobility declined. Water insecurity, food insecurity, and depression/anxiety symptoms scores, all indicators of adversity, predicted greater levels of mobility ideation while livestock wealth was protective against it. Further, we found that higher frequency of mobility ideation during the drought was associated with greater fingernail cortisol concentration and higher probability of elevated FCC, suggesting that extreme droughts working through these pathways can get under the skin. This study highlights the importance of the embodiment construct for understanding how aspects of climate change can trigger thoughts of leaving due to resource insecurity and affect well-being, stress, and human biology. Our results underscore the need for multisector interventions that simultaneously address multiple forms of resource deprivation.

Funding statement

This work was funded by the National Science Foundation (NSF REU #1852406; NSF CNH2-S #1924322; NSF BCS-1759972), a Pennsylvania State University Social Science Research Institute (SSRI) Human Health and Environment Seed Grant, the Ann Atherton Herzler Early Career Professorship in Global Health. It was supported by Penn State's Population Research Institute (NICH01 P2CHD041025) and (NICH01 2T32HD007514-21A1).

Ethics statement

This research was conducted following the Declaration of Helsinki and was approved by the Institutional Review Board of Pennsylvania State University (STUDY00009589) and the Kenyan Medical Research Institute (SERU 3739) and the National Council of Science and Technology: NACOSTI/P/19/869. Permission was also obtained from the Director of Health in the county government of Marsabit, Kenya and from community leaders in all the communities sampled. All participants provided written and verbal informed consent.

CRediT authorship contribution statement

Asher Y. Rosinger: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Justin Stoler:** Writing – review & editing, Conceptualization. **Leslie B. Ford:** Writing – review & editing, Investigation. **Amanda McGrosky:** Writing – review & editing, Investigation. **Srishti Sadhir:** Writing – review & editing, Investigation. **Matthew Ulrich:** Writing – review & editing, Validation, Investigation. **Madeleine Todd:** Writing – review & editing, Investigation. **Nicole Bobbie:** Writing – review & editing, Investigation. **Rosemary Nzunza:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition. **David R. Braun:** Writing – review & editing, Supervision, Resources,

Funding acquisition. **Emmanuel K. Ndiema:** Writing – review & editing, Supervision, Resources, Investigation, Funding acquisition. **Matthew J. Douglass:** Writing – review & editing, Supervision, Resources, Funding acquisition. **Herman Pontzer:** Writing – review & editing, Supervision, Resources, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare they have no conflicts of interest.

Data availability

Data will be made available on request.

Acknowledgements

We thank Samuel Esho, Margrate Kokoi, David Nyasaga, and Ephraim Achau and the community health volunteers that helped with data collection. We thank Purity Kiura, The Koobi Fora Field School, The Turkana Basin Institute, and The National Museums of Kenya for facilitation with the project. We thank the Illeret Health clinic, The Illeret Ward administrator Mr. Koriye Koriye, and all the Daasanach communities and participants. We thank research assistants Tom Otube, Maria Bossert, Chelle Gillan, Charley Bittle, and Carey Musumeci for their help in other aspects of the data collection and/or data entry. We thank the Household Water Insecurity Experiences-Research Coordination Network, which supported a workshop on water and migration in March 2020, which partially led to the conceptualization of this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.socscimed.2024.117280>.

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