Child Marriage and Climatic Factors: Evidence from Survey Data in Kenya

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Abstract

Child marriage remains high in Kenya and could potentially be exacerbated by climate change, which, together with other environmental crises increasingly intersect with social vulnerabilities hence multiplying the known drivers of child marriages such poverty, displacement, conflict and being out-of-school. This study explores the link between climatic factors, specifically high temperature and child marriage in Kenya, using data from the 2014 and 2022 Kenya Demographic and Health Surveys. The analysis employed two-level multilevel models, incorporating individual and cluster-specific random effects, to examine the influence of temperature on child marriage. Geospatial analyses further mapped the geographic patterns of child marriage and temperature across Kenya's sub-counties.

Results revealed a significant positive relationship between high temperatures and child marriage after controlling for other factors, with hotter regions showing higher prevalence rates. These clusters were predominant in coastal and northeastern counties, identifying high-risk areas such as Mandera East, Mandera North, and Samburu North.

The findings underscore the role of high temperatures in perpetuating child marriage and highlight the urgent need for targeted interventions in vulnerable regions. This paper contributes to the poorly understood yet important intersections between climatic factors and child marriage, showing subnational disparities in association between high temperature and child marriage in Kenya, where no such studies exist.

Introduction

Child marriage, defined as a marriage or union taking place before the age of 18 (United Nations Children's Fund 2018), affects girls more than boys. The prevalence of child marriage globally is 19%, and about 640 million girls and women currently alive were married before the age of 18 years (United Nations Children's Fund 2023). The regions with highest prevalence of child marriage are sub-Saharan Africa, at 31%, and South Asia, at 26% (United Nations Children's Fund 2023). Nearly half (45%) of all girls and women who married before age 18 live in South Asia, with India alone accounting for one third (United Nations Children's Fund 2023). While sub-Saharan Africa accounts for 20% of all child marriages, the rate of reduction is slower (than South Asia), and girls in the region experience the highest risk of child marriage in the world, with one in three marrying before age 18, and a rising prevalence among poor families (United Nations Children's Fund 2023).

The situation at country level is no different. Kenya has one of the highest child marriage prevalence rates in the world, estimated at 23% in 2022 (KNBS & ICF 2023a), and is home to over four million child brides (United Nations Children's Fund 2022). Child marriage is a customary practice in communities where it is prevalent, and is practised mainly in rural areas, among the poor, and in households with low education attainment. The practise varies across regions and among ethnic groups, being most common in Northern Kenya (56%), the Coast Province (41%) and Nyanza (32%) (UNICEF 2018). This study aims to investigate whether climate-related stressors, particularly temperature, show an association with child marriage outcomes, net of socio-economic determinants including household wealth, after controlling for individual, household and community characteristics in Kenya. Our analysis is not intended to demonstrate causality, but rather to frame child marriage within its broader climatic context.

In the follow-up sections, we summarise literature on the effects of and factors contributing to child marriage, culminating with the objectives and focus of this study.

Effects of child marriage

Child marriage violates child rights and endangers their life trajectories in numerous ways, including early childbearing, poor health, lower levels of schooling and a lifetime of lost opportunities (Doherty et al. 2024). Early childbearing is associated with many health risks including obstructed or prolonged labour which can result in maternal morbidity and mortality (Fan & Koski 2022; Nove et al. 2014; Wodon et al. 2017). These adverse health effects can lead to increased miscarriage and stillbirths, and can extend to their children, leading to stunting and being off-track for development(Efevbera et al. 2017; Fan & Koski 2022;

Wodon et al. 2017). Children born of young mothers are also more likely to die before their fifth birthday (Fan & Koski 2022; Wodon et al. 2017).

There is a strong relationship between poor educational outcomes and child marriage. Girls who marry early are more likely to drop out of school, and child marriage substantially reduces the likelihood of enrolling in and completing secondary school (Parsons et al. 2015; Psaki et al. 2021; Sagalova et al. 2021; Wodon et al. 2017). In addition, once a girl is married, it is very rare that she will remain in school. Child marriage also has negative intergenerational effects on the education of children of girls who marry early (Delprato et al. 2017; Wodon et al. 2017). Conversely, educating girls is one of the best ways of reducing child marriage. On average, each additional year a girl completes in secondary school reduces the likelihood of marrying as a child by six percentage points on average, with a similar impact on the likelihood of having a first child before age 18 (Wodon et al. 2017; Wodon et al. 2018).

In terms of economic impacts, girls who marry before 18 years are at a greater risk of earning less over their lifetimes (by 9%), face increased vulnerability to economic shocks, have lower income diversity and are more likely to live in poverty than their peers who marry at later ages (Parsons et al. 2015; Sagalova et al. 2021; Wodon et al. 2017). This is because of the reduced labour force participation due to childcare role and adverse health impacts of early and frequent pregnancies, and also reduction in expected returns from participation in paid employment due to lower educational attainment. More importantly, child marriage affects women's agency, leading to limited decision-making within the household, assets ownership and financial inclusion (Parsons et al. 2015; Wodon et al. 2017)

Factors contributing to child marriage

A multitude of factors influence the practise of child marriage. In many low and middle-income countries, the low value placed on girls and women perpetuates the act and acceptability of child marriage in societies where the practice is common. Social norms influence expectations about when a girl is supposed to get married (Kok et al. 2023; Lowe et al. 2022; Petroni et al. 2017). Gender inequality impedes girls' and women's decision-making and self-determination, prioritise boys' education above that of girls, and control girls' sexuality (Kohno et al. 2020; Psaki et al. 2021). Socio-economic factors also influence the practise of child marriage, particularly in poor communities where marriage can be seen as a viable option in a context of few educational and economic opportunities (Parsons et al. 2015; Psaki et al. 2021). Bride price provides an incentive for child marriage as her family receive financial benefits, and marrying off young girls is seen as a way to lighten financial burdens in the household (Asadullah et al. 2021; Asare & and Forkuor 2024; Corno et al. 2020; Kohno et al. 2020; Pourtaheri et al. 2024). Evidence also shows that premarital pregnancy can be a driver, as girls are married off to avoid bringing shame to the family (Kohno et al. 2020; Kok et al. 2023; Petroni et al. 2017; Psaki et al. 2021). Child marriage is also acceptable to protect family honour, particularly as pubertal girls are seen as at risk of premarital sex which could lead to pregnancy (Kok et al. 2023). In other instances, being out of school, driven mostly by financial constraints is a precursor for child marriage (Steinhaus et al. 2016). Lack of labour market opportunities for women, especially those requiring academic skills, may reinforce marriage as the only viable pathway for girls and their families (Kok et al. 2023; Psaki et al. 2021).

Conflict and human insecurity, including living as refugees and in slums, has been identified as a risk to child marriage (Kohno et al. 2020). A review of global evidence reported mixed findings depending on conflict intensity, place and time, with countries reporting increase, decrease or non-significant effects of conflict and child marriage (Krafft et al. 2022).

The association between climate change and child marriage is an emerging area of concern. Climate change and other environmental crises are major obstacles to reducing child marriage as they increasingly intersect with social vulnerabilities hence multiplying the known drivers of child marriages – including poverty, displacement, conflict and being out-of-school (Pastén et al. 2024; Pope et al. 2023). Climate change related events –drought, floods, hurricane, and decreasing crop yields – disrupt livelihoods, worsen poverty, compromise girls' rights and opportunities, and increase girl's vulnerability to exploitation, with child marriage seen as a survival strategy (Ahmed et al. 2019; Asadullah et al. 2021; Asare & and Forkuor 2024; Esho et al. 2021; Pope et al. 2023; van Daalen et al. 2022; Wadekar 2020). There is mixed evidence on the relationship between climate factors and extreme weather conditions and child marriage. On one hand, a scoping review concluded that environmental crises worsen known drivers of child marriage thus pushing families to marry their daughters early (Pope et al. 2023), while a systematic review noted that gender-based violence including child marriage tends to be exacerbated as a consequence of natural disasters (van Daalen et al. 2022). On the other hand, a systematic review was unable to draw conclusions on whether extreme weather events were associated with increased or decreased rate of child marriage (Palmer et al. 2025).

In Kenya, dwindling Maasai livelihoods, driven by climate change was shown to perpetuate harmful practices such as female genital mutilation and child marriage (Esho et al. 2021). Drought has also been associated with increased child marriage in Northern Kenya, with girls taken out of school to be married off (Wadekar & Swanson 2020).

Many areas with the highest rates of child marriage also face the greatest effects of climate change and related environmental crises (UNFPA ESARO 2021). According to the 2023 global girlhood report, around two-thirds of child marriages happen in regions with higher-than-average climate risks (Save the Children 2023). The report further highlights that the number of girls at extreme risk of facing the twin challenges of climate change and child marriage is set to increase by 33% to nearly 40 million globally by 2050. The combination of the impact of the climate crisis and child marriage has created emergency hotspots for girls' rights. As long as climate disasters become more frequent and extreme, child marriage will persist. This calls for recognition of the complexities surrounding child marriage and climate variation, and thus implementation of mitigation initiatives in areas where girls may be at a higher risk of early marriage.

Kenya sits fairly high in the ranks of countries most likely to feel significant impacts of climate change, ranking 53rd among all countries in vulnerability to climate change effects—and 146th in terms of preparedness to deal with these effects (University of Notre Dame 2024). The country's mean annual temperature has been increasing at a rate of 0.21°C per decade since the 1960s (World Bank 2021). Frequent droughts have depleted water and grazeland, and the livestock that are the economic backbone of pastoralists die of hunger and diseases, and millions are in need of humanitarian assistance (Kew et al. 2021; Kimutai et al. 2023; National Environment Management Authority 2015). According to a report by the Ministry of Agriculture, an estimated 30% of Kenyan livestock owners were forced to find new sources of income between 1997 and 2017 (Government of the Republic of Kenya 2017). Desperate families are increasingly pulling their daughters from school and marrying them off in exchange for bride price. Evidence shows that dowry practices are exacerbated in times of crisis and displacement, and contribute to higher prevalence of child marriage the world over (UNFPA 2020).

While climate change is linked to the persistently high child marriage rates in the northern and coastal regions of Kenya despite a declining national average, there is no empirical evidence on the association. Little research has examined the central question of the main drivers of child marriage and its relation -if any- to climate change. None of this emerging research has focused on the relationship with high temperatures in Kenya. As the effects of climate change continue to intensify around the world, younger girls in most at-risk areas are increasingly vulnerable to being married off young. This therefore calls for an analytical study on how high temperatures are linked to child marriage in Kenya. Using average annual land surface temperature, we fitted a multilevel model to explore its association with child marriage, controlling for covariates such as educational attainment. We further explored the spatial association between land surface temperature and child marriage and their geographical patterns across sub-counties in Kenya, by applying a set of univariate and bivariate spatial association analyses.

Materials and methods

Data

Survey data

We used the two most recent cross-sectional datasets from the 2014 and 2022 Kenya Demographic and Health Surveys (DHS) (Kenya National Bureau of Statistics et al. 2015; KNBS & ICF 2023b). These were then combined with climatic variables at the cluster level. The DHS program collects nationally representative household surveys in over 90 countries, which provide indicators on a wide range of topics including population, wealth, maternal and child health, fertility and family planning, nutrition, and education indicators. In the DHS women questionnaire, women are asked about date of birth and the date they began living with their first spouse or consensual partner. The difference between these two gives the age at first marriage, truncated into completed single years. If age at first marriage is below 18 years, then it is referred to as child marriage (Rutstein & Rojas 2006). DHS sampling design is implemented using a two- stage (or sometimes three) stratified sampling design using censuses as sampling frames. During the first stage of selection, enumeration areas (EAs), also known as clusters, are selected using a probability proportional-to-size selection (EA size). During the second stage, households are usually sampled from a complete household listing in the selected EAs using systematic sampling. Clusters are defined as a group of households in the same area or a block (if in urban areas) selected for the interview within the complex survey design used by the DHS. For each of those clusters, geographical positioning system (GPS) information is also usually provided. Specific details on the sampling procedures can be found on the DHS final report (KNBS & ICF 2023a) and DHS Sampling Manual (ICF International 2012).

Cluster level contextual variables

In addition to individual and household level factors including education attainment, household wealth, sex of household head, age at sexual debut, and place of residence, among others, mean land surface temperature as a contextual level factor was constructed for each time point matching the two rounds of the DHS (See Table SI.1.1 in supplement file that shows all the covariates and their definition).

Data on temperature originates from Hulley and Hook (2021) following the methodology developed by Xiao et al. (2021). The data were further standardised and processed by WorldPop at 100 meters Woods et al (2024), then further summarised at 5km resolution to run the zonal statistics by administrative units. The temperature data were measured as annual mean surface temperature [Kelvin] for the years 2015 and 2022, selected as the closest available data to the DHS survey years at the time of the study The temperatures were transformed in Celsius degrees for the purpose of this analysis. For each survey round (2015 and 2022), temperature data were used to characterise the broader climatic era corresponding to the observed child marriage outcomes, providing a contextual framework and allowing us to examine spatial variation across the country, while acknowledging that individual marriages may have occurred in earlier years.

Poverty Rates at Sub-County Level

Poverty headcount rates at the sub-county level, defined as the proportion of the population living below the national poverty line in 2019, were derived from constituency-level poverty estimates obtained from the Kenya National Bureau of Statistics and accessed through the Commission on Revenue Allocation (CRA) (2022). Using Kenya Constituency Administrative Boundaries (Election Polling Stations) sourced from the Independent Electoral and Boundaries Commission (IEBC) and accessible via the Humanitarian Data Exchange (HDX) (OCHA Regional Office for Southern and Eastern Africa 2024) we created a poverty map at the constituency level. Since there are 290 constituencies but 335 sub-counties, a spatial join was performed using the centroid value to assign poverty rates from each constituency to the corresponding sub-counties. This approach allowed for the generation of a poverty map covering all 335 sub-counties. Subnational administrative boundaries of Kenya were sourced from the Population Division, U.S. Census Bureau (U.S. Census Bureau 2024). The analysis was conducted using ESRI ArcGIS Pro v. 3.3.1.

The sub-county-level poverty dataset was integrated with child marriage and temperature data to assess whether poverty (used here as a proxy for broader socio-economic conditions, including income levels, access to resources, and living standards) acted as a confounding factor in the spatial analysis of the association between temperature and child marriage. An external poverty data source was selected over modelled poverty estimates to mitigate the risk of circularity, as many modelled sources incorporate temperature as a variable. Given the limited availability of poverty data at this geographic scale, the 2019 dataset was used for both the 2014 (Round 1) and 2022 (Round 2) spatial analyses.

Study Population

The study population was women of reproductive aged 20–49 years; with an analytical sample of 24,875 (2014) and 25,752 (2022). Child marriage was calculated for women 20 years and above who were married by the age of 18 years.

The use of the 20–49 age group as the denominator in this study is motivated by the need for a sufficiently large sample size to ensure statistical robustness when analysing the relationships between factors such as education, residence, and temperature, and child marriage. These factors are measured cross-sectionally at the time of the survey, and the broader age range allows for comprehensive use of the available data while still being able to explore broader relationships. The objective of the paper is not to measure incidence of child marriage but explore associations. The 20–49 age group has also been used in previous studies (Kamal 2012; Kamal et al. 2014; Rashid et al. 2024).

To address potential differences across age cohorts, the study includes an age variable (e.g., 20–24, 25–29, etc.) in the regression analysis. This allows us to account for generational differences in child marriage prevalence and associated factors, ensuring that the broader age range does not obscure age-specific effects. We note that even though using the 20–24 age group offers a more current estimate of prevalence, there is still a time lag of up to 6 years or more between when child marriage occurs and when it's captured in data. We analysed our model separately for each five-year age group to ensure that the observed associations were consistent with the patterns identified in the full sample.

Methods

We used various methods including descriptive and multi-level logistic regression analysis to explore the factors associated with child marriage in Kenya. In addition, we created sub-county level maps based on the modelled high-resolution map of the child marriage indicator for the two time points. These maps were then employed to conduct spatial analysis and investigate its association with variable temperature. These methods are described in detail in the following sections.

Multi-Level Modelling

After examining univariate and bivariate descriptive statistics to explore the distribution of individual, household and contextual factors associated with child marriage, we fitted a two-level (multilevel) random intercept logistic regression analysis for the probability of having been married by 18 years, with individuals nested within primary sampling units (clusters) (Goldstein 2011; Hox et al. 2017; Snijders & Bosker 2011; Twisk 2006). We applied the svy (survey) command to adjust for unequal sampling probability, clustering, and stratification in calculating sample characteristics, given that DHS employed a two-stage cluster sampling design. We calculated weights for both level one and level 2 to be included in the MML model (Elkasabi et al. 2020). To account for the observed confounding factors, all regression models incorporated woman- and household-level characteristics. Statistical analysis was conducted using Stata version 17 (StataCorp 2023).

Sub-county level maps of child marriage for the two time points

A modelled high-resolution map of the child marriage indicator was employed to conduct spatial analysis and investigate its association with variable temperature. Because DHS data are representative only at the national and county levels, estimates of child marriage at sub-county level were modelled from the cluster level data. High-resolution (1x1km) estimates of child marriage were produced using Bayesian Model Based Geo-statistics (BMBGs) in line with the methods of Pezzulo et al. (2023). We fitted these models in the Bayesian framework using the integrated nested Laplace approximation stochastic partial differential equation (INLA-SPDE) method (Lindgren et al. 2011; Rue et al. 2009). These high-resolution estimates were then aggregated within the sub-county boundaries, using population-weighted averaging over each sub-county. Estimates were produced without using land surface temperature as a covariate to ensure that correct inference can be drawn concerning the relationship between them and temperature. The covariates used in the model include the slope, night-time lights, travel time to health facilities (see full list Table SI.3.1).

Spatial association between surface temperature and child marriage: univariate and bivariate cluster analyses

Univariate spatial analyses

Differently from the first part of the study, which utilised DHS microdata, this section relies on sub-county level data obtained by aggregating high-resolution map data. We employed a set of spatial analyses, both univariate and bivariate, to further investigate the spatial association between temperature and child marriage for each point in time and across 335 sub-counties in Kenya. National and subnational administrative boundaries of Kenya were sourced from the Population Division, U.S. Census Bureau (U.S. Census Bureau 2024). We assessed the degree of global spatial autocorrelation, or the degree to which one spatial unit (sub-county) shares similar or different characteristics with its neighbouring spatial unit, by using Moran's I statistic (using n = 999 permutations yielding a pseudo p value of 0·001). We further employed a spatial cluster analysis using the Local Moran’s I for each variable individually to examine the geographical clustering of child marriage and average land surface temperature for round 1 (2014) and round 2 (2022).

The global Moran's I statistic indicates whether spatial clustering of a characteristic exists across the area, compared with a null hypothesis of a spatially random distribution. Global Moran's I values closer to 0 indicate little or no spatial clustering, whereas positive values indicate spatial clustering where neighbouring units tend to have similar values, and negative values indicate that neighbouring units tend to have different values. We considered each of the 335 sub-counties as spatial units in the context of this study, and the values we assessed under spatial cluster analysis were child marriage and average land surface temperature. We employed the Local Indicator of Spatial Association (LISA) analysis to investigate spatial clusters across the study area, specifically identifying areas with statistically significant clustering of high values (high-high clusters) and low values (low-low clusters), as well as any spatial outliers, high-low, and low-high patterns for each variable. This allowed for a detailed spatial visualisation of where each variable exhibits localised clustering. This method tests for significant spatial clustering by comparing the value of each spatial unit with its neighbouring units, with the null hypothesis positing no spatial association between a unit and its neighbours. The LISA analysis identifies regions where high or low values are spatially clustered, thereby revealing areas with similar attribute values in close proximity (Anselin 1995).

Bivariate spatial analyses

To further investigate the association between land surface temperature and child marriage, we applied bivariate choropleth maps to visually represent the association (or relationship between) of temperature and child marriage at the sub-county level in 2014 and 2022, then we further explored the relationship between the two by investigating the presence of spatial clusters of the two variables, and analysing the spatial autocorrelation (spatial dependence) between them, by using Bivariate Local Indicator of Spatial Association (BiLISA) cluster maps (Anselin & Getis 1992), with associated Bivariate Moran’s I.

While bivariate choropleth maps display the joint spatial distribution of child marriage and land surface temperature at the sub-county level for the two time points, BiLISA offers an advanced spatial analysis technique by identifying statistically significant spatial relationships between two variables. Building on the LISA method, BiLISA tests for significant spatial clustering by comparing the spatial patterns of two variables, with the null hypothesis assuming no correlation between the variables at neighbouring units. BiLISA identifies clusters of similar values (high-high/low-low) and contrasting values (high-low/low-high), highlighting areas where both variables exhibit high or low values (spatial clusters) as well as areas where one variable is high and the other is low (spatial outliers). This approach provides insights into the interrelated spatial distributions of the two variables.

A series of tests were conducted to control for poverty when examining the spatial association between temperature and child marriage for both years of analysis (See SI.4 in Supplements). Using sub-county-level poverty rates, both Ordinary Least Squares (OLS) and Spatial Error Model (SEM) regression analyses were performed to assess the effect of poverty on child marriage and to diagnose spatial dependence (Table SI.4.1.1). The results indicated that while poverty was a significant predictor of child marriage in the OLS model, it was no longer statistically significant in the SEM (Tables S1.4.1.2 and S1.4.1.3). This suggests that when accounting for spatial dependencies, the effect of poverty diminishes, while temperature remains a significant factor. Given these findings, the BiLISA analysis was carried out without controlling for poverty, focusing solely on the spatial association between temperature and child marriage.

Both the univariate (Global Moran's I and LISA) and bivariate spatial autocorrelation analyses (Bivariate Moran's I and BiLisa) were done using GeoDa (version 1.12.1.161) (Anselin 2003). We used the contiguity edges-only method, also referred to as Rook's case, as the conceptualisation method to define the spatial relationship between areas (this method returned a significant, and the highest, Moran's I), applied randomisation (using n = 99 999 permutations), and specified a pseudo p value for clusters of less than 0·01 as the cutoff value.

Bivariate choropleth maps were generated to visualise the quantitative relationship between temperature and child marriage at sub-county level. This was carried out in ESRI ArcGIS Pro v. 3.3.1.

Findings

Descriptive results

A total of 24,875 and 25,764 women aged 20 to 49 years in 2014 and 2022, respectively were included in the study. Among these, more than half (58%) had none or only primary education, 15% had their sexual debut by 15 years, 36% resided in households headed by a woman, 57% resided in rural areas and 17% lived in areas where the land surface temperature was 30 degrees Celsius or more in 2014. The corresponding figures for 2022 were 44%, 17%, 38%,57%, and 14%, respectively. (see Table SI.1.1 in Supplements for detailed results). Generally, prevalence of child marriage among women aged 20–49 years decreased from 27.4% in 2014 to 22.4% in 2022. However, some counties including Kajiado, Kiambu, Kericho, Uasin Gishu and Nairobi experienced increases of 0.5% or more between 2014 and 2022. All individual and household factors except employment status were significantly associated with child marriage, whether positively or negatively in both 2014 and 2022. While increasing education attainment, increasing household wealth, having a female household head, media exposure to reproductive health messages, and agency in household decision-making played a protective role, being a Muslim, residing in rural areas, sexual debut by 15 years and current use of modern contraceptive methods was associated with higher child marriage rates. Tana River, Samburu, Homa Bay and Migori counties showed the highest child marriage rates in both time points. While Turkana, Isiolo and Homa Bay counties showed significant reduction, Samburu experienced an increase in child marriage between 2014 and 2022, reporting the highest child marriage rate among the 47 counties in 2022 (detailed results are found in Table SI.1.1).

Multivariate multilevel modelling

Results from the multivariate multilevel models show slightly different correlates of child marriage in 2014 and 2022. In Fig. 1, higher educational attainment and having a female household head were significantly associated with lower odds of child marriage in both 2014 and 2022 (detailed results are found in Table SI.2.1). Conversely, being sexually active by age 15, being in employment and using modern contraceptives was associated with higher odds of child marriage. The association between both household wealth and age of respondent and child marriage with was not consistent for both years. The contextual factor land surface temperature explained a small share of the variation in child marriage. After controlling for demographic and other socio-economic factors, high temperature (more than 30 degrees Celsius) was associated with a higher risk of child marriage, significant in 2022 but not in 2014. The multilevel model results for each 5-year age group from 20–49 years do not show significant differences with the full sample of 20–49. While all the associations are not significant for age groups 20–24, 40–44 and 45–49, the results for the other age groups are similar to the full sample model, with age groups 25–29 and 30–34 showing significantly higher child marriage for land surface temperatures above 30 degrees Celsius (Figure SI.2.1 (a-f)). These two age groups could therefore be driving the significant associations between high temperature and child marriage observed in the full sample. Despite not seeing many significant associations when looking at the results separately for each five-year age group, we notice that the direction of the association is consistent with the full sample model (20–49).

Geographical Association Between Land Surface Temperature and Child Marriage

Significant positive spatial autocorrelation was observed independently for both child marriage and average land surface temperature in the study area, as measured by separate global Moran's I calculations (see Section SI.4.2 in supplementary file for details). These results indicate that neighbouring areas tend to exhibit similar values for child marriage and for average temperature, respectively, forming clusters associated with these variables in both years.

Figure SI.4.2.1 (supplementary file) shows areas with significant clustering of low–low (cold spots) and high–high (hot spots) child marriage (Panel a) and average temperature (Panel b) in Kenya, as measured through Univariate LISA statistic.

Bivariate Geographic Analysis of Temperature and Child Marriage association

Figure 2 shows bivariate choropleth maps at sub-county level. In Panel a and b, clusters of high-risk areas (i.e., areas with a combination of high temperature and child marriage) are concentrated in the northern, eastern and coastal regions of the country. Although national prevalence of child marriage decreased in 2022, we observe that some sub-counties in the northeast and northwest including Mandera North, Mandera East, Lafey, Samburu North, Lagdera, Loima and Kotulo, and in the coastal regions including Msambweni and Malindi, had higher levels of child marriage and higher temperatures compared to 2014. In Panel c and d, aggregated values for temperature are moderately to strongly correlated with aggregated percentage of child marriage at sub county level (at 0.57 and 0.63, respectively), suggesting some effect of high temperatures on child marriage, with an observed stronger correlation over time.

Local Spatial Analysis of Temperature and Child Marriage Relationship Patterns (BiLisa)

Bivariate Moran's I, which measures the degree of spatial association between temperature and child marriage was positive and equal to 0.523 for round 1 and to 0.592 for round 2 (Fig. 3., confirming the moderate-to-strong spatial association between them [See additional details in Fig SI.4.3.1 to SI.4.3.5 in supplementary file]. This indicates that sub-counties with high (or low) values of child marriage tend to be spatially near sub-counties with high (or low) values of average temperature.

Additionally, results from the BiLISA analysis provided insights into the spatial patterns of these associations at a localised level (sub-county) and for each point in time. Unlike choropleth maps, this approach also allows us to assess significance levels for these localised associations. In particular, the BiLISA cluster maps for both 2014 and 2022 reveal distinct spatial patterns in the association between average temperature and child marriage across Kenya: in the northern and north-eastern regions the "High-High" clustering suggests that sub-counties with higher child marriage rates tend to coincide with higher temperatures in this part of the country; while in the central region both child marriage and temperature have low values, forming a "Low-Low" cluster, suggesting that areas with lower child marriage rates tend to be located near areas with lower average temperatures. Some sub-counties located in the south-western area of the country display high child marriage rates situated near areas with relatively lower temperatures. These spatial outliers suggests that child marriage rates in these high-low areas might be driven by factors other than, or in addition to, temperature, such as social, cultural, or economic dynamics, and the presence of different levels of access to resources or variations in cultural practices compared to their surroundings.

In the case of two sub-counties, and for 2014 only, a Low-High pattern was observed, where low child marriage rates are found alongside high temperatures. This may indicate that other factors, such as economic development or education, play a stronger role in reducing child marriage in these areas, regardless of temperature.

Patterns of clustering between the two rounds are mostly the same. However, there were more sub-counties in the coastal region showing a High-High pattern in 2022 (54) than in 2014 (50). In addition, in 2022, a few more sub-counties in the south-western region of the country showed a High-Low pattern compared to 2014. Further, in the central region of the country, there were fewer sub-counties in 2022 showing a Low-Low pattern. This could imply an increasing risk of temperature related child marriage in 2022.

Discussion

The Sustainable Development Goal 5.3 aims at ending child marriage by 2030. However, the current annual rate of reduction of 1.9% is not fast or equitable enough to achieve this target, with a reduction rate of 23% by 2030 being shown to eliminate the practise (Lo Forte et al. 2019). To achieve this increased rate of reduction, there is need to understand and address the contributing factors not only at the national level but also sub-national level. The results in this study support the importance of exploring the driving factors of child marriage at sub-national level. While we consider individual and household level factors associated with child marriage in Kenya, we conduct a comprehensive analysis on temperature as a contextual variable. After controlling for poverty and other factors including household wealth, ethnicity, religion, region and area of residence, the results have revealed an increasing risk of child marriage related to temperature in Kenya, if we compare 2014 and 2022 results. Land surface temperature was seen to be associated with child marriage in most of the counties, particularly those in the northern, eastern and coastal regions of the country.

Evidence on the association between high temperature and child marriage is limited, and even the minimal evidence available is mixed. Carrico et al (2020) found an association between extreme heat and child marriage rates in Bangladesh, with girls 11–14 and 15–17 years being twice as likely and 30% more likely to marry, respectively, in the year immediately following moderate or severe heat waves (Carrico et al. 2020). Conversely, in a similar study in Bangladesh, extreme temperatures (1 std dev above long-term average) were found not to be associated with any increased risk of child marriage (Tsaneva 2020). Consequently, there is a need for more studies focusing on effect of temperature rises on child marriage specifically, given the evidence that global temperatures continue to rise. This study provides policy relevant evidence that could guide targeted interventions in the country to address child marriage. It also provides subnational analyses of areas that are at a higher risk of increased child marriage that could be associated with increasing temperatures. No other study has achieved this in Kenya.

The BiLISA analysis reveals distinct spatial patterns in the association between average temperature and child marriage rates across the country, with significant policy implications. This pattern persisted even after controlling for household wealth. In the northern region, where high-high clusters dominate, both child marriage rates and temperatures are elevated, suggesting that local interventions may need to address intertwined social and environmental challenges unique to these areas. Central regions, forming low-low clusters, show consistently low values for both variables, indicating conditions that may support positive social outcomes; policy efforts here could focus on sustaining these favourable factors and potentially using them as models for other regions. The few high-low outlier areas, where high child marriage rates exist alongside lower temperatures, point to atypical conditions that may require targeted, localised approaches, possibly involving cross-regional partnerships with nearby areas that have more favourable outcomes. Together, these insights from BiLISA help refine region-specific strategies, allowing interventions to be better aligned with the unique spatial dynamics of each cluster. Caution should however be exercised in interpreting these relationships, as there may be other important influences at play that warrant further investigation. Maps can provide valuable insights into the spatial relationship between temperature and child marriage. However, while these maps can illustrate how temperature correlates with child marriage across different regions, it is essential to acknowledge that they do not capture the entire complexity of the situation.

The associations observed between individual and household level variables and child marriage corroborate previous evidence. Early sexual debut increases likelihood of early marriage, as it increases risk of adolescent pregnancy, which also mediates early marriage (Kohno et al. 2020; Kok et al. 2023; Petroni et al. 2017; Psaki et al. 2021). Education attainment has been shown to reduce child marriage, and this is confirmed in our findings, with lower risk of child marriage with increasing education attainment (Wodon et al. 2017; Wodon et al. 2018). Our findings show that residing in households headed by women had a protective effect on child marriage. While the vulnerability associated with female-headed households has been thought to negatively affect children, with increasing rates of child marriage as a cost reduction mechanism (Al Fara 2024), this evidence is not conclusive (Cassidy et al. 2024; Kuswanto et al. 2024), and there is mixed evidence on whether female-headed households are poorer or not, particularly in Africa (Brown & van de Walle 2021; Oginni et al. 2013). A more nuanced analysis on the type of female –headed household (whether by choice or forced by various circumstances) —for example as done in (Saad et al. 2022)—will help inform policy interventions. Child marriage is shown to be more prevalent in poorer households and among those living in rural areas (United Nations Children's Fund 2023). Our findings are not significant, although in 2014, those in the richest households showed lower rates of child marriage. There are mixed findings on the association between labour force participation and child marriage. While limited education due to school dropout following child marriage could reduce the likelihood of entering the job market in countries where economic opportunities are linked to education, in low-income economies where labour markets are mostly informal, high poverty levels force women to work in order for the household to survive, and thus higher employment level is associated with child marriage (Wodon et al. 2017). Our results show that being in employment was associated with higher odds of child marriage. This could be because most of the economic opportunities are informal, coupled with high poverty levels. The finding that modern contraceptive use was associated with higher likelihood of child marriage is also supported by a study in four Asian countries; Bangladesh, India, Nepal and Pakistan, noting that age at marriage was significantly associated with current modern contraceptive use, although the results were partly mediated by the number of living sons in Nepal and Pakistan (Godha et al. 2013). From our 5-year age group analysis, this is mainly significant among younger women ages 20–29.

There are several limitations to the study. Firstly, the study uses the full sample of women 20–49 ages to estimate child marriage rate, which is contrary to the common definition that focuses on the narrow 20–24 age group. However, the objective of the study was not to measure child marriage or show a causal relationship, but rather associations at subnational level, thus the use of the full sample of women. Secondly, the subnational bivariate and cluster analysis uses child marriage prevalence based on women aged 20–49 and temperature data from the survey years. While this approach provides valuable insights into the geographical overlap of child marriage and environmental factors, there is a potential time misalignment, as the timing of child marriage for older women may not correspond to current temperature conditions. However, the observed spatial associations likely reflect broader, sustained environmental, socio-economic, or cultural factors that have influenced child marriage practices over time. To reduce the impact of this limitation, additional subgroup analyses focusing on younger women, whose marriages occurred closer to the survey year, are considered where relevant. We also explored interactions between county and temperature in the multivariate model. The results showed that the association between child marriage and land surface temperature remained significantly positive even in some relatively wealthy counties such as Kiambu, Kirinyaga and Narok. Lastly, the random displacement of cluster locations can create uncertainty in the modelled relationships during the extraction of cluster-level values, though this effect is typically considered modest (Burgert et al. 2013; Gething et al. 2015). To mitigate this potential error, average values were extracted within a defined buffer surrounding the survey points (Perez-Heydrich et al. 2013).

Despite these limitations, this study provides policy relevant evidence on hot spots with increased risk of child marriage and higher temperatures, with geographical patterns at the subcounty level. The findings also contribute to the limited evidence on the association between temperatures and child marriage, and the first evidence in Kenya, not only at the country level, but also sub-nationally.

Conclusions

Given the projected continued increase in global temperature related to climate change, this evidence will be timely in implementing gender-sensitive interventions in the most at-risk areas. There is need for more research in various countries with the twin challenges of child marriage and increasing temperatures to provide more robust evidence that can be generalised to other contexts. In addition to continued efforts to promote school retention up to secondary school level, delaying sexual debut and increasing community awareness on the harmful effects of child marriage, this study calls for targeted interventions to address geographically specific environmental challenges. Availability of historical data on temperature could eliminate the misalignment identified above. Future work may focus on exploring any causal relationship between temperature increase and child marriage, using longitudinal data. In addition, further research could examine indirect pathways, such as health impacts, or changes in resource allocation within households, to understand the nuanced ways temperature influences child marriage. Future directions may also include investigating how climate change and other crises shape lived realities for women and girls to determine responsive policy and practice.

Declarations

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Author Contribution

E.M.W, C.P. and A.J.T. conceived the study and led the research activity planning. E.M.W, C.P, N.T.G, A.B, P.D, R.P, M.M and M.J. contributed to data collation and analysis. E.M.W. and C.P. drafted the manuscript. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability

The Kenya household survey data are available from the DHS program data portal ([https://www.dhsprogram.com/data/](https:/www.dhsprogram.com/data)) after registration.

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Figures

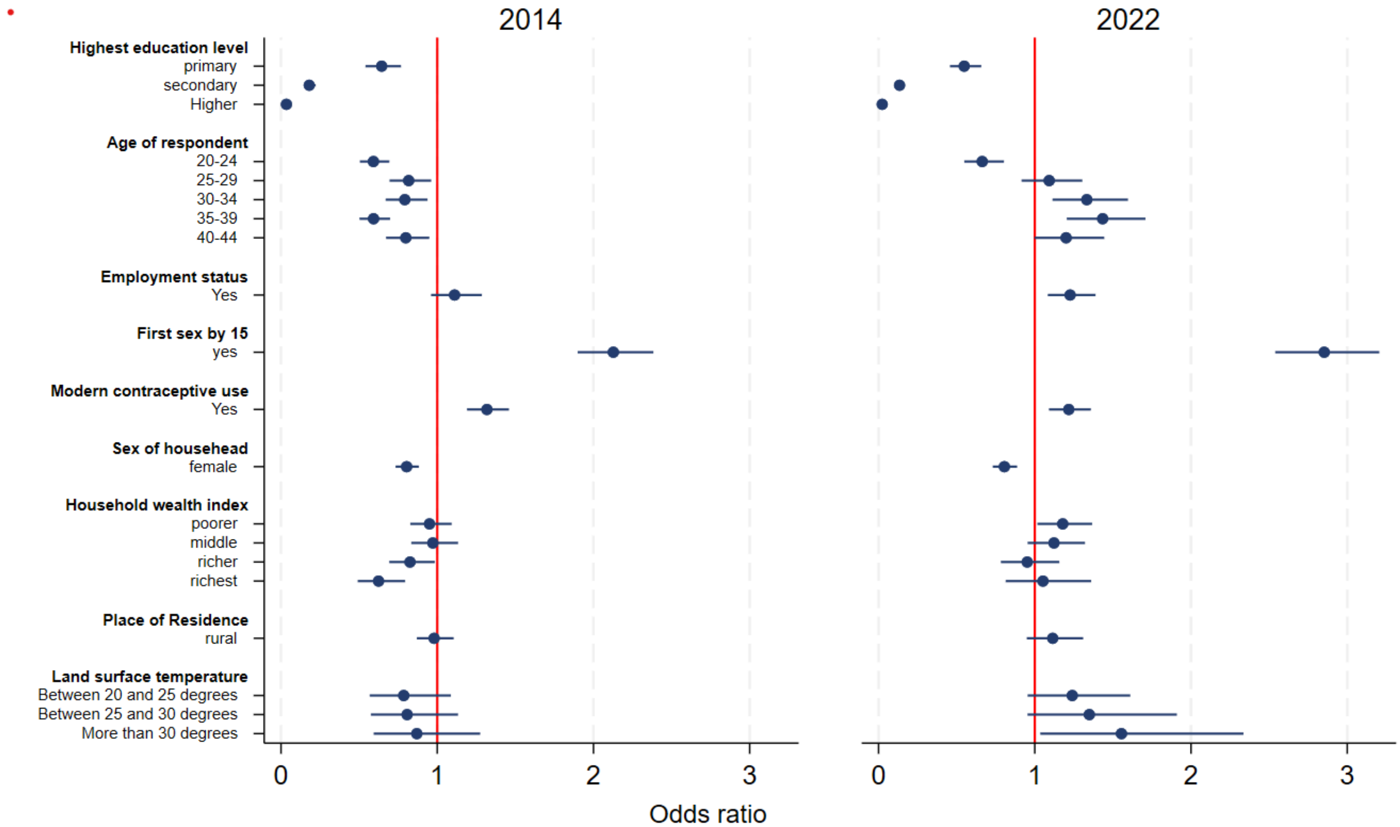

Figure 1

Multivariate multilevel logistic regression for the effect of individual, household and contextual level variable (land surface temperature) on child marriage using KDHS 2014 and 2022. Those plotted are coefficients for fixed effect covariates from a multilevel-multivariate analysis of drivers of child marriage in Kenya (odds ratios and 95% confidence intervals).

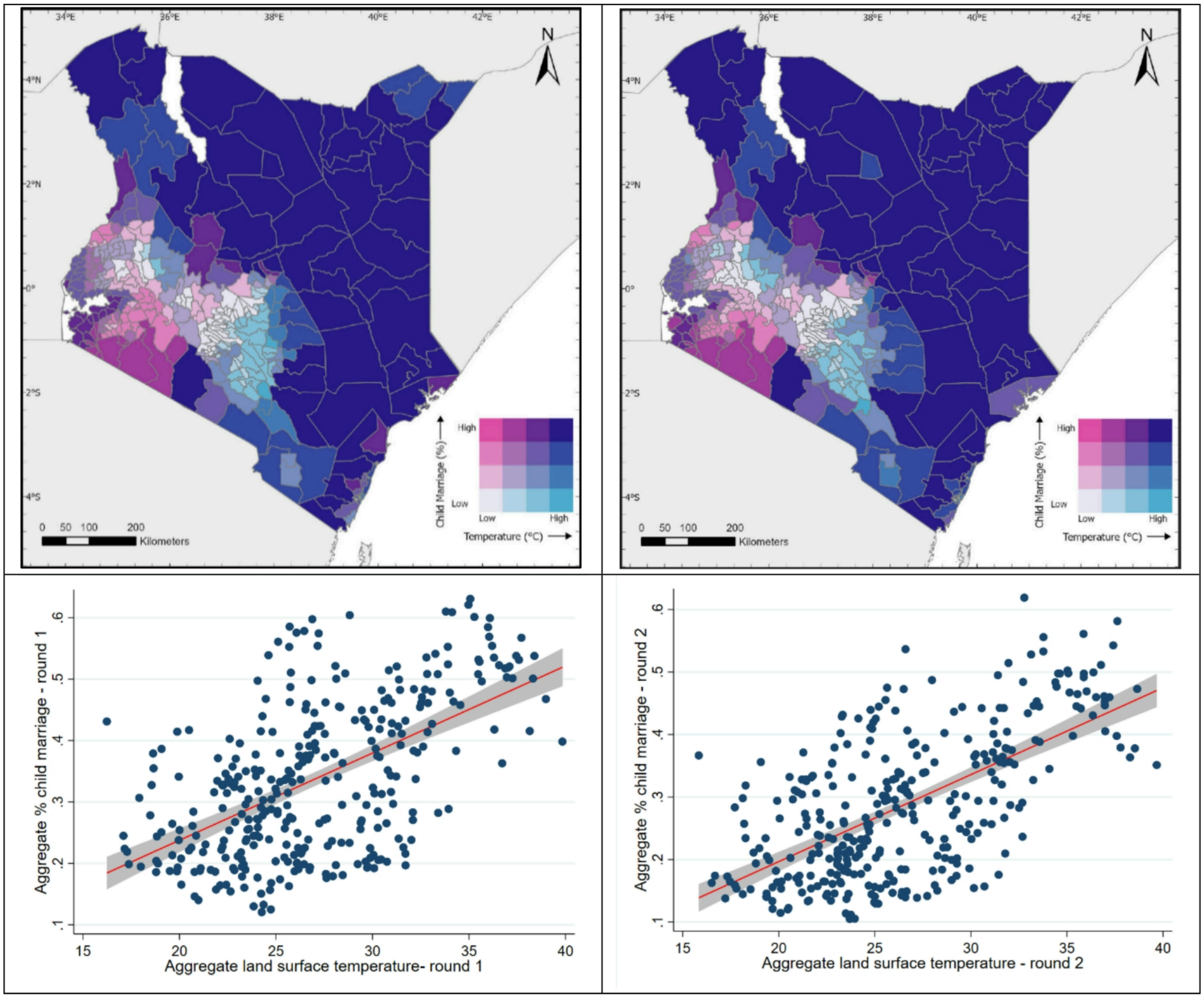

Figure 2

Bi-variate association between temperature and child marriage at the sub-county level in Kenya. Panel (a) shows bi-variate association between temperature and child marriage for round 1 (2014), while Panel (b) represents round 2 (2022). The lower Panels (c) and (d) show plots of the relationships between aggregated values for temperature by aggregated % of child marriage at sub county level, 2014 and 2022. The correlation for round 1 (c) is 0.57, while for round 2 (d) is 0.63. The red lines and grey coloured bands are fitted lines and corresponding uncertainty intervals, respectively.

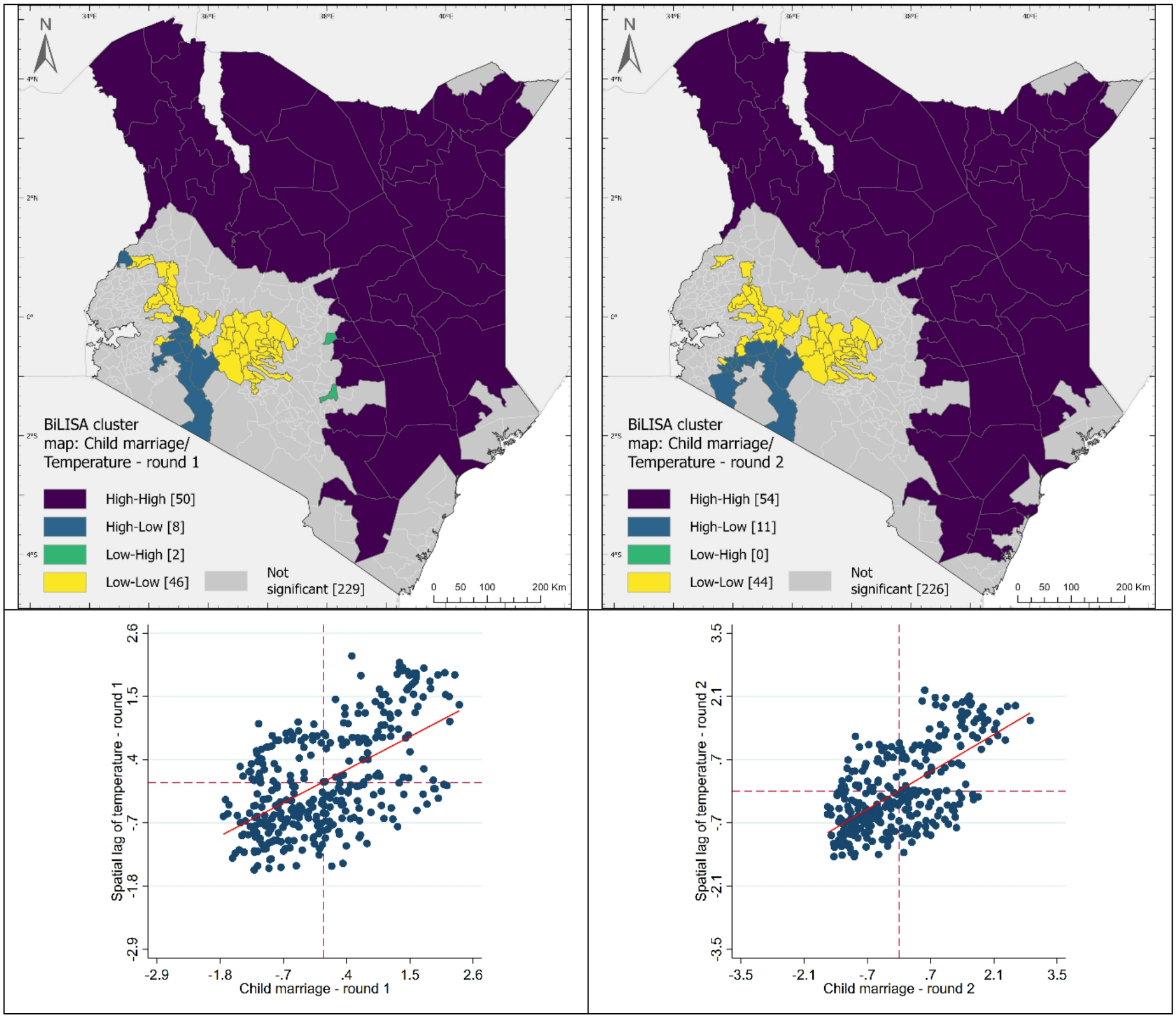

Figure 3

Bivariate Local Indicators of Spatial Association (BiLISA) analysis and Moran's I scatter plots for comparative clustering of temperature over child marriage across two rounds. Panel (a) Spatial clustering patterns of child marriage over temperature for Round 1 using BiLISA. Panel (b) Spatial clustering patterns of temperature over child marriage for Round 2 using BiLISA. Panel (c) Scatter plot illustrating the relative Bivariate Moran's I statistics for Round 1, highlighting spatial autocorrelation between temperature over child marriage (Bivariate Moran's I for Round 1 = 0.523). Panel (d) Scatter plot illustrating the relative Bivariate Moran's I statistics for Round 2, showing temporal changes in the spatial relationship (Bivariate Moran's I for Round 2 = 0.592).

Supplementary Files

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