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RESEARCH ARTICLE

Understanding local expert perceptions of climate security hotspots using participatory mapping

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Data availability statement: The climate security hotspots used in this study are available from the Climate Security Observatory online tool (https://cso.cgiar.org/#/Information/Kenya). Data can be accessed by selecting the "Where" tab and choosing General Hotspot

Abstract

The enactment of climate security actions in Kenya requires tools to support locally targeted climate-resilient interventions. This study developed a participatory mapping framework to integrate local expert perceptions of climate security (CS) hotspots—areas with overlapping socio-economic vulnerabilities, governance challenges, conflict and climate-sensitive livelihoods—in Laikipia, Isiolo, West Pokot, Samburu, Turkana, Garissa, Wajir, Marsabit, Mandera, Tana River and Lamu counties and initiate discussions towards locally led resilient climate security solutions. The framework involved five consensus-based Focus Group Discussions (FGDs) conducted in a three-day workshop using printed and interactive CS hotspot maps derived from spatial analysis of global climate and conflict data. Out of 80 sampled hotspots, 45% of the experts agreed with their classification, 38.75% agreed with either classification of climate conditions or conflict intensity while 16.25% disagreed with both categorisation of climate and conflict. Classification of conflict was more contested than climate. Experts also identified 19 additional CS hotspots, revealing gaps in global datasets and the importance of contextual knowledge. The study demonstrates that participatory mapping provides complementary insights that can augment top-down climate security assessments while exposing locally relevant adaptation strategies. These findings support CS actions within Kenya's National Climate Change Action Plan emphasising the value of community-driven and spatially informed climate resilience approaches.

1. Introduction

Climate change is increasingly undermining human security (economic, food, health, environmental, personal, community and political security), especially in agrarian

Mapping. The data is available under CC-BY-NC 4.0 license. Newly mapped hotspots data is available in S5 Text.

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and pastoral regions [1–4], acting as a significant driver of fragility in Northern Kenya [5]. Climatic hazards interact with socio-economic and political vulnerabilities, giving rise to a complex climate-security nexus (a vicious circle between climate hazards, conflict and overall human security) that influences the emergence and intensity of conflict [1,6]. In this study, climate security refers to risks to human security and community stability induced — indirectly — by changes in climate patterns and their interactions with environmental, socio-economic and other context-specific factors, which usually act as root causes of conflict [4,6]. In Kenya's Arid and Semi-Arid Lands (ASALs), climate-induced hazards aggravate competition over water and pasture, heighten tensions between pastoralists and farmers and contribute to cross-border disputes [5,7]. Intensifying heatwaves, changing gender dynamics due to livelihood loss and the evolution of cattle rustling into organised violence further compound these risks [8–10]. Consequently, climate hazards not only amplify existing peace and security challenges but also increase the vulnerability of communities already exposed to instability [11].

Despite its growth, the climate–security literature faces important conceptual and methodological critiques. Deterministic framings that link climate change directly to violence or portray it narrowly as a "threat multiplier" often overlook complex socio-political mediators and risk misidentifying conflict drivers [2,12]. Securitisation is another concern: treating climate primarily as a security issue may encourage militarised, top-down responses, marginalise vulnerable groups, stigmatise migrants and expand early-warning systems in ways that have contributed to human rights abuses and public resentment [13,14]. Furthermore, much of this research privileges violent outcomes—what Barnett [15] calls "dystopian imaginaries"—while under-examining pathways of cooperation and resilience, even though climate-related contention can also strengthen collective action, contest power imbalances, and trigger governance reforms [16,17].

Recent studies have begun to address these gaps by emphasising context-sensitive approaches. Evidence shows that climate stress interacts with underlying fragilities, leading to instability rather than acting as an independent driver of conflict [3,18]. In this study, *fragility* refers to weak institutional capacity, low levels of development, inequality and histories of violence that amplify the impacts of climate stress, whereas *instability* denotes the heightened uncertainty and volatility that emerges when such vulnerabilities interact with climatic hazards. This framing highlights the need to examine institutional and societal responses across a continuum of conflict and cooperation, including in fragile and violence-affected settings [4]. Critical perspectives further underline that climate policies themselves can generate new risks [19] while inclusive governance, representation and institutional strength are key mediating factors [20]. Yet empirical research on how these dynamics are experienced and acted upon at the local scale remains limited—particularly in African ASALs.

In the wake of these advances, there is a need to invest in approaches that can champion locally driven climate resilient solutions to address the intersecting challenges of climate change and security. While most policy frameworks seek to protect vulnerable populations by minimising exposure to risks and providing information for planning and stimulating adaptation [21], their implementation often lacks sufficient localisation. Calls for stronger involvement of actors in the global South in priority setting, conceptualisation, risk analysis and intervention design are gaining traction [22,23]. These calls are reinforced by evidence that most African countries still lack robust indicators to operationalise adaptation tracking [24]. To support evidence-based policymaking, it is essential to generate timely, nuanced and context-specific information that captures the complexity of climate-security linkages.

Spatial mapping has emerged as one promising approach, offering the ability to visualise both spatial and temporal variations of climate-related risks and vulnerabilities. Recent works demonstrate that combining top-down, data-driven modelling with bottom-up, stakeholder-led mapping is essential for producing climate–security assessments that are both empirically rigorous and locally legitimate. Integrated frameworks are increasingly employed to co-produce spatial intelligence, combining aggregated hotspot or exposure modelling with fine-scale, place-based knowledge to prioritise adaptation and security-sensitive interventions. For example, UNDP and the Life & Peace Institute mapped climate–security adaptations in the Horn of Africa, simultaneously identifying risks and grounding solutions [6]. Evidence from Tanzania shows that projects designed with bottom-up input deliver higher adaptive capacity compared to purely top-down programmes [25]. Participatory mapping—often operationalised through Participatory Geographic Information Systems (PGIS)—enables local experts and stakeholders to contribute nuanced information, such as undocumented conflicts, typically missing from earth observation or modelled data. This enhances both inclusiveness and policy uptake of the resulting hotspot products [26]. Recent practice-oriented initiatives [27] highlight that participatory approaches are increasingly being adopted in policy and programmatic settings, reinforcing their relevance for climate–security planning.

Meanwhile, efforts to develop tools to map the spatial-temporal distribution of climate security hotspots (Climate security hotspots refer to places experiencing compounding risks of socio-economic vulnerabilities, governance challenges, conflict and high levels of climate-sensitive livelihoods.) is slow [4,28–31]. Most tools are limited by data availability, data quality, provide partial explanations of the climate security nexus and to some extent are characterised by insensitivity to local contexts [29]. Moreover, data on small scale conflicts may be biased and miss a significant number of events, especially in remote insecure areas [32]. In addition, there is sparse information on climate change adaptation or mitigation efforts and local conflict/resource management institutions [29,30] which have been shown to impact conflict dynamics [33,34]. Therefore, most of these climate security assessments and mapping efforts remain top-down and expert-driven, often overlooking local perspectives and spatially differentiated risks. This gap is particularly evident in Kenya, where the concept of climate security is still underexplored at the local level.

Our study contributes to the growing body of literature advocating for bottom-up approaches to climate security by proposing participatory mapping as a methodological tool to enhance both the understanding of, and engagement with, local climate security dynamics. By integrating local perceptions and knowledge into spatial analyses, the approach complements conventional climate security frameworks. Building on pre-identified climate–security hotspots from global datasets [35,36], the approach situates these areas within their local contexts to generate more nuanced insights. This not only strengthens methodological debates on the climate–security nexus but also responds to policy priorities by aligning with Article 7(5) of the Paris Agreement and Kenya's National Climate Change Action Plan (NCCAP) III [37], both of which emphasise transparent, locally grounded and scientifically informed adaptation strategies. Specifically, the study seeks to validate global climate–security hotspot models against local expert perceptions, unpack community perceptions, reveal spatially differentiated dynamics that conventional mapping methods can miss and champion context-specific resilience solutions essential for inclusive climate action.

2. Materials and methods

2.1. Materials—study area

The study focused on 11 counties located within Kenya's ASALs namely: Laikipia, Isiolo, West Pokot, Samburu, Turkana, Garissa, Wajir, Marsabit, Mandera, Tana River and Lamu (Fig 1). Two of the 11 counties, namely Lamu and West Pokot,

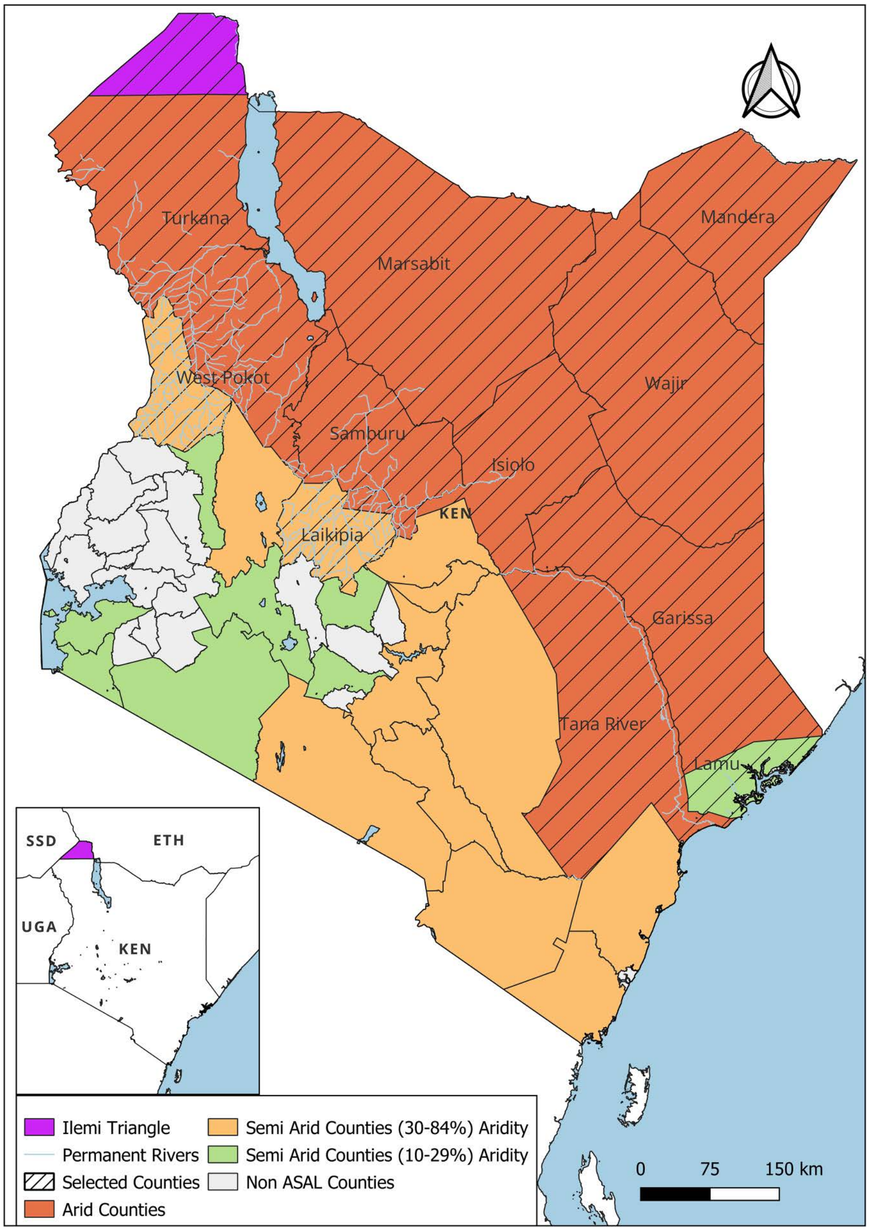

Fig 1. Study area covering Laikipia, Isiolo, West Pokot, Samburu, Turkana, Garissa, Wajir, Marsabit, Mandera, Tana River and Lamu counties. Disclaimer: The Inset map is not an authority on boundaries, even though effort has been made to use country specific accepted boundaries. The administrative county boundaries vector layer used to generate the map can be found here: https://data.humdata.org/dataset/47-counties-of-kenya under Creative Commons Attribution International (CC BY) license ([38]).

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are semi-arid, while the other nine counties are arid. The 11 arid and semi-arid counties were selected due to protracted historical intersection of climate change impacts and conflict dynamics, which were also captured by our hotspot detection approach. ASALs constitute approximately 80% of Kenya's land area and are home to 36% of the population, with pastoralism serving as the primary livelihood [7]. This is significant because the livestock sector, of which 70% is practised in ASALs, employs 90% of predominantly pastoralist communities and generates 95% of their income [39]. The sector contributes 12% to the national GDP, 40% to the agricultural GDP and 22% to the food system GDP [40]. The ASALs, where most of the counties fall, also have other underutilised resources like tourism, livestock trade, minerals, amongst others.

Climatic and environmental conditions vary in the ASALs with key defining features. Their ecosystems are characterised by low, erratic, variable precipitation (with high spatial-temporal variability) and high inter-annual climatic variability. Temperatures in arid areas are high throughout the year, with occasional heat stress reported, resulting in high rates of evapotranspiration. According to Kenya Meteorological Department [41], arid areas receive approximately 100 mm–600 mm of rain per year, while semi-arid areas receive an average of 600 mm–800 mm annually, with the rains occurring during the long rain season (March to May) and the short season (October to December). A recent study by Lawrence et al. [42] indicates that the arid region expanded by approximately 50,000 km^2 between 1980 and 2020, resulting in the loss of humid, semi-humid and semi-arid areas. Natural resource availability varies across the ASALs. Water sources include a few permanent rivers and seasonal streams that flow only during the wet season and remain dry for the rest of the year. Vegetation varies widely both spatially and seasonally. The lowlands are mostly covered by grass and scrubland. In the slightly wetter semi-arid areas, the natural vegetation is woody savannah. Forests, sustained by mist from the clouds, cover higher elevations such as Mounts Marsabit, Kulal and Huri [43].

2.2. Methods

2.2.1. Ethics statement. This research was conducted in partnership with local expert stakeholders with whom the Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) collaborate within the climate security nexus. The activities involved expert workshops and consultations to validate pre-mapped climate security hotspots derived from globally available Earth observation datasets (as described in S4 Text). No personally identifiable or sensitive information was collected. The workshop was conducted in adherence to CIAT's Research Ethics Policy (PO-06-RE), which requires prior informed consent, voluntary participation, protection of participants' privacy and the right to withdraw at any time. In line with this policy, no Institutional Review Board (IRB) application was required. All participants were fully informed about the purpose of the activity and the intended use of the information gathered through official invitation letters. Participation was entirely voluntary, and informed consent was obtained verbally, and affirmations were recorded. This approach was adopted to safeguard participants' privacy. Participants were free to withdraw at any stage without consequence, and no further human engagements were done beyond the questionnaires in S1 Text and S2 Text. Where applicable, participants were adequately facilitated to attend the workshop.

2.2.2. Participatory mapping framework. Participatory mapping—also referred to as PGIS or Public Participation GIS (PPGIS)—is a community-based approach that involves local people and/or experts in mapping places, thereby transforming spatial knowledge into cartographic and descriptive information [44]. This framework enhances locally led climate action by providing access to GIS data and technology, promoting capacity building and bringing together diverse stakeholders to address context-specific challenges [45]. Such approaches can support the development of tailored participatory mapping tools capable of catalysing locally led and community-based climate actions. The maps generated through participatory processes provide unique visual representations of how communities and experts perceive their surroundings, highlighting both physical and sociocultural features of significance [46]. This visual clarity helps simplify spatial complexity by embedding nuanced local context, thereby enhancing interactivity and facilitating dialogue on potential solutions. Consequently, participatory mapping has been applied widely, including in the integration of indigenous and local knowledge with scientific research for community empowerment [47–49], conservation and natural resource management [44,50–52], rangeland planning and management [53], risk management [54], spatial planning [55], land-use conflict mapping [56] and disaster risk awareness [57,58] - amongst others.

Building on these strengths, this study adopted participatory mapping to explore local perceptions of pre-mapped climate security hotspots and to discuss potential adaptation measures. Fig 2 depicts activities and processes adopted

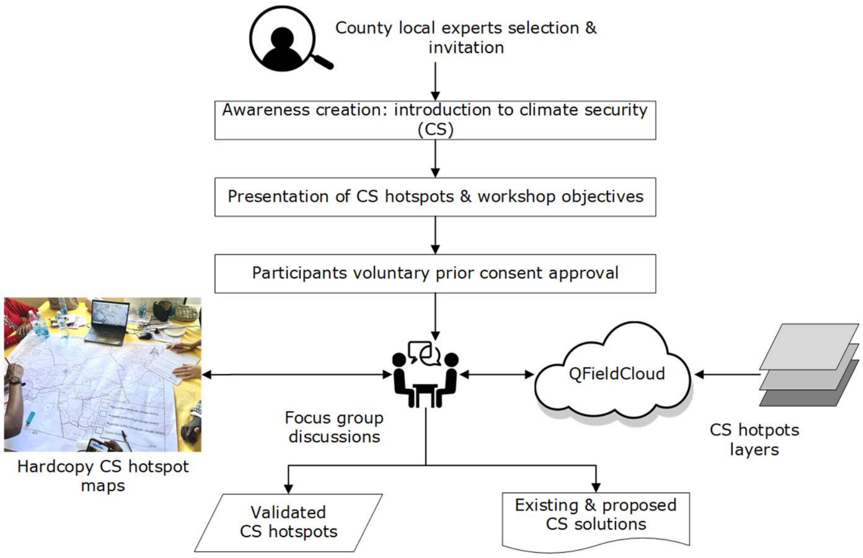

Fig 2. Illustration of the overall participatory mapping process.

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for participatory mapping. A total of 33 experts were invited, of whom 30 confirmed and attended (Fig 3) from the 11 arid and semi-arid counties, following the recommendations of Chalmers and Fabricius [59] who emphasise that local expert knowledge adds value to science compared to randomly selected individuals. Given the study's goal to explore local perceptions of climate security and inform existing policy and programming, the decision to focus on county level experts was deliberate. Since climate security is still an emerging topic in Kenya [37], experts affiliated with departments of climate change and security were invited to the workshop following protocols approved by their respective organisations.

The participants represented a diverse set of institutions and counties: 12 from the Ministry of Interior and National Administration's National Government Administration Officers (NGAOs), 2 from Civil Society Organizations (CSOs), 8 from Non-Governmental Organizations (NGOs), 2 community based organisations with representatives of indigenous peoples and 6 from county departments of environment and climate change. NGAOs are mandated to manage internal security through a devolved structure—ranging from the national level to the village-level '*Nyumba Kumi'* initiative—enabling them to monitor and report daily on conflict dynamics and security issues. The NGOs and CSOs that were invited to the workshop have mandates that include environmental conservation, climate change and peacebuilding, often working closely with communities and indigenous peoples. Our selection ensured that each focus group discussion had a representative from the aforementioned sectors and organisations to provide a comprehensive and localised perspective. This approach accounted not only for thematic expertise but also institutional roles, thereby capturing climate or security policy and implementation dynamics and emerging challenges within ASAL counties.

2.2.3. Expert validation. Validation of pre-identified climate security hotspots was done in a three-day workshop held in May 2024. The workshop kicked off with a session that discussed the climate security nexus. Given that climate security is a relatively new and unfamiliar concept in Kenya, it was important to establish a shared understanding to ensure more informed and relevant discussion outcomes. This entailed a deep dive into key concepts of climate, conflict and security, including examples of pathways through which climate change could increase conflict outcomes. Our scope of conflict was limited to small-scale internal tensions, violence and conflicts, including protests, riots and conflict events with or without fatalities, whose dynamics might be related to the impact of climate on food, land and water systems. These systems both rely on and contribute to ecosystem services that are crucial for sustaining rural livelihoods [4]. Methods and

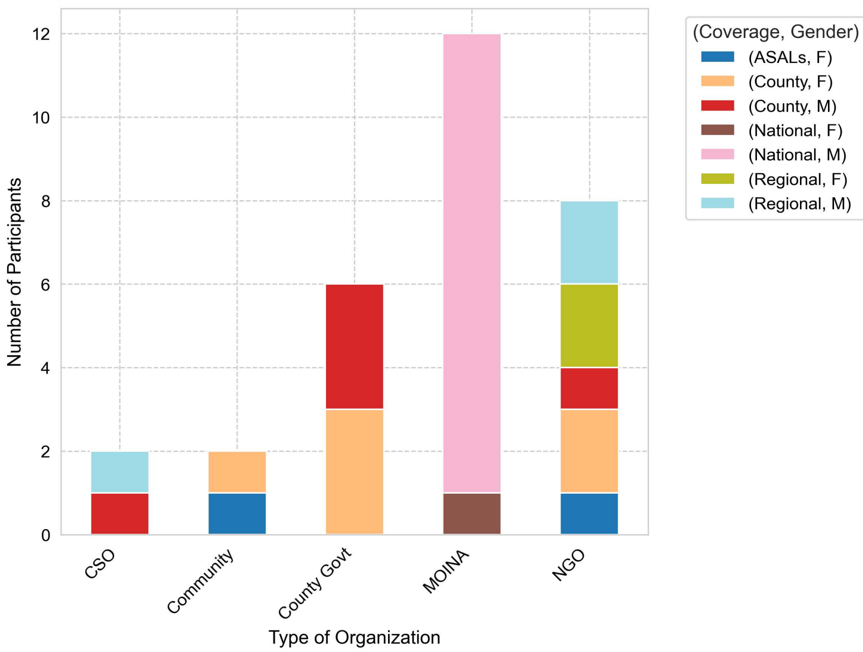

Fig 3. Distribution of experts who attended the workshop with respect to type of organisation [Civil Society Organisations (CSO), Community based organisations (Community), Ministry of Interior and National Administration (MOINA) and Non-Governmental Organisation (NGO)], area coverage and gender. Organisational coverage is classified as Arid and Semi-Arid Lands (ASALs), county, national (i.e., all counties in Kenya) or regional (i.e., spanning more than one county).

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data used to pre-identify the climate security hotspots were also presented in plenary. These included spatial clustering of climate hazards and machine learning-based detection of conflict hotspots using the Armed Conflict Location and Event Data Project (ACLED) [60] as outlined in [36] (see S4 Text for more details). Lastly, the workshop objectives were clearly stated and voluntary prior consent was sought from the experts to participate after establishing a common understanding of climate security and outlining the process transparently, as recommended by [44].

After outlining the workshop objectives, the experts were divided into five Focus Groups Discussions (FGDs), each composed of six experts, organised according to their counties of operation and profession. The five FGDs consisted of the following counties: 1) Turkana and West Pokot, 2) Mandera and Wajir, 3) Garissa, Tana River and Lamu, 4) Marsabit and Isiolo and 5) Laikipia and Samburu, all grouped based on common geographic, climatic vulnerability, socio-economic and cultural characteristics. Each FGD was supplemented with hard-copy printed maps (see Fig 2) and a similar digital map uploaded from a QGIS desktop project to QField mobile application [61]. QField was adopted to enable more interactive participation with additional contextual information from other layers like Google satellite image basemap, whenever clarity was needed. Another advantage of QField stems from its design for mobile/remote mapping applications, which supports a wide variety of spatial data formats, connects to leading spatial databases and utilizes standardised Geoweb services. In addition, the application supports parallel FGDs because of its seamless integration with QFieldCloud which enables teams to work on projects simultaneously from any location at any time (refer to [62] for detailed system illustration). During participatory mapping, QFieldCloud facilitated the synchronisation and merging of data collected by team members in QField.

Each FGD was facilitated by one of the co-authors. The FGDs were structured into three phases with plenary discussions at the end of each phase to foster consensus-based discussions. Given that climate security remains an emerging topic in Kenya and that the number of local experts with relevant cross-sectoral knowledge is limited, a consensus-based approach was considered as the most practical and context-appropriate method for this study. Phase 1 focused on validating hotspots characterised by different co-occurrences of moderate to high climate vulnerability as well as moderate to high exposure to conflict risks. However, in some counties, hotspots where low conflicts co-occurred with different levels of climate vulnerabilities were discussed either because other categories did not exist or experts found them to be of interest, e.g., cross-border ones. This session sought to establish experts' perception of the climate security hotspots categories through a set of guided questions listed in S1 Text. These questions inquired about types of weather shocks, their frequency, the most vulnerable groups/individuals and livelihoods impacted. Similarly, the questions explored triggers of instability, their frequency, actors involved and groups most affected by conflicts, including livelihoods. For reporting purposes, feedback from experts were classified into three distinct categories: i) Agreed - when experts agree on classification of co-occurrence of conflict and climatic conditions of the hotspot; ii) Partially agreed - in case experts do not agree with one of the two components' (either conflict or climate) categorisation; and finally, iii) Disagreed - in case experts completely reject the components categorisation. Phase 2 of FGDs was conducted to locate new climate security hotspots that were not captured due to coverage constraints of ACLED open data used to identify conflict hotspots. The same set of questions used in phase 1 was subsequently discussed after experts located new hotspots. During phase 1 and 2, experts were also able to identify transhumance routes, especially at county or country border points (S3 Text). The last phase – phase 3 – leveraged on participatory mapping to identify existing measures in the face of climate security challenges and to catalyse novel local solutions to climate, peace and security. Feedback from experts in Phases 1 and 2 was digitally entered into GIS shapefiles attribute tables using QField and synchronised to a secure cloud server, whereas qualitative notes and discussions from Phase 3 were recorded manually for subsequent thematic synthesis.

Across all phases, FGDs were designed to enable cross-border discussions, ensuring that experts could examine transboundary dynamics beyond their assigned groups. Plenary sessions at the end of each phase allowed participants to contribute beyond their group discussions, deliberate on contentious issues, and clarify points of uncertainty. These plenaries minimised potential bias and strengthened the coherence of the findings. Finally, the results of the participatory mapping exercise were presented to national stakeholders as part of the dissemination process, and to capture additional input [63].

2.2.4. Data capture and processing. Before the workshop, the pre-identified hotspots, in grids of approximately 21 km^2 referred to as megapixels, were assigned unique field identifier (FIDs). These FIDs were used to link each megapixel's hotspot to the questionnaire in S1 Text during the FGDs. Local experts systematically assessed each hotspot, with all observations and contextual details recorded in a coded questionnaire linked to the corresponding FID. Newly identified hotspots were marked on both hard-copy maps and within the digital environment to ensure consistency between paper and QField electronic records. Following the workshop, questionnaire data were digitised and spatially joined to the respective hotspot using the FID, then subjected to standard quality checks for completeness, code consistency and de-duplication. The cleaned data were synthesised through descriptive aggregation: closed-ended responses were summarised as category frequencies, while open-ended responses were condensed into thematic summaries. The consolidated hotspot-level information was subsequently visualised using thematic maps and plots to illustrate the spatial distribution and emerging patterns of expert assessments.

3. Results and discussion

3.1. Validation of pre-identified climate security hotspots

One objective of the participatory mapping exercise was to unpack local climate security dynamics and determine its intersection with climate security hotspots pre-identified using global datasets (Fig 4). These climate security hotspots, openly available via Climate Security Observatory [35], were validated through FGD with experts. Table 1 summarises key points highlighted during phases 1 and 2 of the FGDs for each mega-pixel (spatial grid of approximately 20 km^2) represented by hotspots' unique identification (IDs). Findings indicate that common climate-related hazards are notably droughts, heat

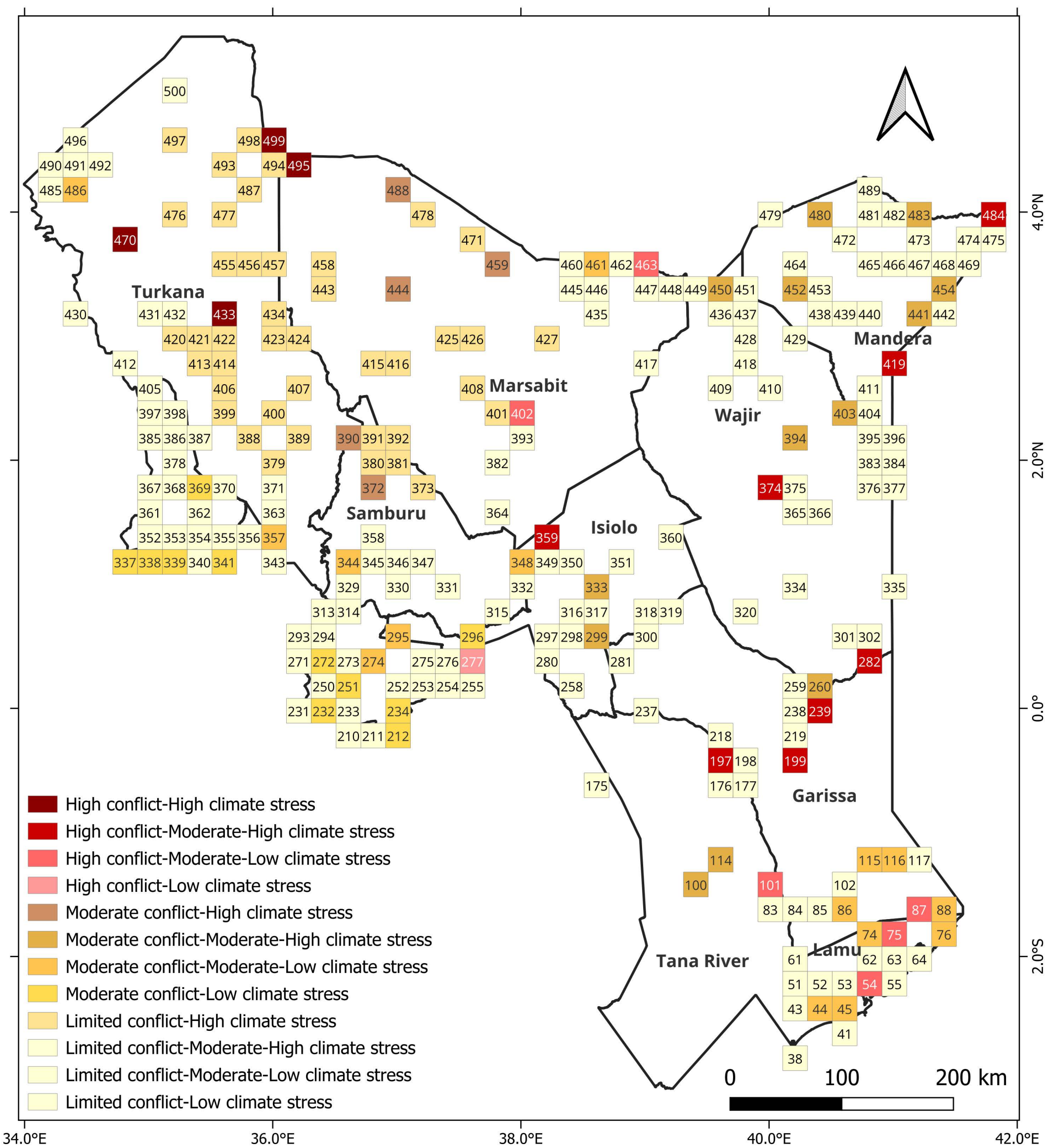

Fig 4. Climate Security hotspots validated through FGD with experts. The administrative county boundaries vector layer used to generate the map can be found here: https://data.humdata.org/dataset/47-counties-of-kenya under Creative Commons Attribution International (CC BY) license ([38]). The climate security hotspots can be accessed through our Climate Security Observatory online open tool, see [35].

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stress related to high temperatures, and floods. Drought was mentioned as a common occurrence in all counties. Some areas are also affected by environmental impacts due to extreme weather events, such as soil erosion and landslides. Participants indicated that these climate related events lead to displacement of communities, destruction of infrastructure and property, migration, loss of lives and decline in production (fish, livestock and crops). Moreover, there are clear connections between extreme events and triggers of instability/conflict. For instance, heavy rainfall triggers flash floods especially from dry riverbeds that lead to excessive inflows of water into Lake Turkana through rivers Omo, Turkwel and Kerio, which results in siltation. Siltation, on the other hand, negatively impacts fish availability in parts of the lake, while the Northern side experiences abundance. As a result, fisherfolks are forced to encroach into other designated Beach

Table 1. Summary of key consensus points from phases 1 and 2 of FGDs: PWDs refers to Persons with Disabilities.

County Group	Hotspot IDs	Weather Shocks	Effects of Climate on Livelihoods	Main Triggers of Instability	How Conflict Affects Livelihoods	Vulnerable Groups	Actors
Turkana & West Pokot	354, 340, 352, 353, 357, 390, 397, 385, 355, 378, 386, 398, 486, 470, 499, 433	• Floods, • Heat Wave, • Drought	• Reduction in fish species, • Destruction of infrastructure • Landslides • Lake siltation declines fish availability	• Encroachment on protected areas of Lake Turkana, • Resource competition, • Proliferation of small arms	• Displacement, • Loss of livestock and fishing gear	• Elmolo, • Turkana, • Dassanech, • Women, Children, Elders	• Kenya Wildlife Service, • Fisher folk, • Pastoralists
Mandera & Wajir	483, 484, 419, 374, 282, 441, 452, 480, 454, 260, 394, 450, 403	• Floods, • High Temperatures, • Drought	• Death of livestock, diseases, displacement and malnutrition	• Resource competition, • Farmer-herder conflict, • Cultural practices.	• Loss of property, • Destruction of infrastructure, • Displacement	• Children, • Women, • PWDs	• Militias, • Youth,
Garissa, Tana River, & Lamu	88, 87, 86, 300, 115, 116, 199, 239, 260, 282, 100, 114, 101, 197, 177, 62, 44, 45, 54, 74, 75, 76, 53, 52	• Floods, • Heat Waves, • Drought, • High Temperature, • Soil Erosion	• Decreasing grazing land, • Changing migration routes, • Decline in fish stock, • Death of livestock, • Decline in crop yields	• Resource competition, • Border disputes, • Clan conflicts, • Radicalization	• Loss of livelihood, • Displacement, • Food insecurity, • Health issues	• Children, • Women, • PWDs, • Indigenous Communities	• Al-Shabaab,
Marsabit & Isiolo	495, 488, 444, 459, 402, 461, 463, 393, 359, 348, 333, 299, 295	• Floods, • Heat Waves, • Drought	• Destruction of property, • Displacement, • Loss of lives, • Cattle rustling	• Resource competition, • Cultural differences, • Boundary issues, • Illegal immigration	• Displacement, • Economic instability, • Disrupted livelihoods	• Women, • Children, • Elderly, • PWDs	• Youth, • Militias, • Miners, • Illicit businessmen
Laikipia & Samburu	344, 390, 348, 372, 274, 295	• Drought	• Overgrazing, • Water scarcity, • Climate-induced migration	• Land degradation, • Overgrazing, • Land disputes	• Migration, • Lack of livelihood diversification, • School dropouts	• Women, • Children, • Pastoralists, • Indigenous Communities (e.g., Yiaku)	• Pastoralists, • Military, • Agro-pastoralists

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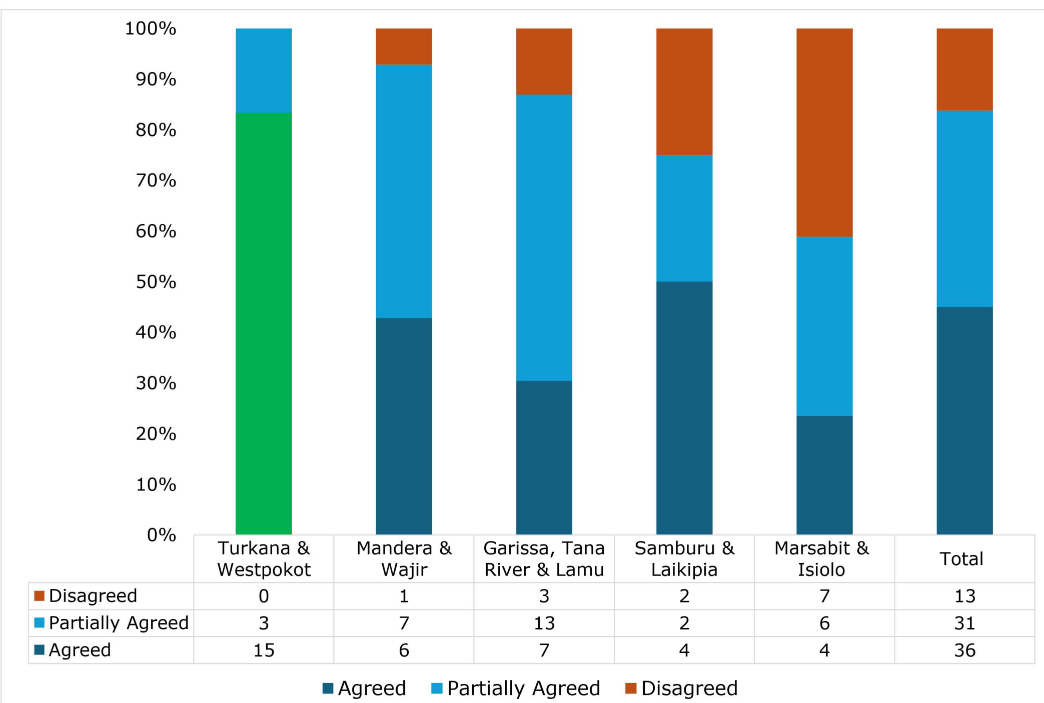
Management Units (BMUs) in search of fish, leading to conflicts with other locals. In addition, fisherfolks encroach protected areas around Sibilio National Park under the control of Kenya Wildlife Service (KWS) further exacerbating tensions. These dynamics adversely affect fisherfolk's livelihoods through reduced fish stocks and loss of fishing equipment, either through conflict or confiscation by KWS authorities. Other notable climate related triggers of conflict identified by participants include water scarcity, overgrazing and a decline in pasture. These findings are consistent with a previous study by [64], which noted a strong relation between climatic conditions, availability of water and pasture and the occurrence of violence.

Migration triggered by weather shocks, such as droughts and floods, was reported during participatory mapping. Although migration is an adaptive mechanism, participants emphasised that it often exacerbates existing tensions around ethnic borders and clan territories, as migrating groups are perceived to encroach upon the resources and territories of others. This observation aligns with findings from [65] , who noted that climate change continues to exacerbate resource scarcity—particularly livestock, water and pasture—among pastoral communities in Kenya's ASAL already facing historical governance challenges, limited education and underdevelopment. In addition, environmental challenges driven by climate change, like landslides (Table 1) and the spread of invasive species (locally known as 'Mathenge'), were further noted as destabilising factors. Moreover, discussions revealed growing concerns over shifting land use systems driven by the establishment of private wildlife conservancies, oil exploration and mining projects, all of which have increased competition over land and water resources. These developments have introduced new conflict actors, including wildlife authorities (KWS), miners and private developers, as summarised in Table 1. Therefore, empirical findings reinforce and expand upon broader concerns in the literature regarding how climate-driven and development-related pressures intensify competition and conflict over natural resources in ASAL areas.

During the participatory mapping exercise, 80 hotspots within the 11 ASAL counties (see Fig 1) were selected and discussed with the county's experts. Fig 5 summarises the perceptions of experts gathered during the validation exercise across different FGDs.

Overall, experts **agreed** with the classification of 45% of the hotspots. Turkana and West Pokot had the highest percentage of experts' consensus on the classification of hotspots from our analysis, with 83% of experts agreeing with the identified areas. Experts **partially agreed** with the classification (either climate or conflict risks) of 38.75% of the hotspots, indicating that while one risk component aligned with their expectations, the other did not. Fig 6 shows the frequency of the disputed components (either climate or conflict classification) of the **partially agreed** hotspots. The spatial distribution of FGDs validation feedback (Fig 7) shows that incidents of partial disagreement are high and dominant in Lamu county, followed by disagreement cases in Marsabit. Most of the disputed hotspots are located on county and country borders.



	Turkana & Westpokot	Mandera & Wajir	Garissa, Tana River & Lamu	Samburu & Laikipia	Marsabit & Isiolo	Total
Disagreed	0	1	3	2	7	13
Partially Agreed	3	7	13	2	6	31
Agreed	15	6	7	4	4	36

Fig 5. Summary of expert's perception of climate security hotspots during participatory mapping: experts either agreed with categories of climate and conflict (Agreed), concurred with climate or conflict categorisation (Partial Agreed) or did not concur completely (disagreed).

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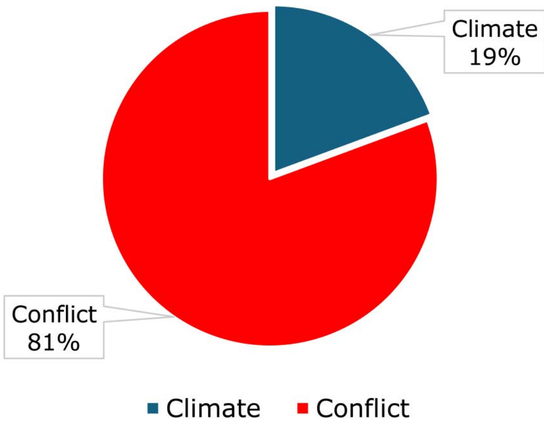

Fig 6. Illustration of percentages of components (climate or conflict) of climate security hotspots categorisation that experts disputed.

https://doi.org/10.1371/journal.pclm.0000746.g006

The categorisation of conflict emerged as one of the most contested classifications during the validation process. It is mentioned 81% of the time, illustrating that most experts' perception did not agree with the categorisation of conflict intensity (***Fig 6***). For instance, there were cases of over- or under-representation of conflict with respect to experts' expectations. For example, experts noted that megapixel 374 covering Wajir town is peaceful, but indicated 480, 454, 451, 441 and 483 along Mandera-Somalia and Mandera-Ethiopia boundaries as very high conflict zones. To some extent, this bias was anticipated, given the known limitations of ACLED data as outlined S4 Text. Our clustering framework mitigated some of these issues by accounting for geocoding inconsistencies; however, other data limitations remained.

A key reason why conflict classification was contested more often than climate classification relates to differences in temporal coverage. Whereas climate data extends back to 1981, ACLED data for Kenya is only available from 1997 onward. This limited historical coverage constrains accurate mapping of long-term conflict density. As a result, megapixels with significant pre-1997 conflict may appear as "low-density," while those affected by major events post-1997 may be classified as "high-density," especially after spatial clustering. Despite data normalisation efforts, this temporal limitation could have introduced bias by skewing the classification of conflict hotspots. Nonetheless, these findings underscore the value of participatory mapping in complementing data-driven analyses. Expert insights can fill critical gaps in historical records, enhance the interpretation of conflict trends, and improve the overall accuracy of climate security hotspot mapping.

In total, 83.75% of the climate-conflict hotspots received either full (45%) or partial agreement (38.75%) from experts, reflecting a high level of alignment between local knowledge and the pre-identified hotspots. This notable convergence suggests that the hotspot mapping approach (see S4 Text) was largely successful in capturing relevant conflict and climate dynamics across the study area, even in remote or complex settings. Although 16.25% of hotspots showed some divergence, this relatively small proportion underscores the complementary value—rather than a corrective necessity—of participatory mapping. The integration of local knowledge further enhanced precision and contextual understanding, but the high agreement observed here reinforces the robustness of the initial hotspot identification approach.

3.2. New climate security hotspots

The last phase of the experts' validation (phase 2 of the FGDs), sought to identify climate security hotspots that were not captured through analysis of ACLED data. A total of 19 new hotspots were identified across different counties, with unique challenges related to climate and conflict summarised in Table 2 and displayed in Fig 8 (data available in S1 Data).

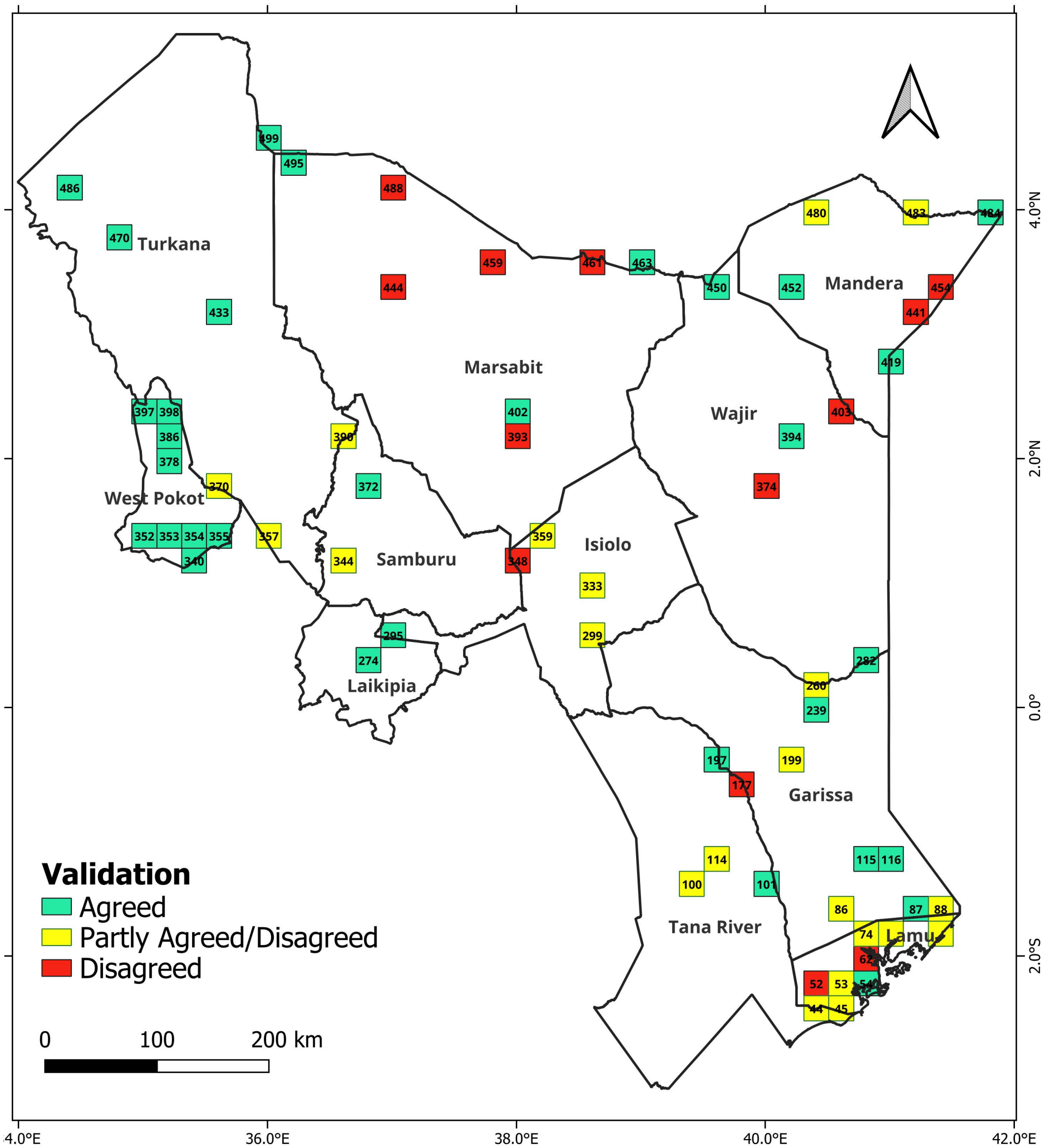

Fig 7. Spatial distribution of how experts during FGDs agreed, partially agreed or disagreed with our initial classification of climate security hotspots. The administrative county boundaries vector layer used to generate the map can be found here: https://data.humdata.org/dataset/47-counties-of-kenya under Creative Commons Attribution International (CC BY) license ([38]).

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These hotspots experience climate change impacts, such as persistent droughts, high temperatures and seasonal floods. Vulnerable groups, particularly women, children, Persons with Disabilities (PwDs) and the elderly, bear the brunt of these challenges. The primary triggers of conflict include resource scarcity, ethnic tensions and radicalisation. The impact of conflict varies spatially, leading to regular displacement, loss of life and destruction of property and/or infrastructure across affected counties.

These expert-identified hotspots (Table 2 and Fig 8) reveal critical dimensions of climate security that are often missed by global geospatial datasets. Many of the locations highlighted through participatory mapping had not previously been recognised as climate-conflict zones, pointing to a substantial mismatch between remote-sensing-based climate security hotspot mapping approaches and on-the-ground realities. For instance, areas such as Mukogodo forest in Laikipia and coastal settlements in Lamu experience slow-onset climate impacts—such as gradual ecosystem degradation, deforestation and saline intrusion—that are not easily detectable through rapid-onset conflict event data like that from ACLED. These creeping environmental stressors gradually erode local resilience, making these areas highly vulnerable even in the absence of acute or high-frequency violent events. Therefore, spatial models often fail to capture such dynamics, leading to an underrepresentation of cumulative risks in ecologically fragile areas. For example, regions with favourable climatic conditions, such as Mukogodo Forest, exhibit high ecological resilience, making them attractive to communities migrating from more degraded environments. This influx increases competition over natural resources and heightens the risk of resource-based conflicts. Such indirect and temporally displaced interactions underscore the limitations of geospatial approaches, as climate stress in one area may generate conflict in another—sometimes with a delayed onset—thereby eluding conventional hotspot detection frameworks.

Moreover, some hotspots identified in counties like Samburu, Wajir and Mandera exemplify entrenched historical grievances and persistent conflict, which may not register with adequate intensity or frequency to be captured in event-based datasets. These areas experience cyclical cattle rustling, inter-clan clashes and cross-border insecurity, frequently exacerbated by institutional marginalisation and underdevelopment. The presence of actors such as Al-Shabaab in Lamu, Tana River and Garissa introduces another layer of insecurity that is both highly localised and influenced by regional geopolitics. Such threats are difficult to quantify yet significantly shape community vulnerability and exposure. The integration of participatory insights thus allows for a deeper understanding of socio-political conflict drivers, including radicalisation, identity-based tensions, and land disputes, which are typically beyond the scope of global datasets or hotspots mapping algorithms.

Interestingly, some of the newly identified hotspots are not traditional centres of violence or extreme climatic stress but rather serve as ecological refuges that attract populations from neighbouring counties. Areas like Mukogodo in Laikipia, though relatively stable, face increasing demographic and ecological pressure as pastoralists from more stressed

Table 2. Summary of weather shocks and triggers of conflict experienced in newly identified hotspots.

County	Hotspot Ids	Weather shocks	Main Triggers of Conflict
Isiolo	11 and 12	Drought, seasonal floods and heat waves.	Water and pasture competition (Turkana, Samburu, Somali and Borana), inter-ethnic clashes, cattle rustling.
Marsabit	25	Drought, sandstorms, floods and heat waves.	Resource competition over pasture.
Marsabit	29	Flooding, competition over water and pasture.	Herders' conflict and human-wildlife conflict.
Lamu	5	Drought, heat waves, sea level rise and increased salinity of underground water.	Al-Shabaab and land issues.
Tana River	2, 4,7,8 and 9	Floods, heat waves, soil erosion and drought.	Farmer-herder conflicts, resource competition, Al-Shabaab and ethnic tensions.
Samburu	16	Drought.	Banditry, cattle rustling (Turkana, Pokot, Samburu) and illegal trade (sandalwood).
Laikipia	3	Favourable climate and water availability.	Resource competition, deforestation and illegal charcoal burning.
Mandera	27	Drought, floods and heat waves.	Ethnic tension, cross-border insecurity and Al-Shabaab insurgency.
Wajir	17, 19, 20, and 24	Drought, floods and heat waves.	Land disputes, radicalisation, clan disputes and cross-border conflict.
Garissa	6 and 15	Heat waves and floods	Ethnic tension and conflict over pasture.

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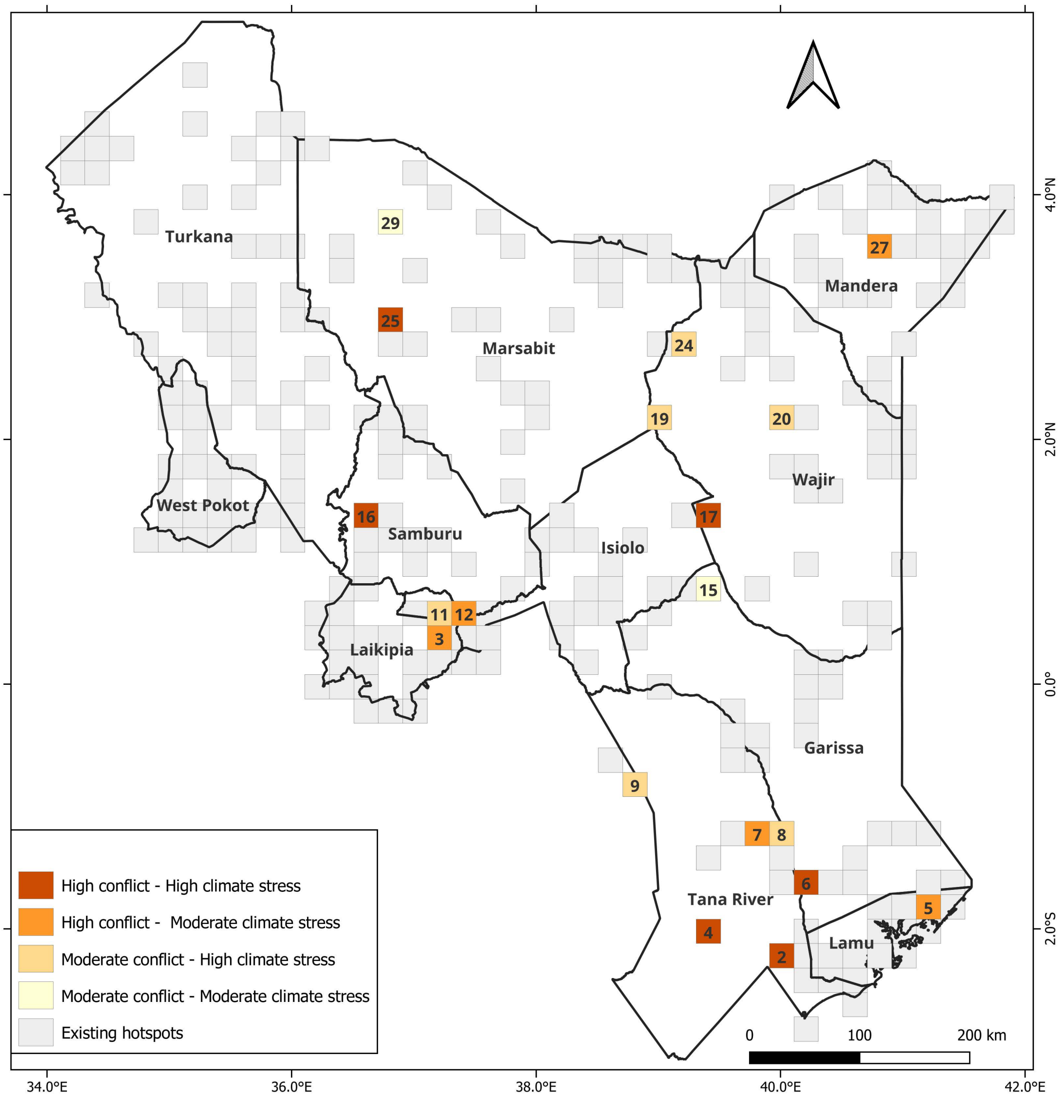

Fig 8. New climate security hotspots (with unique numbered labels) mapped by stakeholders, classified according to their perception of climate conflict co-occurrence (data in S1 Data).The administrative county boundaries vector layer used to generate the map can be found here: https://data.humdata.org/dataset/47-counties-of-kenya under Creative Commons Attribution International (CC BY) license ([38]).

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environments move in search of water and pasture. This influx introduces indirect sources of tension and environmental degradation, such as deforestation, illegal forest resource extraction and overgrazing. These pull factors underscore the need to consider the role of seemingly stable zones in regional conflict dynamics. Without localised knowledge, such secondary hotspots would be overlooked, even though they may become flashpoints due to cumulative stress over time.

The spatial variability and multifactorial nature of the newly identified hotspots affirm the importance of hybrid approaches to climate security mapping. While spatial analysis based on global datasets offers valuable macro-level perspectives, it remains limited in its ability to capture local nuances, latent vulnerabilities and complex historical legacies. By incorporating expert validation and participatory methodologies, this study highlights the need for models that go beyond global analysis to account for lived experience and localised understanding. Such approaches enable the identification of emerging threats in areas previously regarded as stable and can guide more inclusive and anticipatory climate security interventions. As noted by [29], integrating local social and environmental factors into climate security assessments is essential for producing actionable insights, particularly in fragile and data-sparse regions such as Kenya's ASALs.

Overall, the distinction between model-identified and expert-identified hotspots does not lie solely in the type of hazards reported, as both sets include rapid- and slow-onset events (Tables 1 and 2). Rather, the difference emerges from the process of detection and contextualization. The top-down approach classified hotspots based on the co-occurrence of climate hazards and recorded conflict events, meaning that locations affected by gradual ecosystem degradation, underreported local disputes or indirect pressures often remained undetected. In contrast, experts highlighted places where cumulative or historically embedded stressors—such as saline intrusion in coastal Lamu, persistent but low-intensity clan clashes in Mandera or migration-driven pressures in Laikipia—intersect with local vulnerabilities. This demonstrates the complementary value of participatory mapping in highlighting overlooked or latent risks.

3.3. Existing and proposed climate security interventions

Building on the climate security hotspots validation through participatory mapping, this study also sought to understand existing measures established to engage climate security dynamics (Table 3) and catalyse conversations towards future interventions (see Table 4). This was implemented using FGDs guiding questions listed in S2 Text. We established that, in Turkana and West Pokot, there were community-led and government-supported initiatives to address conflict risks and improve resource management. Kraal leaders and peace committees help recover stolen cattle, and traditional compensatory practices promote stability. Similarly, community-driven dialogues involving police collaboration, rotational grazing regulations between Turkanas and Toposas, and community BMUs along Lake Turkana also contribute to promoting sustainable and peaceful resource access and allocation schemes in the area. Alternative livelihoods—such as irrigation farming and small-scale businesses—have also been introduced, along with the opening of regulated livestock markets, to provide economic opportunities and reduce theft. Moreover, environmental conservation efforts at the community level that include indigenous food preservation techniques or the demarcation of conservancies and sacred sites have also supported the promotion of peace and stability in the face of degrading climatic conditions and ecosystems. Such social cohesive inclusive community level programmes are critical in maintaining peace. For instance, a study by [66] established that by leveraging matriarchal influence, social networks, religious spaces and integration of cultural perspectives in peace-making, Pokot women deterred warriors from cattle rustling, promoting peace in the region.

These traditional governance systems, combined with a relatively high concentration of field-based humanitarian and peacebuilding organisations and active civil society engagement in conflict mitigation and resource governance, may help explain why FGDs in Turkana and West Pokot showed lower levels of dispute regarding the mapped hotspots (Fig 7). The sustained presence of these actors has contributed to more institutionalised dialogue platforms and peace governance structures, including county-level peace committees embedded within devolved government operations. Moreover, the longstanding Lokiriama Peace Accord between the Turkana and Pokot communities, alongside ongoing cross-border peace dialogues supported by county authorities and NGOs, may have enhanced awareness and shared understanding of climate–security linkages compared with other counties.

In Wajir, Mandera and Garissa, rangeland management programs and resource-based conflict committees address peace risks. County and climate change committees are key actors in developing strategies to counter rising climate vulnerabilities. Reforestation projects in Mandera, especially those involving women, create employment and foster stability. Similarly, in Lamu and Tana River, interventions like grazing by-laws, peace-building initiatives and capacity-building programs are supported by national and local organisations to prevent resource-based conflicts.

In Marsabit and Isiolo, traditional governance systems such as the Geda, Borana and Yaa play a critical role in managing natural resources, with elders determining grazing patterns. Cultural norms enhance conservation, while inter-ethnic

Table 3. Summary of existing solutions to climate, peace and security in ASAL counties.

Common existing solutions across counties	
Community-led initiatives	Community-driven initiatives and efforts play a crucial role in conflict mitigation and resource management, mainly involving local leaders, peace committees and community dialogues.
Traditional governance systems	Traditional structures and cultural norms, like kraal leaders, elders, and traditional compensation mechanisms are fundamental tools to manage intra- and inter-communal conflicts thus maintaining peace.
Legal and policy frameworks	Cooperation with governmental bodies and the presence of legal measures and policies that promote sustainable resource management are key for long-term peace and stability.
Alternative livelihoods	New economic opportunities and avenues like beekeeping, ecotourism or irrigation farming help reduce dependence on conflict-prone activities like cattle rustling, thus promoting peace.
Environmental conservation and regulated resource use	Community-led conservation efforts, as well as the implementation of regulations for grazing and resource mapping, all support managing natural resources sustainably as well as conserving ecosystems.
Education and sensitisation	Programs to educate and sensitise communities on climate risks and peace-building support community cohesion.

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peace dialogues contribute to peaceful resource-sharing. Samburu and Laikipia counties rely on traditional systems for conflict prevention, including the involvement of elders in regulating cattle rustling. Youth and women-led alternative livelihoods like beekeeping reduce economic dependence on cattle rustling. Community conservancies that promote ecotourism and frameworks aligning with local practices ensure sustainable resource management, mitigating the effects of climate change and fostering social cohesion.

The proposed climate, peace and security interventions that are summarised in Table 4, reflect a multidimensional approach to addressing the interconnected challenges of conflict and climate risks across ASAL counties. For instance, Turkana county grapples with encroachment of protected areas of Lake Turkana and increasing resource competition, which has intensified local tensions. Therefore, interventions such as the construction of dams and boreholes along the border between South Sudan and Kenya, and the establishment of unified fishing regulations for Lake Turkana could promote equitable resource-sharing between vulnerable communities. Additionally, the proliferation of small arms in the region exacerbates insecurity, underscoring the importance of complementary peacebuilding efforts. Reviving refugee settlement projects and drawing lessons from successful peace accords, such as the Lokiriama Peace Accord, may further contribute to fostering sustainable peace. In West Pokot, building social amenities in conflict-prone areas and promoting conservation agriculture and water harvesting initiatives are key strategies for strengthening social cohesion and enhancing environmental sustainability.

In Wajir, Mandera and Garissa, updating land use plans, raising climate change awareness and promoting alternative livelihoods, such as transitioning away from charcoal burning, could prevent resource-based conflicts. Equitable resource distribution and changing land tenure systems to private or registered community land are also vital for reducing tensions over land rights and land allocation. In Tana River and Lamu, spatial planning for grazing zones, promotion of drought-resistant livestock and seed varieties and relocation of most exposed communities are important measures to mitigate climate impacts like droughts and floods.

In the arid and semi-arid regions of Marsabit and Isiolo, northern Kenya, capacity-building for alternative livelihoods such as beekeeping and climate-smart agriculture has emerged as a critical strategy for mitigating conflict risks exacerbated by climate change. Intensifying climatic variability—manifested through recurrent floods, heatwaves, droughts and declining rangeland productivity (see Table 1)—has heightened competition over scarce natural resources, contributing to tensions and violence. Beekeeping serves as a climate-resilient livelihood, requiring minimal land and water resources while providing alternative income streams, thereby alleviating pressure on degraded ecosystems. Concurrently,

Table 4. Overview of proposed solutions to climate, peace and security in ASAL counties.

Common proposed solutions across counties	
Infrastructure development	The construction of infrastructure, such as water dams, boreholes or roads, is vital for supporting communities in accessing resources like water as well as connecting them freely to different areas. Both could contribute to fostering stability in conflict-prone zones.
Environmental conservation	Alternative livelihood strategies that include conservation agriculture and climate-smart interventions could support adaptation to climate change and the promotion of economic stability within communities.
Community integration and cohesion	Building social amenities and fostering social cohesion, particularly between refugees and hosting communities, could be key to creating more unified and resilient communities.
Capacity building and public awareness	Sensitising communities on climate risks and alternative livelihoods could be a valid strategy of building resilience and promoting a culture of stability and security.
Resource distribution and land use planning	Equitable distribution of resources, particularly grazing land and adequate intra-/inter-communal land use planning can prevent the outburst of tensions and foster a harmonious coexistence.
Economic development	Promoting local economies could be useful to reduce the exposure of communities to climate and conflict risks.
Collaboration and policy development	Inter-county collaboration on climate adaptation and peace could be key to promoting the overall regional stability. Harmonised regulations, coordinated policies and shared licensing systems for resource management, alongside investment in new infrastructure, may contribute to sustaining long-term peace.

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climate-smart agricultural practices, including the adoption of drought-tolerant crop varieties and integrated water management, enhance household food security and adaptive capacity. These interventions collectively reduce resource dependency and competition, while fostering resilience. Furthermore, engagement of youth in environmental restoration and peacebuilding initiatives further diverts at-risk populations from illicit activities.

For Samburu and Laikipia, inter-county cooperation on peace and climate change adaptation, expanding land restoration and participatory grazing plans are crucial. Public sensitisation on peace, security and socio-economic development, along with infrastructure development to reduce road banditry and promote market access, will also help stabilise communities. Additionally, promoting climate-smart agriculture can enhance food security and alleviate poverty in these counties. Taken together, these integrated approaches represent a holistic response to the complex nexus of climate change, livelihood insecurity, and conflict dynamics in the region.

Effective implementation of the above proposed climate–peace–security interventions ultimately hinges on governance systems capable of bridging institutional divides and addressing long-standing structural inequalities. The findings highlight that while participatory mapping helped identify hotspots and community-driven solutions, sustainable outcomes depend on how institutions—formal, customary and community-based—coordinate and share authority. Rigid, top-down governance structures remain ill-suited to the uncertainty of climate and conflict dynamics, while institutional silos across policy sectors hinder integration of adaptation and peace objectives [67]. Hybrid and inclusive arrangements that legitimise multiple sources of authority can foster legal pluralism and strengthen accountability [68], particularly in regions where state capacity is limited and local legitimacy drives cooperation. Addressing institutional multiplicity, marginalisation and elite capture is thus central to ensuring that adaptation contributes to peace and resilience [69]. Building adaptive, transparent and participatory institutions that embed conflict sensitivity and equitable resource governance can enhance trust and collaboration, while empowering community-based organisations with broad accountability provides effective entry points for inclusive governance [70]. In this regard, institutional transformation—grounded in representation, responsiveness and cross-sectoral coordination—remains essential for translating participatory evidence into coherent, conflict-sensitive policy and action [71].

4. Conclusion and outlook

Mapping challenges at the climate security nexus requires a multimethod approach that integrates multisource data. This study sought to demonstrate the potential of participatory mapping in enhancing nuanced climate security dynamics by leveraging local experts' knowledge, while simultaneously promoting community-led interventions. The participatory mapping exposed perceptions of experts, from different counties, on climate and conflict intensities and its impact to different individuals and livelihoods. The mapping process identified extreme weather events such as droughts, floods and heat waves as the most prominent in the region. These events often exacerbate resource scarcity, which in turn increases tensions and forces communities to adopt alternative livelihood strategies (e.g., banditry, farmer-herder conflicts and cattle rustling) that undermine social cohesion. Nonetheless, this study established that perceptions of climate hazards and conflict risks vary significantly across counties, depending on the local context.

Experts in the region provided valuable insights into the nature and drivers of climate-related security risks by proposing both existing and innovative solutions to mitigate escalating insecurity linked to worsening climatic conditions. While the participatory mapping process was structured as a validation exercise—introducing participants to the concept and sharing pre-identified climate-conflict hotspots—the high level of agreement (84%) between expert perceptions and quantitative analysis underscores the strength of the initial model. Rather than highlighting experts' unique capacity to independently map climate-conflict hotspots, the findings instead point to their critical role in enriching and contextualising identified risks, especially through their knowledge of existing coping mechanisms and locally viable policy responses. Moreover, the newly identified hotspots raised during the participatory sessions—those not captured by the quantitative model—offer an opportunity to refine and strengthen early warning systems. These insights affirm the importance of participatory approaches not only for validation but for enhancing the depth and relevance of resilience-building strategies in vulnerable regions. By involving experts and representatives from marginalised groups, the study hopes that the participatory mapping framework can support the development of inclusive policies that address existing vulnerabilities and reduce the risk of conflict in ASAL regions. This effort represents a key milestone, as one of the strategic objectives of the third National Climate Change Action Plan (NCCAP III) is to expand, consolidate and disseminate knowledge on climate security in Kenya. Moreover, the Paris agreement encourages capacity building and climate action efforts that are transparent, consider local and indigenous knowledge and incorporate the best available science towards developing local solutions, hence making the developed participatory mapping framework suitable.

Future studies on climate security hotspots mapping should employ hybrid methodologies that combine remote sensing and ground-referenced participatory data. This approach will ensure indirect indicators, such as ecological degradation, land pressure due to in-migration and socio-political marginalisation, including historical and cultural contexts, are accounted for and incorporated into the mapping process. Future research should also apply systematic qualitative analysis to minimise potential selection and facilitator biases within the consensus-based FGD approach adopted in this study, particularly since climate security remains a relatively new topic in Kenya. Such improvements would strengthen the validity of participatory evidence and enhance comparability across contexts. By embracing such hybrid methods, researchers can better capture the complexity of climate-conflict linkages, thereby enhancing the development of early warning systems and peacebuilding strategies that are contextually grounded and locally responsive.

Supporting information

S1 Text. Focus Group Discussions Part 1 & 2: validation of hotspots.
(DOCX)

S2 Text. Focus Group Discussions Part 3: Catalysing climate, peace and security interventions.
(DOCX)

S3 Text. Transhumance.
(DOCX)

S4 Text. Climate Security Hotspots mapping.
(DOCX)

S1 Data. Newly mapped hotspots and transhumance datasets.
(ZIP)

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The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

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References

1. Mobjörk M. Exploring the climate–conflict link: The case of East Africa. Stock Int Peace Res Institute, SIPRI Yearb 2017 Armaments, Disarm Int Secur. 2017. p. 287–99.
2. Koubi V. Climate change and conflict. Annu Rev Polit Sci. 2019;22(22):343–60.
3. Mach KJ, Kraan CM, Adger WN, Buhaug H, Burke M, Fearon JD, et al. Climate as a risk factor for armed conflict. Nature. 2019;571(7764):193–7. https://doi.org/10.1038/s41586-019-1300-6 PMID: 31189956
4. Pacillo G, Medina L, Liebig T, Carneiro B, Schapendonk F, Craparo A, et al. Measuring the climate security nexus: The Integrated Climate Security Framework. PLOS Clim. 2024;3(10):e0000280. https://doi.org/10.1371/journal.pclm.0000280
5. Schilling J, Akuno M, Scheffran J, Weinzierl T. On raids and relations: Climate change and pastoral conflict in Northern Kenya. In: Bronkhorst S, Bob U, editors. Climate Change and Conflict: Where to for Conflict Sensitive Climate Adaptation in Africa? Berliner Wissenschaftsverlag; 2013. p. 241–68.

6. UNDP, LPI. Mapping of Climate Security Adaptations At Community Level in the Horn of Africa. 2023.
7. Nying'uro P, Kimutai J, Mwangi K, Khaemba W. Climate change impacts in Kenya: What climate change means for a country and its people [Internet]. 2024. Available from: https://www.climateimpacts.co.ke/
8. Omolo N. Gender and climate change-induced conflict in pastoral communities: Case study of Turkana in northwestern Kenya. Afr J Conflict Res. 2011;10(2). https://doi.org/10.4314/ajcr.v10i2.63312
9. Greiner C. Guns, land, and votes: cattle rustling and the politics of boundary (re)making in Northern Kenya. Afr Aff (Lond). 2013;112(447):216–37. https://doi.org/10.1093/afraf/adt003
10. Amou M, Gyilbag A, Demelash T, Xu Y. Heatwaves in Kenya 1987–2016: Facts from CHIRTS High Resolution Satellite Remotely Sensed and Station Blended Temperature Dataset. Atmosphere. 2020;12(1):37. https://doi.org/10.3390/atmos12010037
11. Jaramillo L, Cebotari A, Diallo Y, Gupta R, Koshima Y, Kularatne C, et al. Climate Challenges in Fragile and Conflict-Affected States. In: Staff Climate Notes [Internet]. Washington D.C.: International Monetary Fund; 2023. Available from: https://www.elibrary.imf.org/view/journals/066/2023/001/066.2023.issue-001-en.xml
12. Adams C, Ide T, Barnett J, Detges A. Sampling bias in climate–conflict research. Nat Clim Chang. 2018;8(3):200–3. https://doi.org/10.1038/s41558-018-0068-2
13. Hartmann B. Converging on Disaster: Climate Security and the Malthusian Anticipatory Regime for Africa. Geopolitics. 2014;19(4):757–83. https://doi.org/10.1080/14650045.2013.847433
14. Warner J, Boas I. Securitization of climate change: How invoking global dangers for instrumental ends can backfire. Environ Plan C Polit Sp. 2019;37(8):1471–88. https://doi.org/10.1177/2399654419834018
15. Barnett J. Global environmental change I: Climate resilient peace? Prog Hum Geogr. 2018;43(5):927–36. https://doi.org/10.1177/0309132518798077
16. Temper L, Walter M, Rodriguez I, Kothari A, Turhan E. A perspective on radical transformations to sustainability: resistances, movements and alternatives. Sustain Sci. 2018;13(3):747–64. https://doi.org/10.1007/s11625-018-0543-8
17. Ide T, Johnson MF, Barnett J, Krampe F, Le Billon P, Maertens L. The Future of Environmental Peace and Conflict Research. Environ Polit. 2023;32(6):1077–103. https://doi.org/10.1080/09644016.2022.2156174
18. Siddiqi A. The missing subject: Enabling a postcolonial future for climate conflict research. Geogr Compass. 2022;16(5). https://doi.org/10.1111/gec3.12622
19. Conca K, Dabelko GD. The international (in)security order and the climate-conflict-security nexus. Environ Secur. 2024;2(4):501–24. https://doi.org/10.1177/27538796241287358
20. Busby JW. States and Nature. States and Nature: The Effects of Climate Change on Security. Cambridge: Cambridge University Press; 2022. p. i–i. (The Politics of Climate Change). Available from: https://www.cambridge.org/core/product/DB34F261D006452AA18C6DAA1BCE6645
21. Adger WN. Climate change, human well-being and insecurity. New Polit Econ. 2010;15(2):275–92. https://doi.org/10.1080/13563460903290912
22. Šedová B, Binder L, Michelini S, Schellens M, Rüttinger L. A review of climate security risk assessment tools. Environ Secur. 2024;2(1):175–210. https://doi.org/10.1177/27538796241226996
23. Medina L, Ensor MO, Schapendonk F, Sieber S, Pacillo G, Laderach P, et al. Community voices on climate, peace and security: A social learning approach to programming environmental peacebuilding. Environ Secur. 2024;2(1):75–104.
24. Nowak AC, Njuguna L, Ramirez-Villegas J, Reidsma P, Crumpler K, Rosenstock TS. Opportunities to strengthen Africa's efforts to track national-level climate adaptation. Nat Clim Chang. 2024.
25. Sumari B, Pauline N, Bwanduruko E. Integrating bottom-up and top-down approaches in Tanzania's climate change adaptation planning: exploring their impact on adaptive capacity in adaptation projects. J Dev Stud. 2025;61(6):851–68. https://doi.org/10.1080/00220388.2024.2428608
26. Marondedze AK, Mutanga O, Cho MA. Promoting inclusion in urban land use planning using participatory geographic information system (PGIS) techniques: A systematic review. J Environ Manage. 2024;370:123099. https://doi.org/10.1016/j.jenvman.2024.123099 PMID: 39467458
27. UN Climate Security Mechanism. Progress report [Internet]. 2022. Available from: https://mptf.undp.org/sites/default/files/documents/2022-11/csm_progress_report_2022.pdf
28. Busby JW, Smith TG, Krishnan N. Climate security vulnerability in Africa mapping 3.0. Polit Geogr. 2014;43:51–67. https://doi.org/10.1016/j.polgeo.2014.10.005
29. Ide T. Research methods for exploring the links between climate change and conflict. WIREs Clim Chang. 2017;8(3):e456. https://doi.org/10.1002/wcc.456
30. Sitati A, Joe E, Pentz B, Grayson C, Jaime C, Gilmore E, et al. Climate change adaptation in conflict-affected countries: A systematic assessment of evidence. Discov Sustain. 2021;2(1):42. https://doi.org/10.1007/s43621-021-00052-9 PMID: 35425913
31. Young HR, Cha Y, den Boer H, Schellens M, Nash K, Watmough GR. Strata: Mapping climate, environmental and security vulnerability hotspots. Polit Geogr. 2023;100:102791.
32. Ide T, Scheffran J. On climate, conflict and cumulation: suggestions for integrative cumulation of knowledge in the research on climate change and violent conflict. Glob Chang Peace Secur. 2014;26(3):263–79. https://doi.org/10.1080/14781158.2014.924917

33. Tänzler D, Maas A, Carius A. Climate change adaptation and peace. WIREs Climate Change. 2010;1(5):741–50. https://doi.org/10.1002/wcc.66
34. Brzoska M, Fröhlich C. Climate change, migration and violent conflict: vulnerabilities, pathways and adaptation strategies. Migr Dev. 2016;5(2):190–210. https://doi.org/10.1080/21632324.2015.1022973
35. CGIAR FOCUS Climate Security. Climate Security Observatory: A decision support tool helping stakeholders understand and respond to climate-related security risks [Internet]. 2023 [cited 2023 Aug 29]. Available from: https://cso.cgiar.org/#/Information/Kenya
36. Kenduiywo B, Mendez A, Liebig T, Belli A, Villa V, Achicanoy H. Mapping climate insecurity hotspots: Enhancing climate peace and security decision making in East Africa and Greater Horn of Africa. Shaping the Future of Climate Change Action Plans for Sustainable Development in Eastern Africa. Nairobi, Kenya; 2023. p. 1–9.
37. Government of Kenya. National Climate Change Action Plan (Kenya) 2023-2027. Nairobi, Kenya: Ministry of Environment, Climate Change and Forestry; 2023.
38. Humanitarian Data Exchange (HDX). Administrative Counties in Kenya [Internet]. 2019 [cited 2024 Nov 12]. Available from: https://data.humdata.org/dataset/47-counties-of-kenya
39. Njarui DMG, Gichangi EM, Gatheru M, Nyambati EM, Ondiko CN, Njunie MN. A comparative analysis of livestock farming in smallholder mixed crop-livestock systems in Kenya: 1. Livestock inventory and management. Livest Res Rural Dev. 2016;28(66).
40. Bahta S, Wanyoike F, Kirui L, Mensah C, Enahoro D, Karugia J. Livestock sector transformation in Kenya: Current state and projections for the future. Food Syst Transform Kenya. 2023;51.
41. Kenya Meteorological Department. State of the Climate Kenya [Internet]. 2023. Available from: https://meteo.go.ke/index.php/resources/downloads/state-climate-kenya-2022
42. Lawrence TJ, Vilbig JM, Kangogo G, Fèvre EM, Deem SL, Gluecks I, et al. Shifting climate zones and expanding tropical and arid climate regions across Kenya (1980–2020). Reg Environ Chang. 2023;23(2):59. https://doi.org/10.1007/s10113-023-02055-w
43. Boruru EO, Ontita E, Ogara WO, Oguge NO. Climate Change and the Emergence of Helter-Skelter Livelihoods Among the Pastoralists of Samburu East District, Kenya BT - Experiences of Climate Change Adaptation in Africa. In: Leal Filho W, editor. Experiences of Climate Change Adaptation in Africa Climate Change Management [Internet]. Berlin, Heidelberg: Springer Berlin Heidelberg; 2011. p. 97–110.
44. Ramirez-Gomez SOI, Brown G, Fat ATS. Participatory Mapping with Indigenous Communities for Conservation: Challenges and Lessons from Suriname. Electron J Inf Syst Dev Ctries. 2013;58(1):1–22. https://doi.org/10.1002/j.1681-4835.2013.tb00409.x
45. Ndzabandzaba C. Participatory geographic information system (PGIS): A discourse toward a solution to traditional GIS challenges. In: Brunn SD, Kehrein R, editors. Handbook of the changing world language map. Cham: Springer International Publishing; 2020. p. 3825–35.
46. Cochrane L, Corbett J. Participatory Mapping. In: Servaes J, editor. Handbook of Communication for Development and Social Change. Singapore: Springer Singapore; 2018. p. 1–9.
47. Hossen MA. Participatory mapping for community empowerment. Asian Geographer. 2016;33(2):97–113. https://doi.org/10.1080/10225706.2016.1237370
48. Chambers R. Participatory mapping and geographic information systems: Whose map? Who is empowered and who disempowered? Who gains and who loses?. Electron J Inf Syst Dev Ctries. 2006;25(1):1–11. https://doi.org/10.1002/j.1681-4835.2006.tb00163.x
49. Olson R, Hackett J, DeRoy S. Mapping the digital terrain: Towards indigenous geographic information and spatial data quality indicators for indigenous knowledge and traditional land-use data collection. Cartogr J. 2016;53(4):348–55. https://doi.org/10.1080/00087041.2016.1190146
50. McCall MK, Minang PA. Assessing participatory GIS for community-based natural resource management: Claiming community forests in Cameroon. Geogr J. 2005;171(4):340–56.
51. Bayala ERC, Asubonteng KO, Ros-Tonen M, Djoudi H, Siangulube FS, Reed J, et al. Using Scenario Building and Participatory Mapping to Negotiate Conservation-Development Trade-Offs in Northern Ghana. Land. 2023;12(3):580. https://doi.org/10.3390/land12030580
52. Riva M, Kienast F, Grêt-Regamey A. Mapping open spaces in Swiss mountain regions through consensus-building and machine learning. Appl Geogr. 2024;165:103237.
53. Cho MA, Mutanga O. Understanding participatory GIS application in rangeland use planning: a review of PGIS practice in Africa. J Land Use Sci. 2021;16(2):174–87. https://doi.org/10.1080/1747423x.2021.1882598
54. Zeballos-Velarde C. Participatory Geographic Information Systems for integrated risk analysis: A case of Arequipa, Peru. In: Mendes JM, Kalonji G, Jigyasu R, Chang-Richards A, editors. Strengthening Disaster Risk Governance to Manage Disaster Risk. Elsevier; 2021. p. 99–106. https://doi.org/10.1016/b978-0-12-818750-0.00010-6
55. McCall MK, Dunn CE. Geo-information tools for participatory spatial planning: Fulfilling the criteria for 'good' governance? Geoforum. 2012;43(1):81–94. https://doi.org/10.1016/j.geoforum.2011.07.007
56. Brown G, Kangas K, Juutinen A, Tolvanen A. Identifying environmental and natural resource management conflict potential using participatory mapping. Soc Nat Resour. 2017;30(12):1458–75.
57. Gaillard JC, Pangilinan MLCJD. Participatory Mapping for Raising Disaster Risk Awareness Among the Youth. Contingencies Cris Manag. 2010;18(3):175–9. https://doi.org/10.1111/j.1468-5973.2010.00614.x
58. Klonner C, Usón TJ, Aeschbach N, Höfle B. Participatory mapping and visualization of local knowledge: An example from Eberbach, Germany. Int J Disaster Risk Sci. 2021;12(1):56–71. https://doi.org/10.1007/s13753-020-00312-8

59. Chalmers N, Fabricius C. Expert and generalist local knowledge about land-cover change on South Africa's wild coast. Eco Soc. 2007;12(1).
60. Raleigh C, Linke A, Hegre H, Karlsen J. Introducing ACLED: An armed conflict location and event dataset. J Peace Res. 2010;47(5):651–60. https://doi.org/10.1177/0022343310378914
61. Maťašovská V, Kratina J, Kabeláč R. QFIELD–mobile application for data collection established on the principles of open source software. Vodohospodářské Tech Inf. 2024;66(2):22–8.
62. OPENGIS.ch. QFieldCloud System Documentation [Internet]. 2023 [cited 2024 Jun 15]. Available from: https://docs.qfield.org/reference/qfieldcloud/system/
63. Kimani O, Kenduiywo B, Korir V, Omagwa P, Kebut D. Blog. Catalyzing climate security interventions through participatory mapping in arid and semi-arid counties of Kenya. 2024 [cited 2025 Oct 9]. Available from: https://hdl.handle.net/10568/149032
64. Ide T, Schilling J, Link JSA, Scheffran J, Ngaruiya G, Weinzierl T. On exposure, vulnerability and violence: Spatial distribution of risk factors for climate change and violent conflict across Kenya and Uganda. Polit Geogr. 2014;43:68–81. https://doi.org/10.1016/j.polgeo.2014.10.007
65. Ong'eta MW. Resources, climate change, and implications to positive peace among the pastoral communities in Kenya. In: Standish K, Devere H, Suazo A, Rafferty R, editors. The Palgrave Handbook of Positive Peace. Singapore: Springer Singapore; 2021. p. 1–14.
66. Kong'ani LNS. Women's multi-faceted roles in peacebuilding initiatives: Insights from pastoral communities in west Pokot County, Kenya. Confl Resolut Q. 2024. https://doi.org/10.1002/crq.21442
67. Beaumont P, Coning C de. Coping with complexity: toward epistemological pluralism in climate–conflict scholarship. Int Stud Rev. 2022;24(4):viac055.
68. Ratner BD, Meinzen-Dick R, Hellin J, Mapedza E, Unruh J, Veening W, et al. Addressing conflict through collective action in natural resource management. Int J Commons. 2017;11(2):877–906. https://doi.org/10.18352/ijc.768
69. Young H, Goldman L. Livelihoods, Natural Resources, and Post-Conflict Peacebuilding. 1st ed. London: Routledge; 2015. 544 p.
70. Medina L, Pacillo G, Läderach P, Sieber S, Bonatti M. Adapting to climate change under threats of violence: A comparative institutional analysis of incentives for conflict and collaboration. Curr Res Environ Sustain. 2025;9:100276.
71. Sultana P, Thompson PM, Paudel NS, Pariyar M, Rahman M. Transforming local natural resource conflicts to cooperation in a changing climate: Bangladesh and Nepal lessons. Clim Policy. 2018;19(sup1):S94–106. https://doi.org/10.1080/14693062.2018.1527678