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Spatiotemporal patterns of conflict-related sexual violence in Colombia

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Sexual violence is one of the most severe forms of civilian victimization in the Colombian armed conflict, yet population-scale analysis of its patterns remains limited. Here, using two national victimization databases, we profiled victim demographics and applied log-Gaussian Cox process and Hawkes process modelling to examine geospatial clustering and temporal contagion across the entire conflict (1964–2024) and a recent period (2014–2024). Victims were predominantly female (~90%) and disproportionately from minority ethnic groups. Geospatial analysis indicates that sexual violence may be more widely present than raw event counts suggest and has shifted from concentrated, high-intensity incidents to more dispersed patterns. Unadjusted Hawkes models indicated near-critical temporal dependency in both periods, but Hawkes models adjusted for background conflict intensity suggest that event-to-event contagion was minimal in both periods. Identified areas of historically high prevalence remain priorities for victim support, and the temporal dynamics suggest that prevention efforts should proactively address long-term structural and contextual determinants.

The Colombian armed conflict has endured for almost six decades and has disproportionally affected civilians, with an estimated 18.3% of the entire population affected by at least one form of violence[1]. Sexual violence has been identified as one of the most serious types of civilian victimization by the Colombian transitional justice process[2], and victims of conflict-related sexual violence are recognized in law as a healthcare priority in terms of both medical treatment and psychosocial support[3].

The extent of conflict-related sexual violence is of particular concern in Colombia given the exceptional duration of the conflict. It has continued for more than six decades, exposing multiple generations to cycles of violence. The Colombian armed conflict is officially recognized as beginning in 1964 with the formation of the guerrilla group the Revolutionary Armed Forces of Colombia (known by their Spanish acronym, the FARC, later FARC-EP), following a period of bipartisan violence known as *La Violencia* (1948–1958). The origins of the conflict lie in rural inequality, political exclusion and lack of protection from violence, but its expansion and persistence are closely linked to the illicit drug economy, which has provided both funding and strategic incentives for territorial control. The conflict has been characterized by the involvement of a complex array of actors, including numerous guerrilla groups, paramilitary forces, state military units and criminal organizations. Civilians in the conflict have experienced systematic

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Table 1 | Demographics of victims of sexual violence by source of information

	NCHM		RUV	
	N	%	*N*	%
Gender				
Female	15,739	90.1%	32,244	90.6%
Male	1,676	9.6%	2,774	7.8%
Other	–	–	561	1.6%
No information	62	0.36%	4	<0.01%
Ethnicity				
Afrocolombian	1,539	8.8%	7,277	20.5%
Indigenous	239	1.4%	1,212	3.4%
Palenquero	7	<0.01%	42	0.1%
Raizal	2	<0.01%	56	0.2%
Roma	1	<0.01%	19	0.1%
White/Mestizo	15,689	89.8%	26,977	75.8%
Age range				
Infancy (0–5)	149	0.9%	76	0.2%
Young childhood (6–11)	1,018	5.8%	340	1.0%
Adolescence (12–17)	3,896	22.3%	829	2.3%
Young adulthood (18–28)	5,320	30.4%	4,760	13.4%
Adulthood (29–59)	4,466	25.6%	26,895	75.6%
Older age (60+)	95	0.5%	2,671	7.5%
No information	–	–	12	<0.01%
	Mean	s.d.	Mean	s.d.
Age	NA	NA	40.2	12.9

Age reported only by age range in NCHM. NA, not applicable.

victimization and prolonged insecurity as groups have vied for control of populations, resources and strategic locations, resulting in widespread displacement and social fragmentation[4]. Following 4 years of negotiations, a peace agreement was signed in 2016 between the Colombian state and FARC-EP. However, violence has persisted in many regions owing to the continued activity of FARC-EP dissident groups, the presence of armed groups not party to the agreement, uneven implementation of the accord, and ongoing violence motivated by the protection of illicit economies[5].

Sexual violence has been widely reported throughout the duration of the conflict. It remains an important public health issue and an urgent medical priority. Survivors of sexual violence are at increased risk for a range of acute and chronic medical conditions, including sexually transmitted infections, unintended pregnancies, traumatic injuries and poor mental health[6,7]. Globally, sexual violence against civilians is endemic within armed conflict, manifesting in diverse forms and intensities across different contexts, countries and phases of conflict[8]. Consequently, understanding the dynamics of sexual violence in armed conflict is essential to public health approaches, informing prevention and treatment during conflict and in post-conflict periods[9].

Unfortunately, understanding armed-conflict-related sexual violence within Colombia has been difficult due to a paucity of studies that look at population data at a scale commensurate with the conflict itself, although some important earlier work has laid critical groundwork. Within the Colombian armed conflict, sexual violence has been noted to occur opportunistically[10], as part of broader gender-based violence endemic in society[11], as well as being a systematic tool used by armed actors to achieve 'strategic' aims such as intimidation, demoralization, retaliation and territorial control[12,13]. A survey conducted by Urrego et al.[14] found a 45.1% prevalence of sexual harassment, 16.8% prevalence of rape and 3.9% prevalence of forced prostitution, although it involved focused sampling of 1,975 women aged 15–44 in highly conflict-affected areas of Colombia and restricted the sampling range to events occurring between 2010 and 2015. Partial statistics have been published as parts of reports identifying perpetrators or elaborating the impact of sexual violence (for example, refs. 15,16) with broad consensus that the armed-conflict-related sexual violence has disproportionately affected women and girls[17], but there is a lack of studies that have used population-level data to characterize sexual violence covering the duration of the conflict.

Public health approaches are best informed not only by an understanding of the demographic profile of affected individuals but also by evidence on how incidence spreads geographically and evolves over time, an aspect that is likely to be particularly important for understanding the patterns of violence[18]. While existing studies have described prevalence and individual risk factors, understanding how sexual violence clusters spatially and how these patterns evolve in relation to broader conflict dynamics can help target post-violence support and inform realistic timescales for prevention.

Consequently, this study aimed to characterize the demographic profile of sexual violence victims and examine the spatial and temporal dynamics of conflict-related sexual violence in Colombia. To achieve this, we used two population-scale registers of armed conflict victimization to understand the nature of sexual violence in the Colombian armed conflict: (1) the national Register of Victims (*Registro Unico de Víctimas*, RUV), a statutory register of over 8 million people who have been affected by the armed conflict where registration is a necessary step for qualifying for reparations; and (2) the National Centre for Historical Memory (*El Centro Nacional de Memoria Histórica*, NCHM) database of Colombian armed conflict victimizations events—a register of armed conflict events based on multiple information sources that aims to record events nationally and over the entire duration of the conflict.

We focused on two temporal windows: the entire conflict period (1964–2024) and the decade 2014–2024. Analysis of the full conflict period provides a long-term historical perspective on the spatial and temporal evolution of conflict-related sexual violence. The more recent decade coincides with the enactment of Law 1719 (2014) in Colombia, which specifically guarantees access to justice and comprehensive care for victims of sexual violence in the context of the armed conflict. An analysis of cases during this more recent time window is therefore particularly relevant for understanding the nature of sexual violence because there has been a statutory obligation to provide detection, treatment and support.

We used log-Gaussian Cox process (LGCP) modelling to estimate the latent geospatial intensity of sexual violence events. The latent spatial intensity reflects the expected concentration of sexual violence events across locations. Areas with higher intensity indicate where events tend to cluster, even in places with few or no reported cases, after accounting for population density and spatial patterns observed elsewhere. This identifies differences in underlying event concentration across regions and, by itself, does not indicate local event-to-event contagion. To assess whether such contagion is present, we used Hawkes process modelling to test for temporal contagion, where the occurrence of one event may increase the risk of subsequent additional incidents. By comparing Hawkes process models with and without adjustment for baseline rate, we aimed to distinguish the presence of short-term event-to-event contagion from slower-moving trends probably reflecting structural and contextual factors that drive sexual violence.

Results

Demographics of victims of sexual violence and differences between data sources

Demographics in terms of gender, ethnicity and age of victims of sexual violence from each dataset are presented in Table 1.

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Table 2 | Co-occurrence between other Colombian armed conflict exposure events and conflict-related sexual violence in the NCHM database

Armed conflict exposure event	*N*	*N* co-occurrence with sexual violence
Witness to combat operations	51,830	0
Massacres	27,580	12
Terrorist attacks	820	0
Attacks on civilian property	1,469	0
Kidnapping	38,580	4
Damage to civilian property	452	0
Antipersonnel mines	10,440	0
Selective killings	184,031	4
Forced disappearance	80,866	7
Child recruitment to armed groups	18,175	5

Table 3 | Co-occurrence between other armed conflict exposure events and conflict-related sexual violence in the RUV database

Armed conflict exposure event	*N*	*N* co-occurrence with sexual violence	%
Torture	9,912	1,818	18.3%
Physical wounds	13,880	1,657	11.9%
Child recruitment to armed groups	7,756	455	5.9%
Kidnapping	33,487	1,780	5.3%
Witness to combat	82,845	1,924	2.3%
Threats	520,805	9,237	1.8%
Psychological wounds	13,949	226	1.6%
Loss of property	120,168	996	0.8%
Forced disappearance	160,499	759	0.5%
Dispossession of land	31,464	160	0.5%
Forced displacement	7,540,257	29,306	0.4%
Murder	919,051	2,473	0.3%
Forced confinement	75,961	192	0.3%
Antipersonnel mines	11,250	12	0.1%

As can be seen in Table 1, the RUV dataset has a greater proportion of minority ethnic groups and an older age profile of victims than in the NCHM dataset. Perpetrators of sexual violence in terms of armed group were recorded only in the NCHM dataset, but this variable had very high rates of missing data, meaning it is unlikely to provide reliable information: 17,405 cases (99.59%) had no information on perpetrator, and state agents were identified as perpetrators in 41 cases (0.23%), guerrilla groups in 26 cases (0.15%) and paramilitary groups in 5 cases (0.03%).

Co-occurrence with other exposures to the armed conflict

There are very few instances of co-occurrence of sexual violence events with other armed conflict exposures events in the NCHM (Table 2). Registration of sexual violence victimization co-occurs with registration of other armed conflict exposures at much higher levels in in the RUV (Table 3). These data indicate that sexual violence tends to be associated with more personally directed forms of armed conflict exposure, such as torture and physical injury, rather than with property damage or group-level events such as antipersonnel mines and displacement.

Raw geographic dispersion of sexual violence events

Although location is coded differently in each database (event by specific latitude and longitude in the NCHM database, registration by municipality in the RUV), the two datasets show comparable patterns in terms of areas of high prevalence, as shown in Fig. 1. In particular, higher concentrations of reported sexual violence are apparent in the Andean region and in several historically conflict-affected areas, including close to the Pacific coast, particularly Chocó, Valle del Cauca, Cauca and Nariño, and northwestern departments such as Antioquia and Córdoba.

Latent geospatial structure of conflict-related sexual violence

Spatial analysis using the LGCP revealed a latent geospatial structure of sexual violence that was clustered within defined geographic extents (Fig. 2), distinct from raw geospatial density (Fig. 1). The broader intensity surface estimated by the LGCP model suggests that, over the entire conflict period, sexual violence may be more widely present than is apparent from raw event counts, and this is particularly notable in areas East of the Andean region. Mesh-based integration weights are shown in Extended Data Fig. 1, and spatial projections of the latent Gaussian Markov random fields are shown in Extended Data Fig. 2 (see also Fig. 3i).

For data spanning the entire conflict period (1964–2024), the unadjusted LGCP model estimated significant spatial clustering (LGCP $\beta = 2.580$; s.e.m. 0.600) with a spatial range of 2.385 km (s.e.m. 0.297; 95% confidence interval (CI) 1.802–2.968), indicating that locations within this distance are spatially correlated and have similar underlying event probability, and latent field standard deviation of 2.323 (s.e.m. 0.215). After adjusting for population density, which showed a significant positive association with sexual violence events (LGCP $\beta = 0.530$; s.e.m. 0.088), the spatial range reduced to 1.733 km (s.e.m. 0.278), and spatial variation declined to 1.783 (s.e.m. 0.152; 95% CI 1.188–2.278), indicating that population density explained approximately 27% of the spatial range and 23% of unexplained spatial heterogeneity. For sexual violence from 2014–2024, there was a strongly reduced baseline intensity (LGCP $\beta = 1.171$; s.e.m. 0.570 in the unadjusted model; LGCP $\beta = 0.551$, s.e.m. 0.385 in the adjusted model). Spatial clustering extended over a wider area: 2.523 km in the unadjusted model (s.e.m. 0.371; 95% CI 1.797–3.250) versus 1.868 km (s.e.m. 0.221; 95% CI 1.219–2.517) when adjusting for population density. The population density effect remained significant in the recent period (LGCP $\beta = 0.458$; s.e.m. 0.082), demonstrating the persistent influence of population distribution on the spatial patterning of conflict-related sexual violence throughout the conflict timeline. Full parameters for all LGCP models are presented in Extended Data Table 1. Plots for models not adjusted by population density are shown in Extended Data Fig. 3a,b, alongside spatial uncertainty plots for all models (Extended Data Fig. 4a,b).

The LGCP model validation checks indicated adequate model fit for both time periods. Ripley's K-function confirmed that the observed spatial distribution of sexual violence events was markedly distinct from spatial randomness. The observed event counts fell near the centre of the distribution of simulated counts from the 1,000 realizations drawn from the fitted intensity surfaces, indicating that the models accurately reproduced the expected number of events, although with a slight (below 1%) underestimation of density of sexual violence events for the 1964–2024 period. Posterior predictive checks indicated that the mean simulated density surfaces closely matched the observed spatial density, reproducing the same major high intensity locations across Colombia, with the observed density falling within the 95% CIs. Simulation results are reported in Extended Data Figs. 5 and 6. Sensitivity analyses showed that LGCP models fitted with both coarser and finer mesh sizes captured the same underlying spatial distribution, differing only in resolution, as expected given the varying mesh sizes, as shown in Extended Data Fig. 7.

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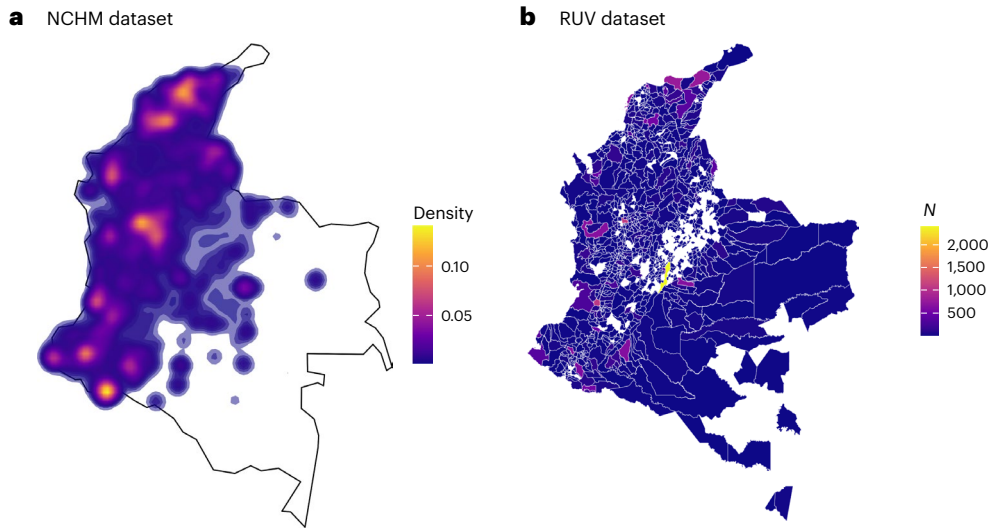

Fig. 1 | Raw density of total sexual violence events. a,**b**, As recorded in the NCHM database (**a**) and RUV database (**b**) by municipality in the Colombian armed conflict. Map data from Natural Earth (https://www.naturalearthdata.com).

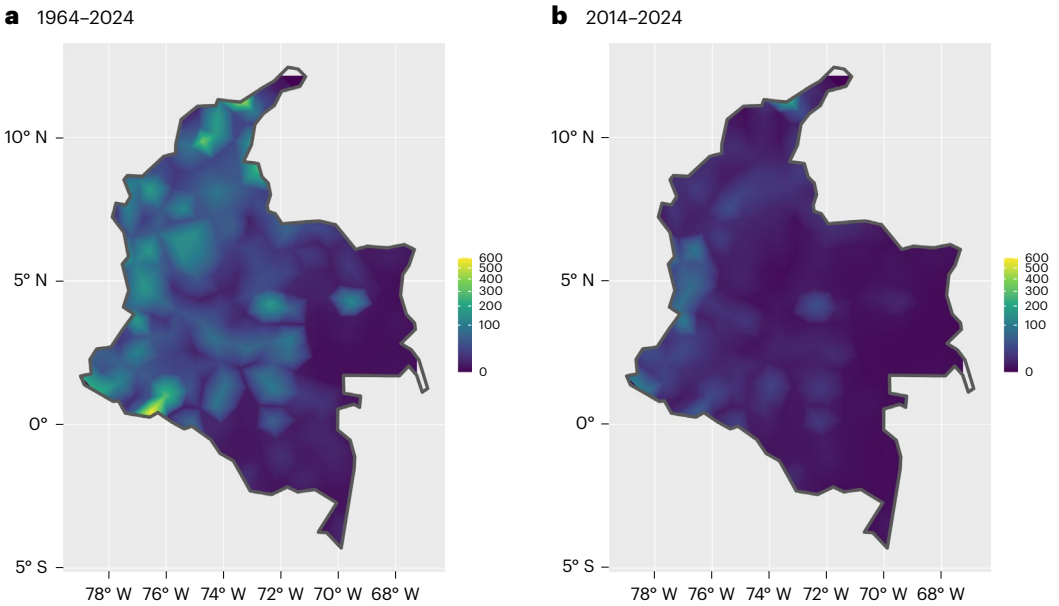

Fig. 2 | LGCP intensity plot of latent geospatial structure identifying areas of elevated probability of sexual violence. a,**b**, LGCP intensity plots of sexual violence events from the NCHM database for the entire duration of the conflict 1964–2024 (**a**) and for 2014–2024 (**b**). Both adjusted for population density. Map data from Natural Earth (https://www.naturalearthdata.com).

Temporal contagion of sexual violence events

Hawkes process modelling of the entire conflict data (1964–2024) indicated moderate temporal contagion of sexual violence. The Hawkes process with a constant baseline showed a low baseline rate of events ($\mu = 0.009$; s.e.m. 0.001), corresponding to a 0.9% chance of occurrence per day, with modest temporal dependence ($\alpha = 0.186$; s.e.m. 0.011). The decay rate (Hawkes $\beta = 0.188$; s.e.m. 0.011) suggested that the contagion effect was time-limited, with a half-life of approximately 3.7 days (ln(2)/Hawkes β). The branching ratio (α/Hawkes $\beta = 0.989$) indicates a near-critical process, in which each event generates, on average, just under one additional event. When adjusting for non-homogeneous baseline rate, there was a stronger immediate increase in intensity for subsequent events ($\alpha = 1.283$; s.e.m. 0.040), but the decay rate (Hawkes $\beta = 3.757$; s.e.m. 0.117; half-life 0.18 days) was below the 1-day temporal resolution of the data owing to the 1-day artificial jitter added to ensure no simultaneous events as the Hawkes model assumes continuity, meaning any temporal contagion effect occurred over less than a day, suggesting negligible temporal contagion when background rate changes are accounted for. For Hawkes process modelling of sexual violence events from 2014–2024, the constant baseline model showed a lower baseline rate ($\mu = 0.007$; s.e.m. 0.003), corresponding to a 0.7% daily chance of occurrence, with lower temporal contagion ($\alpha = 0.069$; s.e.m. 0.010) and a longer decay rate (Hawkes $\beta = 0.069$; s.e.m. 0.010; half-life 10.04 days). The branching ratio ($\alpha/\beta = 1.000$) indicated near-critical dynamics, in which each event increases the expected rate of subsequent events by approximately one additional event. The model adjusted for changing baseline rates revealed higher immediate intensity increases ($\alpha = 0.537$; s.e.m. 0.068) but a decay rate below the 1-day temporal resolution of the data (Hawkes $\beta = 2.843$; s.e.m. 0.367; half-life 0.24 days), suggesting negligible temporal contagion when background rate changes are accounted for. Comparison between conflict periods reveals a weakening of temporal contagion

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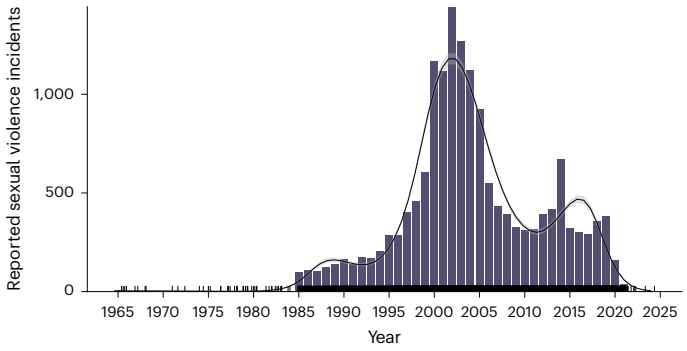

Fig. 3 | Sexual violence events by year with trend line. Sexual violence events by year as reported in the NCHM database.

over time, with sexual violence events in recent years appearing less clustered and more independent once broader fluctuations in conflict intensity are accounted for. Plots for the Hawkes process models are reported in Extended Data Figs. 8 and 9.

The Hawkes model validation using posterior predictive checks supported the adequacy of the Hawkes process models for the 1964–2024 and 2014–2024 time periods. For the constant baseline models, the observed mean interevent time of 1.32 days fell within the simulated 95% interval (0.49–4.70 days) for 1964–2024, and 1.49 days fell within the simulated 95% interval (0.42–31.87 days) for 2014–2024. The large 95% intervals for the 2014–2024 estimate reflect lower precision for individual parameter estimates due to a skewed 'long tail' distribution of events, although the peak of the mean interevent time closely recovers the observed mean interevent time (Supplementary Fig. 2a), indicating that the model robustly recovers the core temporal dynamics. For the models adjusted for baseline rate of sexual violence, the observed mean interevent time fell within the simulated 95% interval (1.26–1.34 days) for 1964–2024, and within the simulated 95% interval (1.23–1.55 days) for 2014–2024. Simulation results are reported in Supplementary Figs. 1 and 2, and goodness-of-fit metrics are reported in Supplementary Fig. 3. Sensitivity analysis showed the model parameters were stable in light of alterations to optimal spline smoothing, as illustrated in Supplementary Fig. 4.

Discussion

We report a population-scale profile of sexual violence within the Colombian armed conflict using complete data from the statutory RUV and the NCHM database of armed conflict victimization. Victims of sexual violence were overwhelmingly female and disproportionally from minority ethnic groups. Sexual violence was more likely to co-occur with types of armed-conflict-related violence that more directly targeted individuals. Geospatial analysis revealed that sexual violence may be more widely present than is apparent from raw event counts and exhibited significant geographic clustering with distinct temporal patterns across conflict periods. For the entire conflict period, event density was highly clustered within relatively confined geographic ranges, with locations within approximately 2.4 km of one another sharing similar underlying probability of events. By contrast, during 2014–2024 there was reduced spatial intensity and broader geographic clustering. Analysis of temporal contagion indicated that apparent event dependence was largely attributable to variation in the background rate. After adjustment, residual event-to-event contagion was minimal, decaying in less than one day, suggesting that temporal clustering is driven by structural and contextual conditions rather than incident-specific characteristics. These findings suggest that sexual violence patterns in the Colombian armed conflict have become geographically more dispersed in recent years with reduced temporal contagion effects, indicating potential changes in conflict dynamics and perpetration over time.

Research on the perpetration of sexual violence by armed groups indicate that it is not an inevitability of armed conflict but subject to group norms, leadership, conflict dynamics and broader political conditions[20]. These may have changed significantly in recent years. Since the height of the Colombian armed conflict, the reduction in violence has been accompanied by a fragmentation of armed groups. There is now less concentrated areas of control with influence spread more thinly across wider territories[21,22]. This may explain the transition from higher-intensity, geographically focused patterns of sexual violence, potentially more associated with it occurring as part of combat operations, to broader clustering with less intense and shorter-lived temporal contagion, potentially reflecting its relationship with longer-term territorial control and community subjugation, as well as a reaction to public recognition and condemnation[12,23].

Theoretically, accounts of conflict-related sexual violence differ in whether they emphasize event-level triggering or social norms as causal factors. Accounts in which sexual violence is deployed strategically as a response to specific events[24], whether as part of coordinated operations or in retaliation against rival groups, would be more consistent with event-to-event contagion. By contrast, 'practice' account[25] and socialization framework[26], in which sexual violence is tolerated or condoned within armed groups for non-strategic reasons, would predict that rates are sustained by group-level conditions rather than primarily triggered by prior events. Our findings suggest that the latter account is more consistent with the data from the Colombian armed conflict. Across both periods, attenuation of temporal contagion after adjustment for background rate indicates that temporal clustering is largely explained by structural factors rather than prior events triggering subsequent ones. However, comparison between time periods suggests that event-level effects have become weaker still in the 2014–2024 period, consistent with violence persisting as a normalized group-level practice rather than as deployed in pursuit of specific objectives.

Geographic clusters of armed-conflict-related sexual violence indicate priority areas for provision of services for victims. Clinical response to sexual violence requires emergency and post-acute care[27] as well as long-term support services[28,29]. Barriers relating to stigma, fear and health service preparedness may also delay service engagement[30], and we note that initiatives to promote access to existing services are themselves likely to lead to increase in the number of successfully supported victims. The geographic clustering of sexual violence covers large cities, where health services are concentrated in Colombia, as well as rural areas and small towns, including those where control is disputed between armed actors and health services may be limited. This makes the equitable provision of healthcare a significant challenge due to problems with access, resources and active interference by armed groups that particularly affect services related to women's health and sexual violence[31,32]. Consequently, while specialist sexual violence pathways may be feasible in areas of high concentration of health services, better integration of sexual violence treatment and support pathways in primary and community care may be an alternative option for rural areas[33].

Colombia's national PAPSIVI programme (an acronym from its Spanish language title *Programa de Atención Psicosocial y Salud Integral a Víctimas*, in English 'Psychosocial Care and Comprehensive Health Program for Victims') provides healthcare and psychosocial support to victims of the armed conflict nationally. Analysis of service data indicates it successfully provides priority access with appropriate support provision to victims of the conflict registered as experiencing sexual violence[34,35], although clinical and social outcomes, and the extent to which victims of sexual violence who have not registered as such are being successfully supported, are currently unknown.

By comparing Hawkes process models with and without baseline adjustment, we identified that temporal contagion is largely driven by slower-moving trends in sexual violence probably driven by structural

factors associated with broader conflict dynamics, rather than short-term event-to-event contagion more associated with incident-specific characteristics. Immediate intervention to prevent further incidents of sexual violence may be practical in some situations. However, these results suggest that depending solely on a policy of reactive intervention is unlikely to be the most successful strategy for prevention of armed-conflict-related sexual violence in the Colombian context because the temporal window for preventing local contagion effects may be very small—estimated at below 1 day in our study. To address these, social and structural interventions focused on prevention may be more appropriate. Indeed, interventions to reduce sexual violence by armed groups in conflict settings have focused on exactly these processes—including reducing potential victims' exposure to situations that would allow opportunistic violence, increasing women's autonomy and reducing economic dependence, reducing impunity and the perception of impunity through improved legal accountability, while deploying public campaigns aimed at increasing awareness and reducing acceptance of sexual violence[36]. More recent initiatives have developed and deployed specific behaviour change interventions for both state and non-state armed actors aimed at reducing the perpetration of armed conflict-related sexual violence[37], including in Colombia[38], although the effectiveness of these interventions has yet to be determined.

We note some limitations of this study. With regard to the demographic data, the profile of victims is relatively consistent across data sources, with some notable differences. Victims in the national RUV were older than victims in the NCHM database. This is probably due to the fact that, while the NCHM database records specific events, the national RUV is a record of victims' registrations, who may register several years after experiencing sexual violence. There is a higher proportion of victims from minority ethnic groups in the RUV, potentially reflecting its sole reliance on self-registration rather than a third-party reports, the latter of which may be more limited in areas with large populations of primarily Indigenous and Afrocolombian populations.

We also note that the diversity of sexual violence is not well accounted for by the single coding of 'sexual violence' used in this study. Sexual violence may variously include rape, forced prostitution, sexual slavery, forced abortion, forced nudity or sexual assault, to name but a few relevant criminal acts[39], and it is likely there may be different geographical spread and dynamics that depend on the specifics of these acts.

In addition, conflict-related sexual violence is probably underreported and underdetected, with good evidence that this is the case in Colombia[40]. Nevertheless, different national data sources, including crime statistics, armed conflict victim registrations and multisource identification, tend to show similar relative changes in incidence in sexual violence that track changes in the intensity of the conflict indicating they may be sampling a similar population[19]. Nonetheless, the extent to which there are specific groups who are more likely to have incidents of sexual violence remain unrecorded is not yet fully understood. Indeed, we note that individuals living in areas of active conflict[41], displaced women[10], sexual and gender minorities[42], and people from minority ethnic groups[43] have been identified as facing particular structural barriers in reporting sexual violence and accessing care.

However, there is not a simple relationship between underreporting and underrecognition in the geospatial models reported in this study. LGCP modelling can identify areas of likely high prevalence despite low raw counts through inferences from spatial clustering and population density, so mapped patterns should be read as estimates of inferred risk rather than a complete representation of all victimization. Nevertheless, selective underrecognition may occur where barriers to reporting are unevenly geographically distributed in a way that is not accounted for differences in population density, for example, where populations of similar densities and similar underlying exposure to sexual violence show different levels of reporting due to differences in stigma, chance of reprisals or accessibility of services. Although differences in reported and inferred prevalence may indicate areas at higher risk of undetected sexual violence, underreporting is a widely recognized feature of sexual violence and addressing this challenge requires dedicated initiatives. Although this issue remains understudied in Colombia, evidence from a range of conflicts suggests that sexual violence reporting and detection may be improved by destigmatising victims; reducing risks faced by survivors; strengthening trust in institutions; ensuring the availability of multiple, accessible reporting and detection pathways; systematically curating data; guaranteeing that reports lead to meaningful responses; and implementing gender- and culture-sensitive services[44–47], and these are probably important initiatives to apply in Colombia.

In conclusion, the trajectory of sexual violence in the Colombian armed conflict reflects a shift from geographically concentrated, high-intensity incidents towards more diffuse patterns, with clear areas of high historical prevalence where victim support remains essential. The temporal dynamics of sexual violence suggest that interventions that proactively address structural and long-term contextual determinants may be an important component of prevention.

Methods

The project received ethical approval from both the Ethics Committee of the Fundación Santa Fe de Bogotá in Colombia (ID CCEI-15951-2023) and the University College London Research Ethics Committee in the United Kingdom (project ID: 8275/002).

Data sources

We used two data sources to profile victims of sexual violence in the Colombian armed conflict. We describe each of these data sources below.

National RUV of the Colombian armed conflict. The RUV was established in 1985 and records individuals affected by the armed conflict, serving as a prerequisite for accessing state-provided reparations. Enrolment in this registry occurs at designated offices, such as municipal authorities or the national Victims' Unit. As part of the registration process, individuals undergo an interview detailing the circumstances and nature of the victimizing events, and may be required to submit additional evidence. Under the legal framework, victims are defined as those who have experienced harm directly, or as immediate family members (including parents, children or siblings) of those affected. Location is recorded in terms of municipality, the smallest administrative division of Colombia of which there are 1,104 in the country. Victims of sexual violence are eligible to register within a 3-year period following the occurrence of the event. In 2024, legislation was passed acknowledging the unique barriers to reporting sexual violence, including a grace period extending until 2026 for victims whose prior registration attempts were denied solely due to the expiration of earlier statutory deadlines. This dataset was provided under agreement with the Colombian government and is not publicly available.

NCHM database of violent events of the internal armed conflict in Colombia. The NCHM is a statutory institution in Colombia responsible for recording experiences of the victims of the armed conflict and was created as part of the country's transitional justice efforts. It maintains a database of violent victimization that occurs as part of the armed conflict and gathers and cross-references data from several sources, including government records (for example, legal rulings and military reports), non-governmental organization reporting, truth commissions, testimonies from victims and communities, media reports and academic studies. Events are timestamped and geolocated with latitude and longitude. The database is open licensed and publicly available online.

Exposure

Exposure to sexual violence is coded specifically in both databases, and this was used as the exposure variable. For the RUV, sexual violence is defined in the Victims Unit assessment criteria[48] as "Crimes against sexual freedom and integrity" and is defined as any act that violates the dignity, freedom or sexual integrity of a person through the use of physical, psychological or moral force that imposes a sexual behaviour against their will. The NCHM database does not itself have a specific definition of sexual violence, although the NCHM define sexual violence as "Any act of a sexual nature imposed through the use of force, coercion, psychological oppression, abuse of power, or fear of violence"[49].

Statistical analysis

For RUV data, analysis was completed using R version 4.5.0[50] on a Windows secure analysis platform. For the NCHM data, analysis was conducted with R version 4.5.0 on a Linux x86 platform. Analysis code and output is available as Jupyter notebooks via GitHub at https://github.com/ElisavetPappa/col-conflict-sv. All maps were created using the public domain data in the rnaturalearthdata R package[51].

Summary statistics were calculated to describe the sample, identify the profile of victims and understand co-occurrence with other types of exposure to the armed conflict. We also used two approaches to identify geospatial and temporal clustering of sexual violence events for the entire armed conflict (1964–2024) and, more recently, 2014–2024.

Latent geospatial structure of conflict-related sexual violence. Due to the inclusion of timestamps and geographic coordinates for victimization events, we used the NCHM database to analyse the underlying geospatial structure of reported sexual violence incidents using LGCP models[52]. LGCP models estimate spatial variation in event intensity by accounting for latent factors that influence risk patterns not directly observable in the data but detectable through spatial clustering beyond what would occur by random chance. Using the stelfi package[53], we fitted LGCP models. The LGCP model estimates three key parameters: the baseline log-intensity (LGCP β), representing the overall mean spatial intensity on the log scale; the spatial range, which indicates the distance over which the latent field exhibits strong spatial correlation (with smaller values suggesting tighter, more localized clustering); and the latent field standard deviation, quantifying the magnitude of unexplained spatial variation after accounting for covariates. Together, these parameters characterize both the overall intensity and the geographic structure of clustering. To account for population density, we rasterized back-projected census data (population divided by area) from the Colombian National Population and Housing Census available from the ColOpenData package[54] and extracted log-transformed values at mesh nodes. We compared this with a model that did not control for population density to assess the extent to which population density contributes to event clustering. The resulting intensity surfaces and latent fields were then projected to identify and visualize geographic clusters with elevated risk for sexual violence.

Temporal contagion of sexual violence events. To investigate whether sexual violence events increase the probability of further sexual violence, we used the NCHM database and Hawkes process modelling to test for temporal contagion (also known as event dependence or self-excitation) using Hawkes process models via the stelfi package[53]. We added one day of random jitter to event times, which is necessary in Hawkes process models to prevent events recorded with the same time from artificially inflating contagion estimates, but means that any contagion estimate of less than one day falls below the effective temporal resolution of the analysis. Parameters were estimated via maximum likelihood. The Hawkes process models estimated a baseline intensity (μ), an excitation parameter (α) and a decay rate (Hawkes β). We also calculated the branching ratio (α/Hawkes β) to quantify the proportion of events expected to trigger additional events, reflecting the degree of event dependence in the process[55]. A value approaching 1 indicates a near-critical, self-reinforcing system, in which each event is likely to lead to subsequent events. To understand to what extent temporal contagion was accounted for by changes in background rate, we compared the unadjusted model with a model adjusted with a non-homogeneous background rate function created by fitting splines to the incidence rate.

Model validation. We completed model validation steps on both LGCP and Hawkes process models. To assess whether the LGCP adequately captured clustering of sexual violence events, we conducted simulation-based validation. To check that clusters were not artefactual interpretation of noise, we compared the observed pattern with spatial randomness using Ripley's K-function. In addition, we simulated 1,000 point patterns from the fitted model and performed two posterior predictive checks. First, we compared the distribution of total event counts across simulations to the observed count, to assess the extent to which the model reproduced the overall event frequency. Second, we computed spatial density estimates for the observed and simulated patterns, calculated means and 95% CIs of the simulated densities, and compared these with the observed spatial density surface to assess whether observed local events densities were consistent with the model's posterior predictive uncertainty or reflected systematic under- or overestimation of spatial clustering. Third, we tested the sensitivity of the results to courser and finer mesh specifications. To assess the adequacy of the fitted Hawkes process models, we performed a posterior predictive check to assess whether the model reproduced timing patterns seen in the observed data. For each model, we simulated 1,000 datasets using the model parameters over the observed time window. We then compared the observed mean interevent time with the distribution of simulated means to check that the observed value fell within the central 95% of the simulated distribution, indicating that the fitted model adequately reproduces the temporal spacing of events. We also assessed sensitivity to spline specification by refitting the non-homogeneous background rate Hawkes model using splines with alternative smoothing parameters set below and above the cross-validation selected optimum used in the main analysis.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

We used two data sources in this study. The National Register of Victims of the Colombian Armed Conflict was provided under agreement with the Colombian government and is not publicly available. The National Centre for Historical Memory dataset is open data and available at https://micrositios.centrodememoriahistorica.gov.co/observatorio/portal-de-datos/base-de-datos/. The full dataset we used in this study is available via GitHub at https://github.com/ElisavetPappa/col-conflict-sv.

Code availability

The code used for data selection, processing and analysis is available via GitHub at https://github.com/ElisavetPappa/col-conflict-sv.

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Author contributions

E.P.: conceptualization, methodology, software, validation, formal analysis, visualization, interpretation, data curation, writing—original draft and writing—review and editing. A.A.-O.: conceptualization, interpretation, writing—review and editing and project administration. C.C.F.: software, formal analysis, interpretation and writing—review and editing. M.C.G.D.: conceptualization, interpretation, writing—review and editing and project administration. C.M.J.T.: methodology, software, validation, formal analysis, visualization, interpretation and writing—review and editing. R.S.: conceptualization, interpretation, writing—review and editing, project administration and funding acquisition. F.S.: conceptualization, interpretation, writing—review and editing, project administration and funding acquisition. W.T.-A.: conceptualization, interpretation, writing—review and editing and project administration. F.I.: conceptualization, interpretation, writing—review and editing, supervision, project administration and funding acquisition. V.B.: conceptualization, methodology, software, validation, formal analysis, data curation, visualization, interpretation, writing—original draft, writing—review and editing, supervision, project administration and funding acquisition.

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Competing interests

The authors declare no competing interests.

Additional information

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Extended Data Table 1 | Parameter estimates for Log-Gaussian Cox Process (LGCP) model of sexual violence events in Colombia adjusted and unadjusted for population density

Parameter	Adjusted for population density				Unadjusted for population density			
	1964-2024		2014-2024		1964-2024		2014-2024	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
B_0 (intercept)	2.032	0.369	0.551	0.385	2.580	0.600	1.171	0.570
B_1 (covariate)	0.530	0.088	0.458	0.082	-2.279	0.085	-2.097	0.101
log τ	-2.334	0.121	-2.170	0.134	0.170	0.125	0.114	0.147
log κ	0.490	0.161	0.415	0.177	2.385	0.297	2.523	0.371
Range	1.733	0.278	1.868	0.331	2.323	0.215	2.523	0.371
Standard deviation	1.783	0.152	1.632	0.159	16253.06	–	2530.72	–
Expected no. of events	16251.87	–	2529.286	–	2.580	0.600	1.171	0.570

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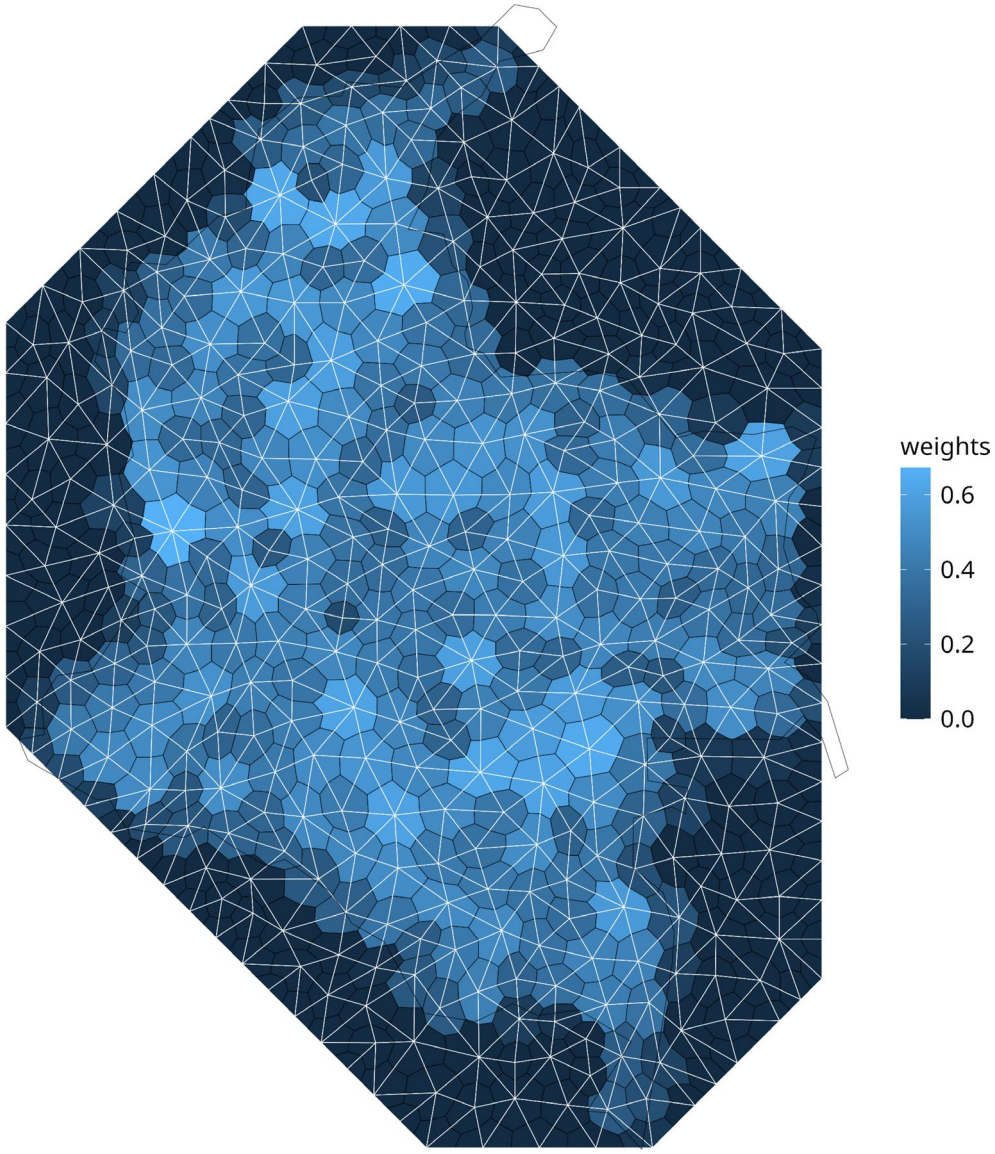

Extended Data Fig. 1 | Mesh-based integration weights for log-Gaussian Cox process models. Integration weights, derived from the mesh, underlying the log-Gaussian Cox process models fitted to Colombia.

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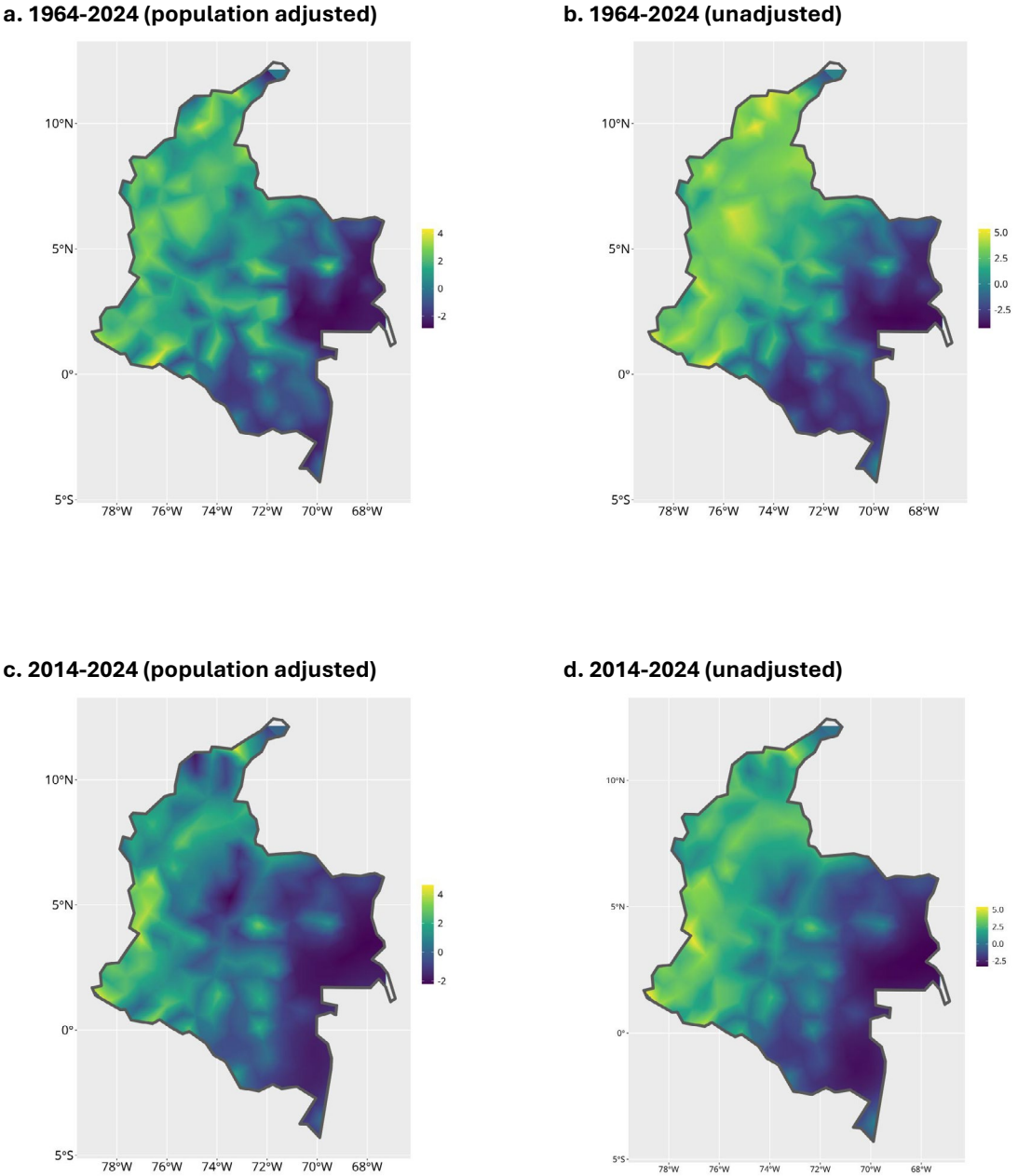

Extended Data Fig. 2 | Spatial projection of the latent Gaussian Markov random field (GMRF) from the fitted log-Gaussian Cox process model of sexual violence events. For **a)** 1964–2024 (population density adjusted), **b**) 1964–2024 (unadjusted for population density), **c)** 2014–2024 (population density adjusted) and **d)** 2014–2024 (unadjusted for population density).

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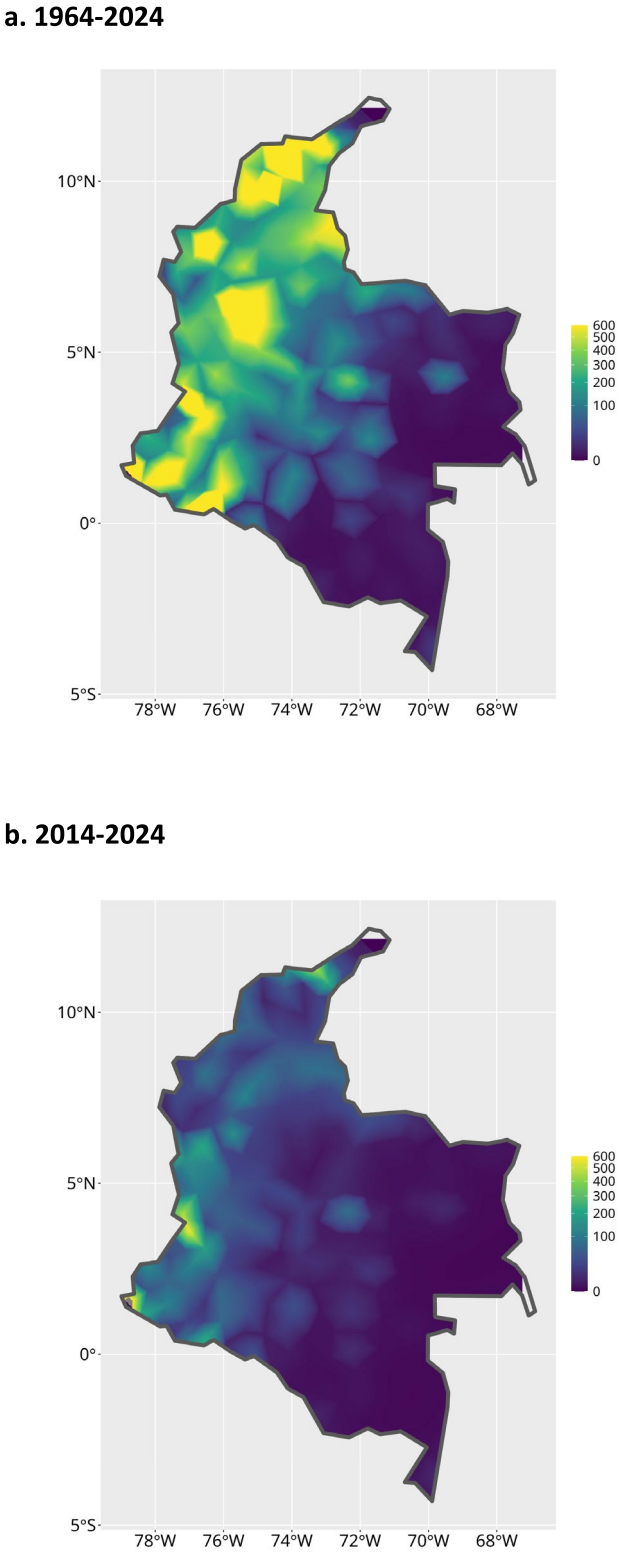

Extended Data Fig. 3 | Log-Gaussian Cox process intensity plots without adjustment for population density. For: **a)** entire duration of the conflict (1964–2024) **b)** 2014–2024.

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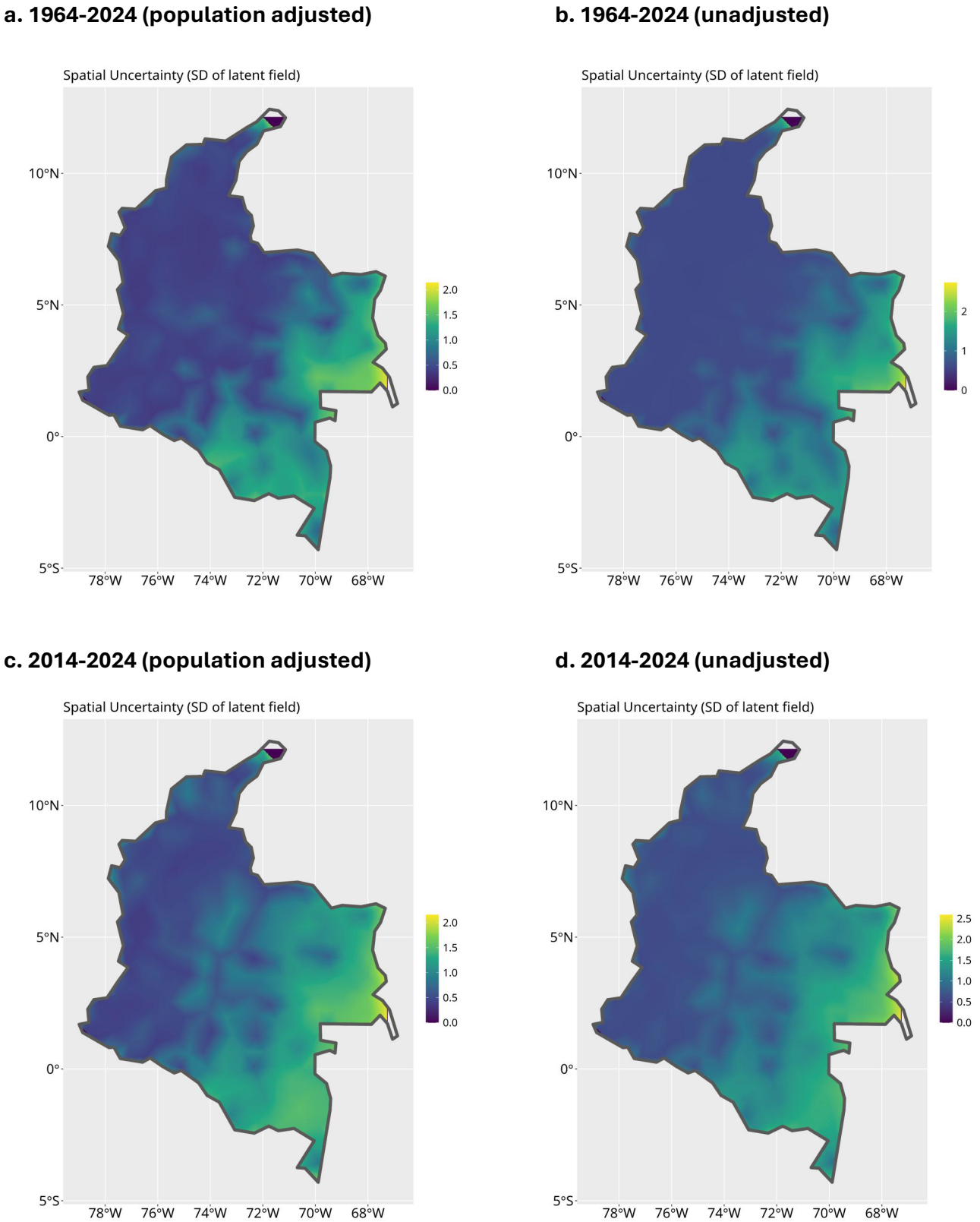

Extended Data Fig. 4 | Spatial uncertainty plots showing standard deviation of latent field. For **a)** 1964–2024 (population density adjusted), **b)** 1964–2024 (unadjusted for population density), **c)** 2014–2024 (population density adjusted) and **d)** 2014–2024 (unadjusted for population density).

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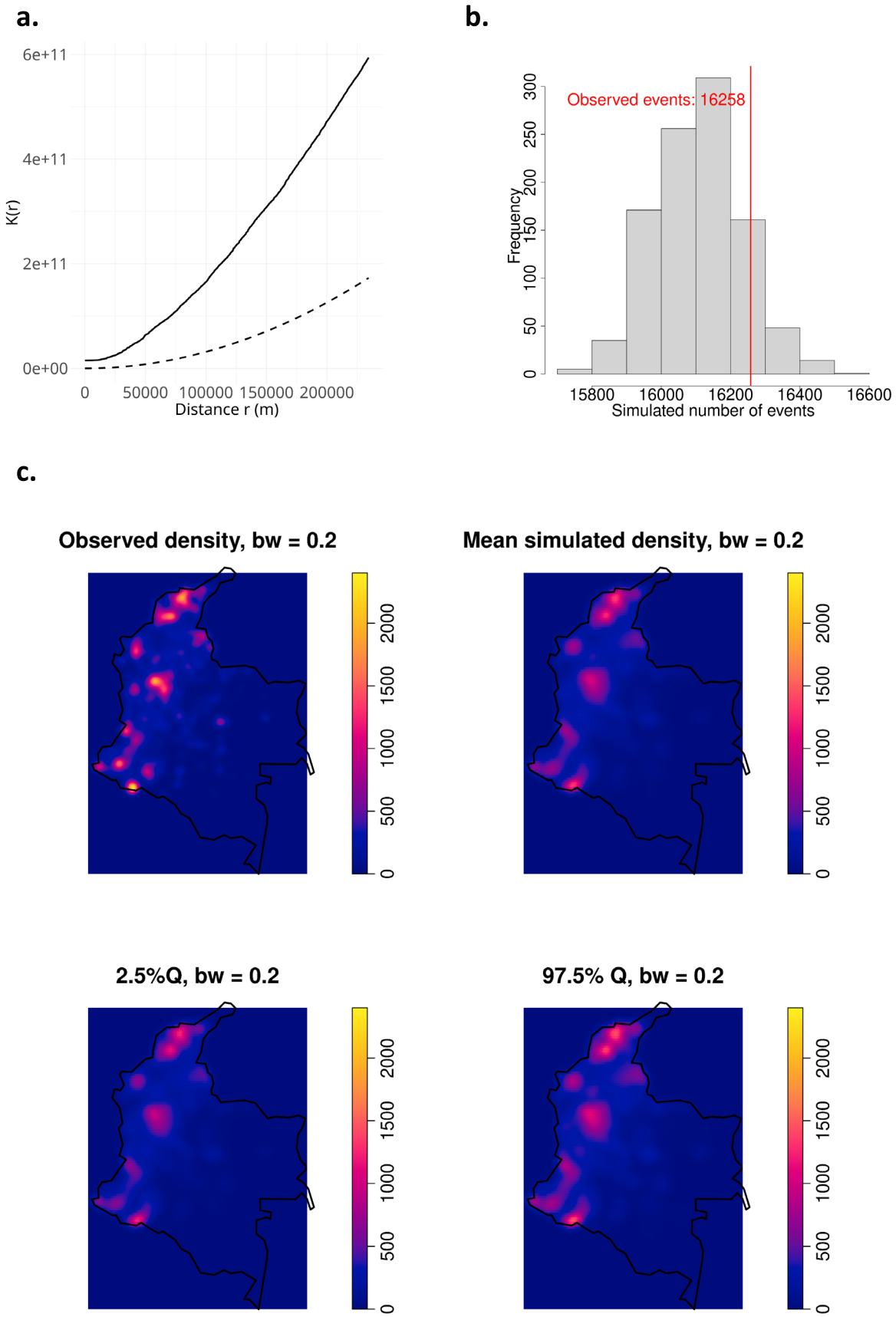

Extended Data Fig. 5 | Validation test results for 1964–2024 population adjusted data. The figures show **a)** Ripley's K-function; **b)** simulated vs observed number of events; **c)** mean and 95% CIs of simulated datasets from intensity surface in comparison to observed density.

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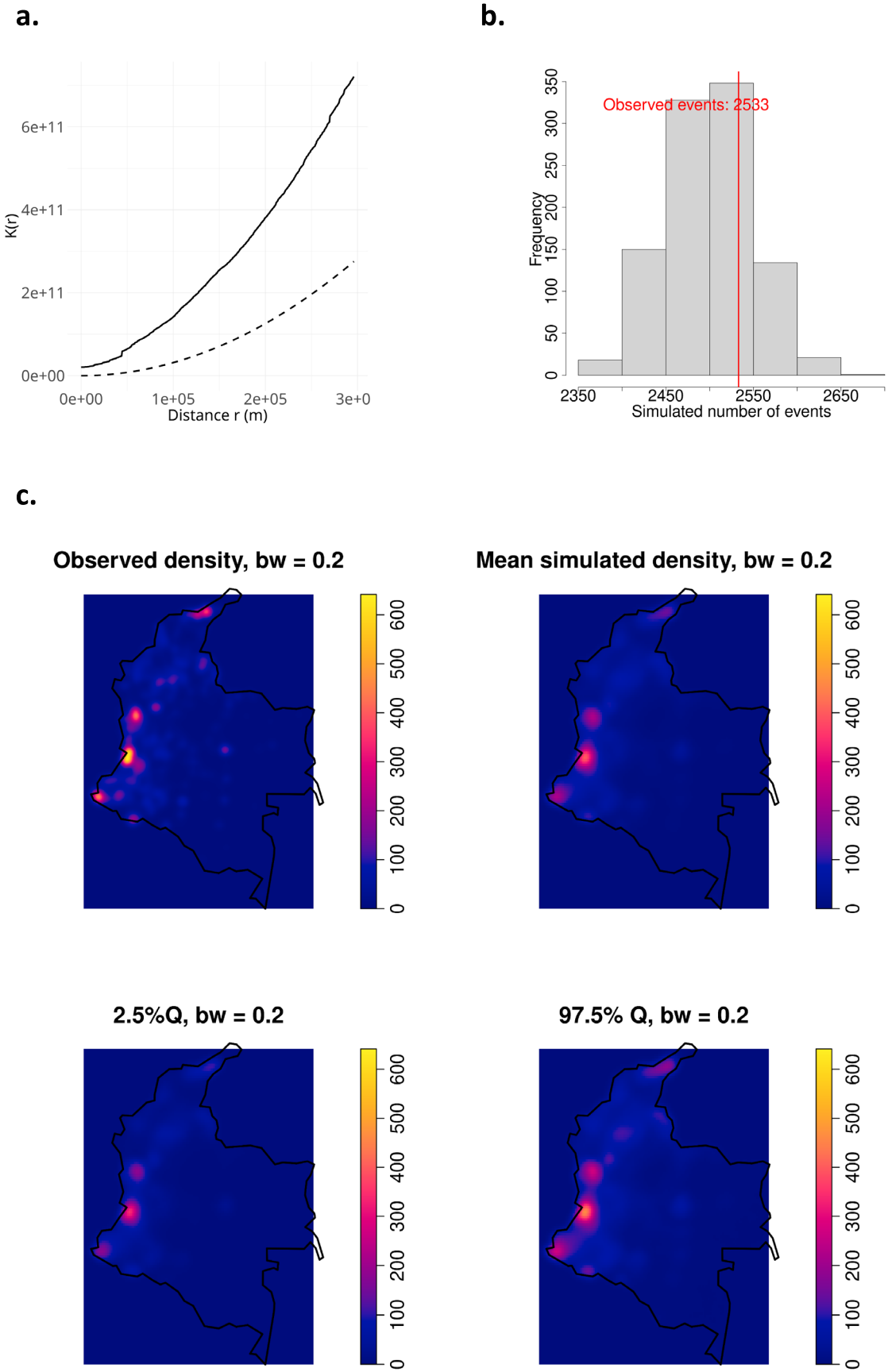

Extended Data Fig. 6 | Validation test results for 2014–2024 population adjusted data. The figures show **a)** Ripley's K-function; **b)** simulated vs observed number of events; **c)** mean and 95% CIs of simulated datasets from intensity surface in comparison to observed density.

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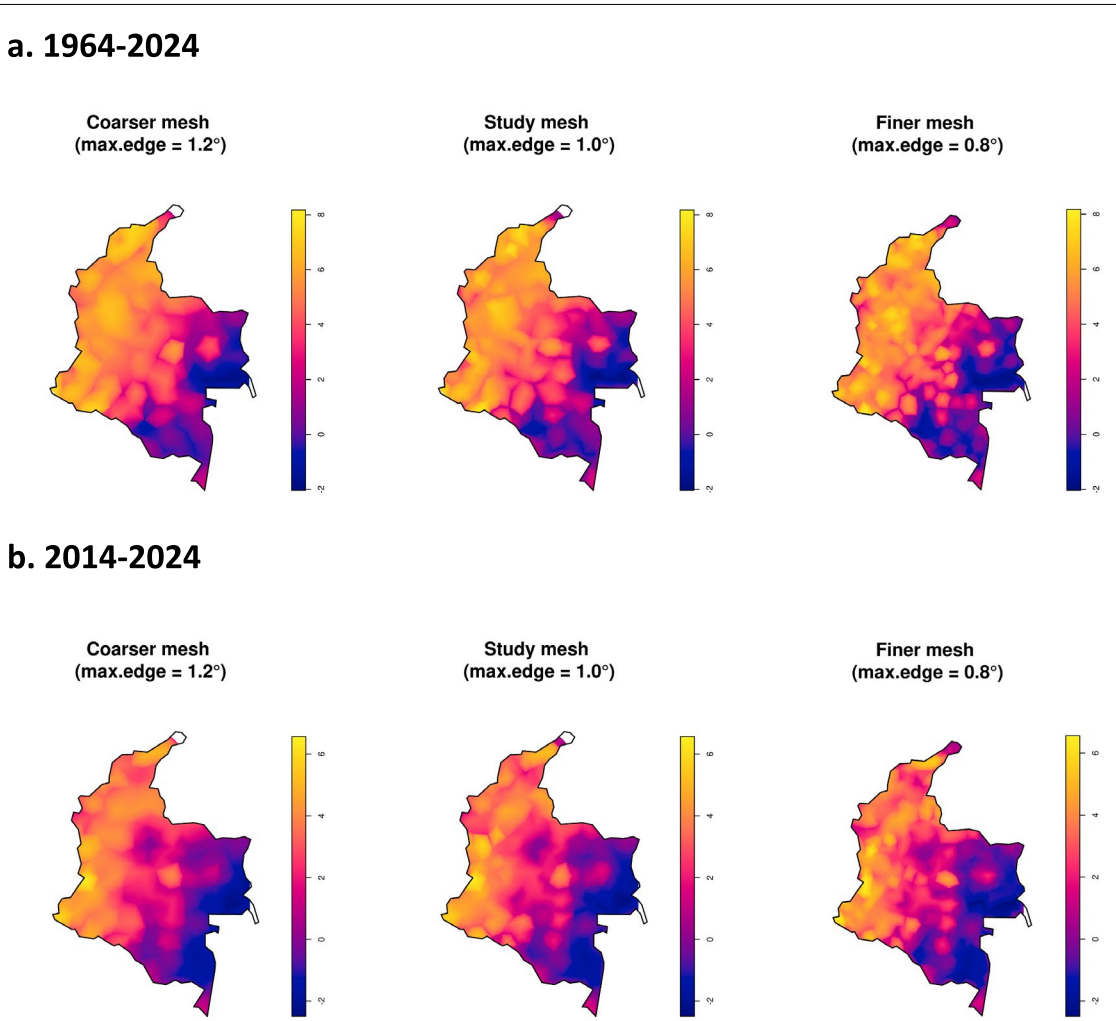

Extended Data Fig. 7 | Sensitivity analysis of LGCP models using coarser and finer mesh size alternatives. Data for **a)** 1964–2024 and **b)** 2014–2024. Intensity is displayed on a matching log scale across plots within the same period to facilitate comparison.

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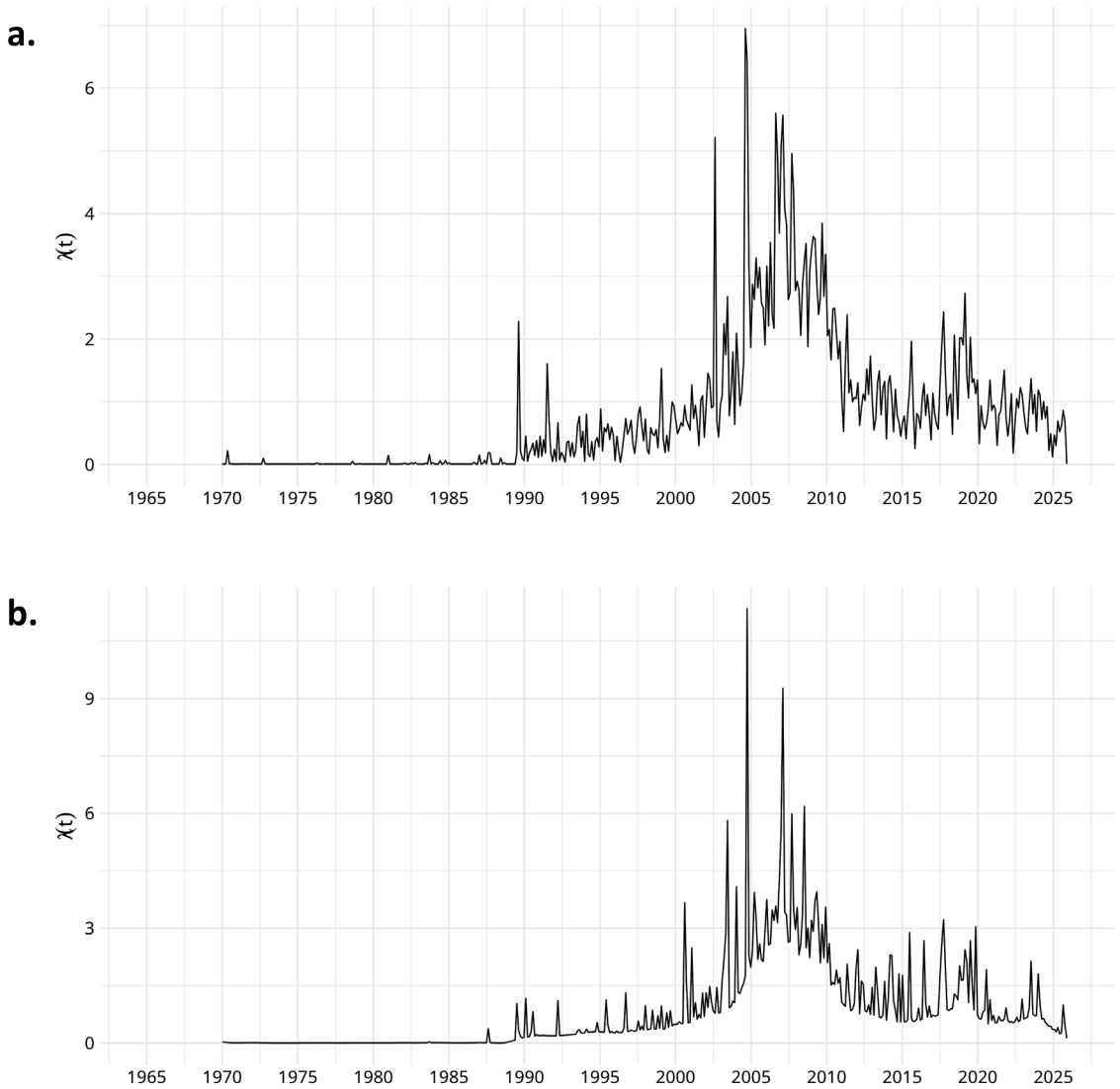

Extended Data Fig. 8 | Hawkes process models of sexual violence events in the Colombian armed conflict for 1964–2024. With **a)** constant baseline **b)** adjusted for base rate.

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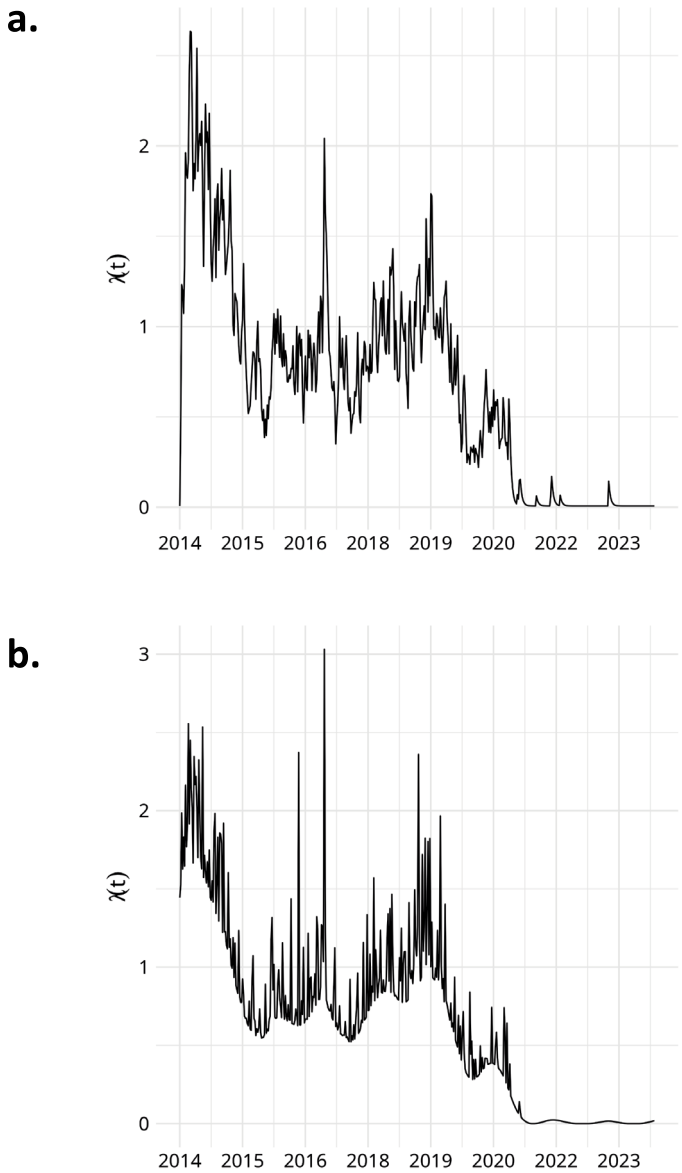

Extended Data Fig. 9 | Hawkes process models of sexual violence events in the Colombian armed conflict from 2014–2024. With **a)** constant baseline **b)** adjusted for base rate.

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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	n/a
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Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

We used two data sources in this study. National Register of Victims of the Colombian Armed Conflict was provided under agreement with the Colombian government and is not publicly available. The National Centre for Historical Memory dataset is open data and the full dataset we used is available on the open GithHub archive: https://github.com/ElisavetPappa/col-conflict-sv

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	We identify the proportion of victims of sexual violence based on pre-exisiting categories in the data. These were male / female / other in the National Victims Register and male / female in the National Centre for Historical Memory database.
Reporting on race, ethnicity, or other socially relevant groupings	We used the ethnicity categories already coded within the datasets used in this study which are ethnicity categories used by the Colombian census.
Population characteristics	These are reported in Table 1 of the manuscript.
Recruitment	This study is a secondary analysis of existing datasets and so no direct recruitment was completed.
Ethics oversight	The project received ethical approval from both the Ethics Committee of the Fundación Santa Fe de Bogotá in Colombia (ID CCEI-15951-2023) and the University College London Research Ethics Committee in the United Kingdom (Project ID: 8275/002).

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Quantitative secondary data analysis.
Research sample	Sexual violence victims of the Colombian armed conflict
Sampling strategy	All victims of the Colombian armed conflict who reported sexual violence as included in National Register of Victims of the Colombian Armed Conflict and the National Centre for Historical Memory (NCMH) Database of Violent Events of the Internal Armed Conflict in Colombia
Data collection	This was a secondary data analysis of existing data, so we did not directly collect any data. For the National Victims Register, victims apply and as part of the registration process, individuals undergo an interview detailing the circumstances, and nature of the victimising events, and may be required to submit additional evidence. The NCMH database gathers and cross-references victimisation events from several sources, including government records (e.g. legal rulings, military reports), non-governmental organisation reporting, truth commissions, testimonies from victims and communities, media reports, and academic studies
Timing	1964-2024
Data exclusions	The two databases we used include all victims of the Colombian armed conflict. This study only focused on sexual violence. Of the victims of sexual violence, no data were excluded
Non-participation	Not participation based data so not applicable
Randomization	Not applicable

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks	n/a
Novel plant genotypes	n/a
Authentication	n/a