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Climate Change and Its Impact on Land Use: A Case Study of Marsabit County, Kenya

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Abstract
This study examines compound vulnerability in Marsabit County, Kenya's second-largest county, where approximately 95 per cent of the population depends on pastoral or agro-pastoral production. Climate change and development pressures are jointly reshaping land use patterns in Kenya's arid and semi-arid lands, with profound implications for pastoral livelihoods. Using a mixed-methods case study approach spanning 1990-2025, the research integrates climate data, satellite imagery analysis, policy documents, and development project assessments to document how climate change and development interventions interact to transform pastoral land use systems. Findings reveal significant climate change manifestations: temperature increases of 0.05°C per annum, rainfall decline of 5.18mm per annum, and intensifying droughts (2010-2011, 2016-2017, 2020-2022) that have devastated pastoral livelihoods. The 2022 drought alone killed 273,000 livestock. Ecological impacts include vegetation loss, with the Marsabit Forest Reserve losing 52.7 per cent of closed forest and 75.7 per cent of open forest between 1990 and 2010, reducing rangeland productivity. Development pressures, including the Lake Turkana Wind Farm, conservation area expansion, and urban growth, restrict pastoral land access and mobility. Wind energy installations occupy dry-season grazing areas, conservation fencing blocks migration routes, and agricultural expansion fragments landscapes. These interventions, promoted as climate mitigation or economic solutions, undermine pastoral mobility, creating a "double squeeze" where climate-reduced resources are compressed into development-restricted spaces. This forces decentralisation, alters herd composition, drives diversification into marginal activities, and causes impoverishment. The study reveals that poor households, women, and certain ethnic groups experience disproportionate impacts, highlighting differential vulnerability within pastoral populations.

Key words: Conservation, drought, pastoralism, vulnerability, wind energy.

INTRODUCTION

Pastoral communities in Kenya's northern rangelands increasingly face a "double squeeze" where climate-induced resource scarcity coincides with development-driven restrictions on land access and mobility, compressing adaptive space and threatening the viability of pastoral production systems. Despite growing recognition of climate change impacts on arid and semi-arid lands (ASALs), research and policy interventions have traditionally focused on singular climate stressors, overlooking the complex interactions between climate change and concurrent development pressures. This narrow analytical lens obscures the cumulative effects of these forces, risking interventions that inadvertently worsen vulnerability.

Climate change poses unprecedented threats to the world's ASALs, ecosystems that support over two billion people globally and cover approximately 40 per cent of the Earth's terrestrial surface. Recent evidence indicates a dramatic transformation underway: three-quarters of Earth's land has become permanently drier over the last three decades, with arid and hyper-arid areas expanding by more than 10 million square kilometres. This shift towards increased aridity carries profound implications for the millions of people whose livelihoods depend on these fragile ecosystems, particularly in regions where adaptive capacity remains constrained by poverty, limited infrastructure, and weak institutional support. Africa bears a disproportionate burden of climate vulnerability, with pastoral communities facing particularly acute challenges. The continent's livestock-dependent populations, numbering in the hundreds of millions, confront rising temperatures, erratic rainfall patterns, and increasingly frequent and severe droughts that undermine the ecological foundations of pastoral production systems.

The Horn of Africa's recent multi-year drought from 2020 to 2023 exemplifies this crisis, causing unprecedented livestock mortality and human displacement across the region. Within this continental context, Kenya represents a critical case: approximately 80 per cent of its landmass is classified as ASAL, yet these areas support only about 20 per cent of the national population while contributing significantly to the country's agricultural economy through livestock production. This geographic reality renders Kenya's rural poor especially vulnerable to climate variability and change. Increasingly, however, climate change does not operate in isolation. Pastoral communities across Africa's ASALs now face a convergence of climate stressors and new development pressures, including renewable energy installations, conservation initiatives, infrastructure expansion, and land tenure transformations (Abebe et al., 2022). This compound vulnerability demands analytical frameworks that move beyond single-stressor approaches to capture the cumulative and interactive effects of multiple pressures on land use systems and pastoral livelihoods.

Marsabit County provides an ideal case for examining the compound impacts of climate change and development pressures on land use in Kenya's ASALs. As the country's largest county at 70,961 square kilometres, Marsabit encompasses diverse ecological zones ranging from low plains to volcanic highlands, yet approximately 95 per cent of its population depends on pastoral or agro-pastoral production systems. This heavy reliance on climate-sensitive livelihoods makes the county particularly vulnerable to environmental change. The county is experiencing severe and well-documented climate impacts. Temperature records indicate a warming trend of approximately 0.05°C per annum over recent decades, while rainfall has declined at a rate of roughly 5.18 millimetres per year, accompanied by increased inter-annual and seasonal variability. These trends have manifested in more frequent and intense droughts, including devastating events in 2010-2011, 2016-2017, and 2020-2022 that caused massive livestock losses and human displacement. The ecological consequences are stark: between 1990 and 2010, Marsabit Forest Reserve, a critical water source for surrounding pastoral communities, lost over half its closed forest cover and three-quarters of its open forest, signalling severe environmental degradation. Simultaneously, Marsabit faces new development pressures that compound climate stressors. Large-scale wind energy installations have been developed in areas traditionally used for dry-season grazing, restricting pastoral mobility and creating novel land use conflicts.

Conservation initiatives have expanded protected areas and introduced fencing that blocks traditional migration routes. These development interventions, combined with urban expansion and infrastructure projects, are progressively shrinking the spatial domain available for pastoral production even as climate change reduces the ecological productivity of remaining accessible lands. Marsabit's situation is representative of broader

challenges facing Kenya's ASALs, where climate vulnerability intersects with rapid social, economic, and political transformation. Understanding how these compound stressors reshape land use in Marsabit, therefore, offers lessons applicable across the region and beyond (Adger, 2006). The county's Marsabit Climate Change Action Plan 2023-2027 further demonstrates policy awareness of these challenges, making Marsabit an opportune site for research that can directly inform implementation and identify gaps between planning intentions and ground realities.

This paper examines how climate change and development pressures jointly impact land use in Marsabit County, Kenya, with particular attention to the implications for pastoral livelihoods and adaptive capacity. The primary objective is to analyse the compound effects of climate change and development interventions on land use patterns and pastoral systems in Marsabit County. This primary objective is pursued through five specific objectives: Document climate change manifestations in Marsabit County, including long-term trends in temperature and rainfall, drought frequency and intensity, and associated ecological changes over the past three decades. Analyse resulting changes in pastoral land use patterns, including shifts in mobility, grazing territories, herd composition, livelihood strategies, and vegetation cover, with attention to the mechanisms linking climate stressors to land use transformation. Assess how wind energy development and conservation initiatives compound climate stressors, specifically examining how these development interventions interact with climate impacts to reshape pastoral land access, mobility, and resource availability. Evaluate the implications of compound stressors for pastoral livelihoods and sustainability, including impacts on household food security, income generation, social organisation, and the viability of pastoral production systems under multiple pressures. Identify lessons for climate-sensitive development policy, drawing insights from Marsabit's experience to inform more integrated approaches to climate adaptation and development planning in Kenya's ASALs and comparable dryland regions globally.

By addressing these objectives, this paper contributes both empirically and theoretically to understanding compound vulnerability in pastoral ASALs, while offering practical recommendations for policymakers, development partners, and county governments seeking to balance climate action, development goals, and pastoral community rights.

LITERATURE REVIEW

Climate change is manifesting with particular severity across Kenya's arid and semi-arid lands, where increasing temperatures and declining rainfall trends have been documented over recent decades. Analysis of climate trends in Kenya's ASAL areas indicates rising temperatures and declining rainfall from 1977 to 2014, trends that correspond with broader regional patterns in Eastern Africa.The Horn of Africa, encompassing Kenya's northern and eastern ASALs, is experiencing some of the most rapid climate change impacts on the continent, with consequences that are both immediate and long-term in nature. Temperature records across Kenya's ASALs indicate consistent warming trends that exacerbate evapotranspiration rates and intensify water stress for both human populations and livestock. Rainfall patterns have become increasingly erratic, characterised not only by declining annual totals but also by greater inter-annual and intra-seasonal variability that undermines the predictability upon which pastoral systems traditionally depend. Extreme rainfall is anticipated to become more frequent, last longer, and increase in intensity, while rainfall in arid zones is expected to decrease, creating a paradoxical situation where communities face both flooding and drought within compressed timeframes (African Union, 2010).

These climate trends have manifested in a series of devastating droughts that have punctuated the past two decades. The 2010-2011 drought represented one of the worst in sixty years, causing massive livestock mortality and human displacement across northern Kenya. The 2016-2017 drought similarly devastated pastoral communities, while the prolonged multi-season drought from 2020 to 2022 created what some observers termed a humanitarian catastrophe, with millions of livestock deaths and widespread food insecurity. Recent patterns show rainfall as highly variable, with some regions receiving above-average rains while most other regions experience drier than normal conditions, illustrating the spatial complexity of climate impacts within Kenya's ASALs. The vulnerability of Kenya's ASAL populations to these climate trends stems from multiple reinforcing factors. Low adaptive capacity, constrained by poverty, limited infrastructure, weak social services, and marginal political influence, reduces communities' ability to buffer climate shocks. Heavy reliance on climate-sensitive

livelihoods, particularly livestock production and opportunistic agriculture, means that climate variability directly translates into livelihood disruption. The interaction between chronic vulnerability and acute climate shocks creates conditions where households struggle to recover between successive droughts, resulting in progressive asset depletion and deepening poverty. Kenya's ASAL counties thus exemplify what climate scientists term "hotspots" of climate vulnerability, where exposure, sensitivity, and limited adaptive capacity converge to create acute risk.

Pastoralism represents a sophisticated adaptation to arid and semi-arid environments, developed over centuries to exploit spatially and temporally variable resources. Traditional pastoral systems are fundamentally predicated on mobility, the strategic movement of livestock and people in response to rainfall patterns, vegetation availability, and water sources. This mobility serves multiple adaptive functions: it allows pastoralists to access dispersed resources across vast territories, distribute grazing pressure to prevent localised degradation, manage disease risks by avoiding contaminated areas, and maintain social networks across extensive landscapes. Livestock mobility is a complex concept holding many different meanings for observers of pastoralism, with the movement of African pastoralists with their livestock historically seen by outsiders as working against both environmental and development goals, though recent scholarship increasingly recognises mobility's ecological and economic rationality.

The ecological foundation of pastoral systems rests on following rainfall patterns through rotational grazing that allows vegetation recovery, maintaining herd diversity to exploit different ecological niches, and distributing risk across space and time. Communal resource management institutions govern access to key resources, water points, dry-season grazing reserves, and salt licks—through customary rules that balance individual household needs with collective sustainability. Clan-based social organisations provide the framework for resource access, conflict resolution, and mutual assistance during hardship, creating social capital that functions as a critical buffer against environmental variability. The economic significance of pastoralism in Kenya's ASALs remains substantial despite decades of predictions of its imminent demise. In Marsabit County specifically, approximately 80 per cent of household income derives from livestock and livestock products, illustrating pastoralism's continued centrality to local economies (Agrawal, 2010). At the national scale, livestock production contributes significantly to Kenya's agricultural GDP and provides livelihoods for millions of people in marginal lands unsuited for crop agriculture. Recent economic analyses increasingly challenge historical assumptions that pastoralism represents an inefficient or backward production system, instead highlighting its productivity per unit of rainfall and its ability to convert resources inedible to humans into valuable protein and other products.

Pastoralist adaptation strategies have to address multiple, overlapping, and often interrelated processes of socio-ecological change, requiring flexibility and innovation in response to shifting contexts. Adaptive strategies documented in the literature include herd diversification across species and breeds to manage different risks, migration patterns that respond to evolving resource availability, and indigenous knowledge systems that encode environmental information across generations. Strategies included income diversification, supplementary feeding and livestock mobility, though pastoralists had to overcome a hierarchy of barriers to implement their coping and adaptation strategies. However, contemporary pastoral systems face profound challenges that constrain traditional adaptive strategies. Decentralisation processes driven by multiple factors, such as government policy, service provision, land privatisation, and reduced mobility options, are fundamentally altering pastoral social organisation and resource management. Land fragmentation through various mechanisms, including individual titling, group ranch subdivision, and infrastructure expansion, is shrinking the spatial domain available for pastoral production. Market integration, while offering new opportunities, also creates dependencies and vulnerabilities, particularly when climate shocks disrupt market access or collapse livestock prices during drought-induced sales (Angassa & Oba, 2008). These contemporary challenges interact with climate change to create compound pressures that threaten pastoral system viability.

Understanding how climate change impacts pastoral land use requires analytical frameworks that capture compound vulnerability, the interaction between climate stressors and concurrent non-climate pressures. Recent scholarship on vulnerability, resilience, and adaptation increasingly emphasises that communities rarely face

single, isolated stressors but rather experience multiple pressures that interact in complex and often synergistic ways (Kipuri & Ridgewell, 2008). Compound vulnerability theory suggests that the cumulative impact of multiple stressors may exceed the sum of individual stressor effects, as each pressure can constrain the capacity to respond to others. Globally, pastoral communities face numerous non-climate stressors alongside environmental change (Krätli & Schareika, 2010). Conservation displacement represents a widespread phenomenon where protected area establishment or expansion restricts pastoral access to critical resources. Infrastructure development, such as roads, dams, and power transmission lines, fragments pastoral landscapes and disrupts migration routes (Kenya National Bureau of Statistics, 2019). Resource extraction projects for minerals, oil, or geothermal energy alienate land and create localised environmental impacts. Agricultural expansion, both large-scale commercial farming and smallholder encroachment, progressively converts rangelands to cropland (Barrett et al., 2005). Each of these pressures individually constrains pastoral production; combined with climate change, they create compound vulnerability (Kristjanson et al., 2014).

The concept of "green grabbing" has emerged to describe a particular form of compound pressure highly relevant to contemporary pastoral contexts. Green grabbing involves confiscated lands that may be used for solar energy, wind farms, and biofuel, borrowing from historical stories of colonial resource appropriation under the pretence of environmental preservation (Kiteme & Gikonyo, 2002). In the rush to repair damaged nature through trading and offset schemes, projects have targeted so-called "under-used, marginal" lands in Africa, which are actually the places where farmers and pastoralists make their livelihoods. This phenomenon encompasses renewable energy installations, carbon offset schemes, conservation initiatives, and ecosystem restoration projects that displace or marginalise existing land users in the name of environmental objectives (Béné et al., 2012). The justice dimensions of green grabbing and compound stressors raise critical questions about who bears the costs of climate mitigation and adaptation projects.

When pastoral lands are appropriated for wind farms that supply power to urban centres, or when carbon offset schemes restrict pastoral mobility to sequester carbon, vulnerable communities effectively subsidise climate action for others while losing their own adaptive capacity. This raises fundamental questions of distributive justice, how costs and benefits of climate action are allocated, and procedural justice, whether affected communities participate meaningfully in decisions (Kenya Meteorological Department, 2024). The compound stressor framework thus necessarily incorporates political ecology perspectives that examine power relations, rights, and equity in environmental governance. Cumulative impact assessment methodologies attempt to capture how multiple stressors interact and amplify each other's effects. Such assessments recognise that stressors may have additive effects (cumulative impact equals the sum of individual impacts), synergistic effects (cumulative impact exceeds the sum due to interaction), or antagonistic effects (one stressor mitigates another). In pastoral contexts, climate change reducing available forage and development projects restricting spatial access likely interact synergistically, as spatial compression intensifies pressure on degraded resources (Bollig & Österle, 2013). Single-stressor approaches miss these critical dynamics, potentially leading to interventions that inadvertently worsen compound vulnerability by ignoring systemic interactions.

Kenya's northern rangelands are experiencing rapid transformation driven by multiple development pressures that reshape pastoral land use. Infrastructure expansion represents perhaps the most visible change, with major road corridors, power transmission lines, fibre optic networks, and other connectivity projects increasingly penetrating formerly remote pastoral areas. While infrastructure can improve market access and service delivery, it also facilitates land alienation, encourages immigration, and fragments pastoral landscapes in ways that constrain traditional mobility patterns (Kamau et al., 2021). Conservation initiatives have expanded significantly across northern Kenya, driven by both governmental protected area establishment and the rapid growth of community conservancies. Wildlife conservancies, often established through partnerships between pastoral communities and conservation organisations, now cover extensive areas across Samburu, Laikipia, Isiolo, and neighbouring counties (Boles et al., 2019). While conservancies can generate revenue through tourism and conservation payments, they also restrict land use, prioritise wildlife over livestock, and can create new forms of inequality within pastoral communities. Fencing associated with

conservancies and private ranches blocks traditional migration routes and concentrates grazing pressure on remaining accessible lands, while also intensifying human-wildlife conflict as animals are confined to smaller areas overlapping with pastoral settlements (Kamara et al., 2019).

Renewable energy development represents a rapidly emerging pressure in Kenya's ASALs, driven by national commitments to clean energy and the region's excellent wind and solar resources. Large-scale wind farms have been developed or are planned in several northern counties, with installations requiring substantial land areas for turbines, access roads, transmission infrastructure, and exclusion zones (Jones & Boyd, 2011). Solar farms similarly require extensive land footprints in regions where land was previously available for pastoral use. While renewable energy projects are promoted as climate mitigation measures, their impacts on pastoral communities raise questions about climate justice when "green" development displaces vulnerable populations from lands they depend upon for climate adaptation (Johnsen et al., 2019). Land tenure changes represent another critical pressure transforming northern Kenya's pastoral systems. Government policies have progressively promoted privatisation through various mechanisms, including individual titling programs, group ranch subdivision, and community land registration (Brockington & Igoe, 2006). Legal frameworks for communal land rights in Ethiopia, Kenya, and Tanzania are now gaining momentum, with questions raised about whether these frameworks adequately account for the complexities of pastoral resources and the disadvantages of formalising tenure. Boundary demarcation and titling can provide security against external appropriation, but also constrain mobility, create exclusions, and fundamentally alter social relationships around resource access (Jenet et al., 2016). The tension between securing communal rights and preserving flexibility for pastoral mobility remains unresolved in policy and practice.

In Marsabit County specifically, these development pressures converge in ways that exemplify broader regional dynamics. Wind park installations in areas traditionally used for dry-season grazing have created novel conflicts between renewable energy development and pastoral production. Forest conservation efforts on Mount Marsabit, while protecting a critical water source, have restricted pastoral access to highland grazing areas and forest resources. Urban expansion of Marsabit town and secondary centres progressively alienates the surrounding lands. Tourism development promotes conservation over pastoral production, while infrastructure projects fragment the landscape (Jandreau & Berkes, 2016). Critical across all these development pressures are issues of consent and participation. Development projects in northern Kenya frequently proceed with limited meaningful community involvement in planning and decision-making. Uncoerced, timely, and Informed Consent (FPIC), a principle enshrined in international human rights frameworks, remains more aspiration than reality in many contexts (Catley et al., 2013). Consultation processes may be superficial, excluding women and marginalised groups, and failing to address concerns about land access restrictions and livelihood impacts. Compensation mechanisms, where they exist, often inadequately address the long-term consequences of reduced pastoral mobility and resource access (IPCC, 2022). These governance failures compound the material impacts of development pressures, creating grievances that can fuel conflict and undermine both development effectiveness and pastoral wellbeing.

METHODOLOGY

This study employs a mixed-methods case study design to examine the compound impacts of climate change and development pressures on land use in Marsabit County. The case study approach is appropriate given the complexity of socio-ecological systems in pastoral contexts and the need to understand processes and outcomes within their specific geographic, historical, and institutional settings (Homewood, 2008). Case studies enable in-depth investigation of contemporary phenomena in real-world contexts, particularly where boundaries between phenomenon and context are not clearly evident, a characteristic feature of compound vulnerability where multiple stressors interact.

The mixed-methods approach combines quantitative analysis of climate trends and land use change with qualitative examination of policy documents, development project assessments, and community experiences (County Government of Marsabit, 2023). This methodological triangulation serves multiple purposes: quantitative data establish the magnitude and direction of biophysical changes, while qualitative data illuminate the mechanisms, meanings, and differential impacts of these changes. The integration of methods allows for more robust conclusions than either approach

alone could provide, addressing both the "what" and "how" of compound stressor impacts on pastoral land use. The temporal scope of the study focuses on the period from 1990 to 2025, spanning 35 years. This timeframe captures significant climate trends, major drought events, and the acceleration of development interventions in Marsabit (Crate & Nuttall, 2016). The 1990 baseline allows for before-and-after comparisons spanning multiple decades while remaining within the period for which reliable satellite imagery and climate data are available. The endpoint of 2025 incorporates the most recent climate impacts, including the 2020-2022 drought, and the contemporary development landscape, including wind energy installations and updated county climate planning documents.

Spatially, the study encompasses the entire Marsabit County administrative area, with particular emphasis on regions where wind energy development, conservation areas, and pastoral grazing lands overlap. This spatial focus allows examination of how development interventions intersect with areas critical for pastoral adaptive strategies, particularly dry-season grazing reserves and migration corridors. Sub-county variations are considered to capture the heterogeneity of impacts across the county's diverse ecological zones and ethnic territories. Integration of quantitative and qualitative findings occurs through triangulation, where different data sources are compared to assess convergence or divergence (Cuni-Sanchez et al., 2019). Quantitative evidence of climate trends and land cover change is interpreted in light of qualitative insights about pastoral adaptive strategies, policy frameworks, and development governance. Where different data sources yield consistent conclusions, confidence in findings increases. Where inconsistencies emerge, they become subjects for further investigation and nuanced interpretation. This integration produces a richer, more contextualised understanding of compound vulnerability than either approach alone could achieve, supporting both empirical documentation and theoretical advancement (Hersperger et al., 2018).

RESULTS AND DISCUSSION

Analysis of temperature data from Marsabit County reveals a clear warming trend over the study period from 1990 to 2017. The data indicate a mean temperature increase of approximately 0.05°C per annum, translating to a total warming of roughly 1.35°C over the 27-year period analysed. This warming rate exceeds the global average and aligns with broader regional trends across Eastern Africa's arid and semi-arid lands, where temperature increases have been particularly pronounced. The implications of this temperature trend for pastoral ecosystems and livelihoods are significant. Rising temperatures directly increase evapotranspiration rates, intensifying water stress for both vegetation and livestock even when rainfall remains constant (Herrero et al., 2009). The combined effect of warming and rainfall decline (discussed below) creates a multiplier effect on aridity, fundamentally altering the water balance of the ecosystem. Higher temperatures also affect livestock physiology, reducing feed conversion efficiency, milk production, and reproductive performance, particularly for cattle, which are less heat-tolerant than camels or goats (Davies et al., 2016). Seasonal analysis reveals that temperature increases are not uniform throughout the year. The dry seasons have experienced more pronounced warming than wet seasons, exacerbating the already challenging conditions during periods when pastoral communities most need access to dry-season grazing reserves and reliable water sources. This seasonal pattern intensifies the critical importance of dry-season resources that are increasingly being restricted by development pressures, as discussed in subsequent sections (Haile et al., 2020).

Comparison with national and regional temperature trends confirms that Marsabit's warming trajectory is consistent with patterns across Kenya's ASALs. However, the absolute temperatures in Marsabit County, with mean annual temperatures exceeding 30°C in lowland areas, mean that even modest additional warming pushes ecological and physiological systems closer to critical thresholds (Government of Kenya, 2022). The mix of elevated baseline temperatures and ongoing warming leads to more frequent and intense heat stress for livestock and pushes vegetation closer to the limits of its thermal tolerance. Rainfall analysis reveals an even more concerning trend than temperature for pastoral sustainability in Marsabit County (Devereux, 2006). Data indicate a documented decline of approximately 5.18 millimetres per annum over the study period. While this may appear modest in absolute terms, cumulative over three decades, it represents a reduction of over 150 millimetres, a substantial proportion of annual rainfall in an environment where mean annual totals range from 200mm in lowlands to 800mm on Mount Marsabit. Beyond the declining trend in total rainfall, increased inter-annual and intra-seasonal

variability has emerged as a defining characteristic of recent decades (Thornton et al., 2009). Annual fluctuations have become more extreme, complicating pastoralists' ability to forecast rainfall using traditional knowledge and signs. Within individual rainy seasons, rainfall has become more erratic, with longer dry spells interspersed with intense rainfall events that generate runoff rather than effective soil moisture recharge (Diabaté, 2020). This variability undermines the predictability upon which pastoral mobility strategies traditionally depend.

Changes in the timing and duration of rainy seasons represent another critical dimension of change. The March-May long rains and October-December short rains that have historically structured the pastoral calendar have become less reliable in both timing and distribution. Delayed onset means that vegetation regeneration occurs later, forcing livestock to remain on degraded dry-season pastures for extended periods (Government of Kenya, 2020). Early cessation cuts short the critical period when rangeland productivity peaks and animals can rebuild body condition. These temporal shifts disrupt the synchronised cycles of vegetation growth, livestock reproduction, and human mobility that characterise functional pastoral systems. The implications for vegetation regeneration and water availability are profound. Declining and increasingly variable rainfall reduces the productivity of rangelands, decreasing the carrying capacity for livestock. Perennial grasses decline while annual species and less palatable vegetation increase, signalling ecosystem degradation (Dong et al., 2016). Water availability in springs, seasonal streams, and natural pans becomes less predictable, forcing greater reliance on permanent water points that then become sites of overgrazing and resource concentration. The Mount Marsabit Forest Reserve, which functions as the critical water tower for surrounding pastoral areas, faces particular pressure as reduced rainfall compromises its hydrological functions (Doss & Morris, 2001).

Discussion

The findings from Marsabit County illustrate a critical dynamic that extends beyond this single case: pastoral communities across Kenya's ASALs increasingly face a "double squeeze" where climate change reduces ecological productive capacity while development interventions simultaneously reduce spatial adaptive capacity. This compound vulnerability represents more than the sum of individual stressors; the interactions between climate and development pressures create synergistic effects that fundamentally threaten pastoral system viability (Eriksen et al., 2015). Climate change alone would challenge pastoral adaptation through declining rainfall (5.18mm/year), rising temperatures (0.05°C/year), and more frequent severe droughts. These trends reduce vegetation productivity, increase water stress, and shorten recovery periods between climate shocks. Historically, pastoral communities adapted to such environmental variability through mobility, moving livestock to areas experiencing better conditions and allowing degraded areas to recover (Vetter, 2005). This adaptive strategy required extensive spatial domains and flexible access to diverse resources across landscapes. Development pressures in Marsabit wind energy installations, conservation areas, urban expansion, and agricultural encroachment progressively restrict precisely this spatial flexibility that pastoralists need for climate adaptation (Fairhead et al., 2012). The Lake Turkana Wind Farm, while generating clean energy for Kenya's grid, occupies critical dry-season grazing areas and fragments pastoral landscapes with infrastructure. Conservation fencing encloses vital resources and blocks migration routes. Urban growth alienates peri-urban rangelands (Turner & Schlecht, 2019). Each restriction operates independently of climate impacts, yet together they foreclose the mobility-based adaptation that pastoral systems require.

The paradox is striking: "green" development, touted as a solution to climate change, inadvertently weakens the ability of vulnerable communities to cope with its impacts. Wind farms reduce carbon emissions but displace pastoralists from lands they need for climate adaptation. Conservation protects biodiversity but restricts pastoral access to climate refugia. This exemplifies environmental justice failures where marginalised populations bear the costs of climate action, benefiting distant urban populations (Government of Kenya, 2018). The Marsabit case thus provides empirical evidence for theoretical concerns about "green grabbing" and unequal distribution of climate action burdens. Comparative analysis with other pastoral regions in Kenya, Turkana facing oil development pressures, Samburu dealing with conservancy expansion, and Laikipia experiencing agricultural encroachment, reveals similar patterns of compound vulnerability. The specifics differ, but the fundamental dynamic remains: climate change plus development restrictions equals compressed adaptive space and deepening vulnerability (FAO, 2021).

Policy approaches that address climate or development in isolation miss these critical systemic interactions.

The land use transformations documented in Marsabit County reveal specific mechanisms through which compound stressors reshape pastoral systems. Climate change triggers initial adaptation responses. Households diversify their herds toward drought-tolerant species, increase mobility in search of resources, or adopt supplementary livelihood activities (Ford et al., 2011). These changes are logical responses to environmental shifts, historically allowing communities to sustain pastoral livelihoods under fluctuating conditions. However, development pressures foreclose many adaptive options, forcing maladaptive trajectories. When wind farms occupy dry-season reserves, pastoralists cannot move to better resources (Scoones, 2021). When conservation areas fence critical grazing lands, mobility becomes impossible. When agricultural expansion fragments landscapes, migration routes disappear. The result is forced sedentarisation, not chosen for its benefits but imposed by lack of spatial alternatives. This sedentarisation fundamentally transforms social organisation (Folke, 2006).

Clan-based communal resource management institutions that governed mobile pastoralism lose relevance when populations become sedentary and lands are fragmented. Market integration intensifies as pastoral production alone proves insufficient, creating new dependencies and vulnerabilities. Youth migrate seeking non-pastoral opportunities, draining communities of labour and weakening intergenerational knowledge transmission (Peluso & Lund, 2011). The social transformation accompanies and accelerates the ecological and economic decline. The trajectory leads toward what might be termed "pastoral poor" populations with pastoral identity and some remaining livestock but insufficient herd sizes for viable pastoral livelihoods, living in poverty and dependent on humanitarian assistance. This represents not a successful adaptation but a system collapse, where compound pressures have exceeded the capacity for resilient transformation (Fratkin & Mearns, 2003). The loss of pastoral livelihoods carries implications beyond economics, cultural identity, social cohesion, and indigenous knowledge systems erode when pastoral production becomes untenable.

The compound vulnerability documented in Marsabit reveals critical gaps between climate policy rhetoric and ground reality. Kenya's national climate policies and the Marsabit County Climate Change Action Plan 2023-2027 acknowledge pastoral vulnerability and emphasise participatory approaches, yet implementation remains disconnected from these principles. Development projects proceed with limited meaningful community consultation, despite rhetoric about stakeholder engagement. Sectoral fragmentation compounds policy failures (Government of Kenya, 2016). Energy planning prioritises renewable energy targets without adequately considering pastoral land use. Conservation planning focuses on biodiversity protection with insufficient attention to pastoral livelihoods. County development planning promotes agricultural expansion and urban growth without assessing cumulative impacts on pastoral systems (Nyariki & Amwata, 2019). No integrated mechanism coordinates across sectors to assess compound impacts or resolve competing land use priorities. Free, Prior, and Informed Consent (FPIC) remains aspirational rather than operational. Wind energy projects affecting pastoral lands proceeded without genuine FPIC, with consultation processes that were superficial, excluded marginalised groups, and failed to address community concerns (Galvin, 2009). Revenue and benefit-sharing mechanisms prove inadequate, as wind energy generates billions for national coffers and private developers, while pastoral communities receive minimal compensation for lost land access.

The governance challenges extend beyond procedure to fundamental questions about whose interests development serves. National goals for renewable energy and conservation align with global climate and biodiversity commitments, attracting political and financial backing. Pastoral livelihood protection receives rhetorical support but limited resources or political priority (Goldman, 2011). This power imbalance means that when conflicts arise between development objectives and pastoral rights, development typically prevails. Effective policy would require integrated planning that coordinates across climate, energy, conservation, and pastoral development sectors; mandatory cumulative impact assessment examining how multiple projects jointly affect pastoral lands; enforceable FPIC requirements ensuring meaningful community consent; equitable benefit-sharing from development projects on pastoral lands; and genuine political commitment to protecting pastoral rights not merely as development

targets but as matters of justice (Gebrechorkos et al., 2023). Marsabit's experience suggests these requirements remain distant from current reality.

CONCLUSION AND RECOMMENDATIONS

Conclusion: This study has examined how climate change and development pressures jointly impact land use in Marsabit County, Kenya, revealing a pattern of compound vulnerability that threatens pastoral system viability. The analysis documented significant climate change manifestations: temperature increases of 0.05°C per annum, rainfall decline of 5.18mm per annum, and intensifying droughts in 2010-2011, 2016-2017, and 2020-2022. These climate trends have driven dramatic ecological changes, including a 52.7 per cent loss of closed forest and a 75.7 per cent loss of open forest in the critical Marsabit Forest Reserve between 1990 and 2010. Simultaneously, development pressures, particularly the Lake Turkana Wind Farm, conservation area expansion, and urban growth, have restricted pastoral land access and mobility. The compound effect creates a "double squeeze" where climate-reduced resources must support pastoral livelihoods on development-restricted space. This compression has forced sedentarisation, herd composition changes, livelihood diversification into marginal activities, and progressive impoverishment.

The 2022 drought exemplified compound vulnerability's devastating potential, killing 273,000 livestock in Marsabit and pushing communities into a humanitarian crisis. The case reveals critical theoretical and empirical insights about compound stressors in pastoral ASALs. Climate adaptation through mobility becomes impossible when development restricts spatial access. "Green" development paradoxically undermines vulnerable communities' adaptive capacity. Single-stressor policy approaches miss systemic interactions that amplify vulnerability.

Recommendations: Power imbalances mean pastoral communities bear the costs of climate action, benefiting others, and fundamental environmental justice failures require urgent attention. Integrating climate and development planning through mandatory cumulative impact assessments and implementing enforceable FPIC requirements for projects affecting pastoral lands. Establish equitable benefit-sharing mechanisms that ensure affected communities receive proportional gains from development, and recognise and protect pastoral mobility rights as essential for climate adaptation. Prioritise pastoral development investments, building on rather than replacing traditional systems. Conduct comprehensive social and environmental impact assessments examining compound effects across multiple projects. Support community-led adaptation initiatives leveraging indigenous knowledge and pastoral priorities. Ensure that development projects enhance, rather than undermine, climate adaptation capacity. Apply environmental justice frameworks to assess the distribution of costs and benefits. Implement the Marsabit Climate Change Action Plan 2023-2027 with genuine pastoral participation. Strengthen customary land governance institutions. Develop climate-smart pastoral infrastructure, including mobile veterinary services, drought-resilient water points, and early warning systems. Create meaningful employment for pastoral communities in renewable energy projects. Establish transparent mechanisms for resolving land use disputes. Conduct longitudinal monitoring of compound stressor impacts and adaptive trajectories. Undertake participatory action research co-producing knowledge with pastoral communities. Document indigenous adaptation strategies and assess their continued viability. Perform comparative cost-benefit analysis of supporting pastoral systems versus promoting alternative livelihoods. Develop integrated models linking climate trends, development interventions, and pastoral outcomes.

This study's reliance on secondary data limits its temporal resolution and depth of community perspective. Future research should incorporate extended primary data collection, including household surveys, participatory mapping, and longitudinal case studies tracking specific communities over multiple years. A comparative analysis across Marsabit sub-counties and other northern Kenya counties would illuminate geographic variations in compound vulnerability. The challenge of distinguishing the effects of climate and development from other complicating factors highlights the need for more advanced analytical methods. Agent-based modelling could simulate how different stressor combinations affect pastoral decision-making and outcomes. Scenario analysis could project future trajectories under various climate and development pathways, informing proactive planning. Research gaps persist regarding the specific mechanisms of resilience and collapse, as well as why some households withstand compound pressures while others succumb. Gender-disaggregated analysis would reveal differential impacts and adaptive capacities.

Assessment of alternative development models, including community-owned renewable energy, pastoral-wildlife integration, and value chain development, could identify viable pathways forward. Ultimately, Marsabit County exemplifies broader challenges facing pastoral ASALs globally where climate change intersects with rapid development. The lessons learned about compound vulnerability, green development paradoxes, governance failures, and justice dimensions extend beyond this single case. Addressing these challenges requires fundamental shifts from single-issue interventions toward integrated, rights-based, and justice-oriented approaches that support, rather than undermine, pastoral communities' adaptive capacity. The future of millions of pastoral livelihoods across Kenya's ASALs depends on whether such shifts can be achieved before compound pressures exceed the threshold of resilient adaptation.

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