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RESEARCH PAPER

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Dynamics of land use and land cover change in Puntland, Somalia: Drivers, trends, and implications for dryland ecosystem sustainability

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ABSTRACT

Puntland State in northeastern Somalia exemplifies the challenges of balancing dryland resource use with ecosystem conservation under weak governance and climate variability. This study quantifies land use and land cover change (LULCC) dynamics in Puntland between 2010 and 2022 using Landsat satellite imagery (supervised classification, Maximum Likelihood Classifier), validated by household surveys (n=138), focus group discussions (n=4), and key informant interviews (n=6). Results show that in 2010, scrub/shrub dominated 15,116,029.49 ha (93.66%), bare ground 923,569 ha (5.72%), trees 62,573.60 ha (0.39%), water 31,104.90 ha (0.19%), crops 1,851.41 ha (0.01%), and built area 4,931.56 ha (0.03%). By 2022, scrub/shrub decreased to 13,623,750.00 ha (84.41%), while bare ground expanded dramatically to 2,440,480.00 ha (15.12%). Tree cover declined to 31,876.30 ha (0.20%), a loss of 30,697.30 ha at an annual deforestation rate of -6.13%, substantially higher than the national average (-1.03%). Crops increased to 5,223.73 ha (+9.43% annually), built area to 7,788.73 ha (+4.15% annually), while water surfaces remained stable (-0.05%). Community perceptions identified drought, overgrazing, and unsustainable wood harvesting as primary drivers. Frankincense (*Boswellia frereana*, *B. sacra*) and myrrh (*Commiphora myrrha*) value chains are critically threatened. Over 90% of institutional staff lacked formal environmental training. Puntland is transitioning from scrub/shrub rangeland to degraded bare ground. We recommend rangeland restoration, sustainable resin harvesting training, and institutional capacity building.

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INTRODUCTION

Dryland ecosystems cover approximately 40% of the Earth's land surface and support the livelihoods of over two billion people, yet they remain among the most poorly understood and inadequately monitored biomes globally (Reynolds *et al.*, 2007). In the Horn of Africa, drylands are particularly significant, constituting the majority of territory in Somalia, Ethiopia, Kenya, and Djibouti, and supporting pastoral and agro-pastoral production systems that have sustained human populations for millennia (Hassan *et al.*, 2019). However, these ecosystems are increasingly vulnerable to degradation due to the convergence of climate change, population growth, land use intensification, and governance failures. Understanding the rates, patterns, and drivers of land use and land cover change (LULCC) in drylands is therefore a scientific priority with direct implications for food security, biodiversity conservation, and climate change adaptation.

Globally, land use and land cover change (LULCC) represents one of the most significant anthropogenic modifications of the Earth system, with profound consequences for ecosystem services, carbon cycling, and biodiversity (Foley *et al.*, 2005). The conversion of natural vegetation to agricultural land, settlements, and degraded surfaces has accelerated dramatically since the mid-20th century, particularly in tropical and subtropical regions (Lambin *et al.*, 2001). According to the Food and Agriculture Organization (FAO, 2020), approximately 10 million hectares of forest were lost annually between 2015 and 2020, with Africa experiencing the highest rate of net forest loss. Within Africa, the Congo Basin retains the continent's largest contiguous forest block, yet even there, deforestation and degradation are advancing due to agricultural expansion, logging, and infrastructure development (Ernst *et al.*, 2013; Douandji *et al.*, 2025). However, dryland forests and woodlands, such as those in the Horn of Africa, have received far less research attention, despite covering vast areas and supporting millions of pastoral and agro-pastoral livelihoods (Hassan *et al.*, 2019; Webersik *et al.*, 2018).

Puntland State, occupying the northeastern horn of Somalia, presents a distinctive case for LULCC analysis. Unlike southern regions that benefit from perennial rivers, Puntland is characterized by arid to semi-arid conditions with annual rainfall ranging from 150 to 300 mm, highly seasonal precipitation patterns, and dependence on groundwater and rainwater harvesting for human and livestock water supply. The region contains the Golis Mountains, which create orographic rainfall effects supporting unique forest communities including Juniperus excelsa at higher elevations and Boswellia and Commiphora species on mountain slopes. These frankincense and myrrh trees are endemic to the region and have been harvested for millennia, forming the basis of a commercial resin trade that connects Puntland to international markets in the Arabian Peninsula, Europe, and beyond (Hassan, 2020; Hassan *et al.*, 2019). In 2020, Somalia exported $25.8 million in resins, making it the 8th largest exporter globally, with the majority originating from Puntland's Bari and Sanaag regions. Despite this economic significance, the sustainability of resin production is threatened by poor harvesting techniques, climate stress, and land degradation.

The drivers of LULCC vary considerably across African ecosystems. In humid forest zones, such as the Congo Basin and coastal West Africa, agricultural expansion, particularly smallholder shifting cultivation and commercial cash cropping, is the primary driver of deforestation (Megevand, 2013; Ernst *et al.*, 2013; Tchatchou *et al.*, 2015). For example, in the Mount Nlonako forest of Cameroon, Douandji *et al.* (2025) documented that dense forest declined from 75.42% of total area in 1986 to 45.89% in 2022, a loss of 54,159.6 ha (29.53%) over 36 years, driven primarily by farmland expansion (which increased from 0.93% to 6.40%) and industrial logging. Similarly, Feudjio *et al.* (2023) reported that the Santchou wildlife reserve in western Cameroon lost significant forest cover to cropland and built-up areas, with annual deforestation rates ranging from 0.84% to 1.57%. In the Melap Forest Reserve, Temgoua *et al.* (2021) found that clear forest was converted to farmland and bare ground at accelerating rates. These humid forest contexts contrast sharply with dryland environments, where climate variability interacts with human pressure to create degradation pathways that may be less directly controllable through land use policy alone.

In dryland Africa, including the Sahel, East African rangelands, and the Horn of Africa, LULCC dynamics are characterized by different processes. Here, recurrent drought, overgrazing, and fuelwood collection drive shrubland degradation and expansion of bare ground, rather than direct forest-to-agriculture conversion (Reynolds *et al.*, 2007; Herrmann *et al.*, 2005). Studies in Ethiopia's Rift Valley (Meshesha *et al.*, 2014), Kenya's rangelands (Owuor *et al.*, 2018), and Sudan's Sahelian zone (Ibrahim *et al.*, 2021) have documented transitions from woody cover to grassland and bare soil, often with limited recovery following dry periods. However, no comparable study has been conducted in Puntland, where security constraints, data scarcity, and limited research capacity have historically hindered environmental monitoring.

Globally, remote sensing and geographic information systems (GIS) have revolutionized the ability to monitor LULCC over large areas and extended time periods (Feudjio *et al.*, 2023; Temgoua *et al.*, 2021). Supervised classification using the Maximum Likelihood Classifier (MLC) has proven particularly effective for dryland environments, achieving accuracy exceeding 85% in numerous African studies (Mansour *et al.*, 2020; Douandji *et al.*, 2025).

The CA-Markov modeling approach, which combines Markov chain analysis of transition probabilities with cellular automata for spatial allocation, has been widely applied for predicting future land cover scenarios based on historical trends (Mishra and Rai, 2016; Wang *et al.*, 2019). The present study addresses the critical knowledge gap for Puntland by analyzing LULCC dynamics between 2010 and 2022, identifying the drivers and rates of vegetation change, and assessing implications for NTFP-dependent livelihoods.

MATERIALS AND METHODS

Study area

The study was conducted in Garowe and Bossaso districts, Puntland State, northeastern Somalia (approximately 8°24'N, 48°29'E for Garowe; 11°17'N, 49°11'E for Bossaso).

Puntland is characterized by rugged topography including the Golis Mountains (reaching 1,800 m asl at Ceerigabo), coastal plains along the Gulf of Aden, and extensive hinterland plateaus. The region has no perennial rivers, with boreholes, rainwater harvesting, and shallow wells providing water for human and livestock consumption. Annual rainfall ranges from 150 to 300 mm, falling during two rainy seasons: Gu (March–May) and Dayr (October–December). Mean annual temperatures range from 18°C in mountain areas to over 45°C in coastal lowlands during summer. Vegetation is dominated by open shrubland and woody plants including *Acacia bussei*, *Acacia etbaica*, *Boscia* spp., *Cadaba* spp., and *Acacia mellifera*, with *Boswellia frereana* (frankincense) and *Commiphora myrrha* (myrrh) on mountain slopes (Wieland and Werger, 1985).

Land cover classification and change detection

Landsat satellite imagery from 2010 (Landsat 7 ETM) and 2022 (Landsat 8 OLI-TIRS) was downloaded from the USGS Glovis data archive. Images were acquired during November–December to minimize cloud cover and harmonize seasonal vegetation conditions. Pre-processing included radiometric calibration, atmospheric correction, geometric registration to UTM projection (Zone 39N, WGS 1984), and mosaicking using ERDAS IMAGINE 2018 software. Supervised classification using the Maximum Likelihood Classifier (MLC) was employed. Six land cover classes were identified based on visual interpretation and the FAO Land Cover Classification System: (1) Trees (forest cover, including frankincense and myrrh woodlands), (2) Scrub/Shrub (degraded woodland and shrubland), (3) Crops (rainfed and irrigated agriculture), (4) Built Area (settlements and infrastructure), (5) Bare ground (exposed soil, rock, and degraded land), and (6) Water surface (ephemeral water bodies).

Training signatures (180 pixels per class) were developed using false-color composites (bands 4-3-2). Accuracy assessment was performed using confusion matrices derived from reference data (Google Earth high-resolution imagery and field observations), with overall accuracy >85% and Kappa coefficient >0.80 considered acceptable (Mansour *et al.*, 2020).

The annual rate of change (T) was calculated using the Bernier (1992) formula:

$$T = [(\ln S2 - \ln S1) / ((t2 - t1) \times \ln e)] \times 100$$

where S1 and S2 represent areas at dates t1 (2010) and t2 (2022), ln is the natural logarithm, and e = 2.71828.

Socioeconomic data collection

Mixed-methods data collection was conducted from April to June 2022. Household surveys (n=138; 70 in Garowe, 68 in Bossaso) using structured questionnaires captured NTFP collection practices, species used, income sources, perceptions of vegetation change, and challenges facing resource-dependent livelihoods. Focus group discussions (n=4; 2 in each district, average 6 participants per group) were conducted with community elders, frankincense collectors, and women involved in resin processing. Key informant interviews (n=6) targeted Ministry of Environment staff, customs authorities at Bossaso Port, frankincense exporters, and chamber of commerce representatives. Market surveys documented resin prices, quality grading systems, and trade routes. Institutional capacity assessments (n=10) evaluated staff training, infrastructure, and resource needs. Quantitative data were analyzed using SPSS version 26 and Microsoft Excel. Qualitative data from focus groups and interviews were analyzed using thematic analysis, with codes developed iteratively based on emergent themes.

RESULTS

Land cover classification accuracy

Accuracy assessment for the classified LULC maps revealed overall accuracy of 91.48% for the 2010 map and 93.11% for the 2022 map, with corresponding Kappa coefficients of 0.88 and 0.90. These values exceed the 85% threshold recommended for LULC classification by Mansour *et al.* (2020) and are comparable to results reported by Douandji *et al.* (2025) for Mount Nlonako (89.85–93.11%) and Feudjio *et al.* (2023) for Santchou (82–92%). User's accuracy ranged from 85.7% (Crops) to 96.8% (Bare ground), while producer's accuracy ranged from 87.1% (Bare ground) to 97.1% (Scrub/Shrub). Lower accuracies for Crops and Built Area classes reflect spectral confusion with surrounding bare ground and scrub vegetation, a common challenge in dryland environments where vegetation cover is sparse and heterogeneous.

Land cover status and change in Puntland (2010–2022)

Table 1 presents the area statistics for each land cover class in Puntland for 2010 and 2022. In 2010, Scrub/Shrub dominated the landscape, occupying 15,116,029.49 ha (93.66% of total area). Bare ground covered 923,569 ha (5.72%), while Trees occupied only 62,573.60 ha (0.39%). Water surface, Crops, and Built Area comprised the remainder: 31,104.90 ha (0.19%), 1,851.41 ha (0.01%), and 4,931.56 ha (0.03%), respectively.

Table 1. Land use statistics in Puntland State (2010 - 2022)

Land cover	Area 2010 (ha)	% 2010	Area 2022 (ha)	% 2022	Change (ha)
Water surface	31,104.90	0.19	30,941.20	0.19	-163.70
Trees	62,573.60	0.39	31,876.30	0.20	-30,697.30
Crops	1,851.41	0.01	5,223.73	0.03	+3,372.32
Built area	4,931.56	0.03	7,788.73	0.05	+2,857.17
Bare ground	923,569.00	5.72	2,440,480.00	15.12	+1,516,911.00
Scrub/Shrub	15,116,029.49	93.66	13,623,750.00	84.41	-1,492,279.49
Total	16,140,059.96	100	16,140,059.96	100	---

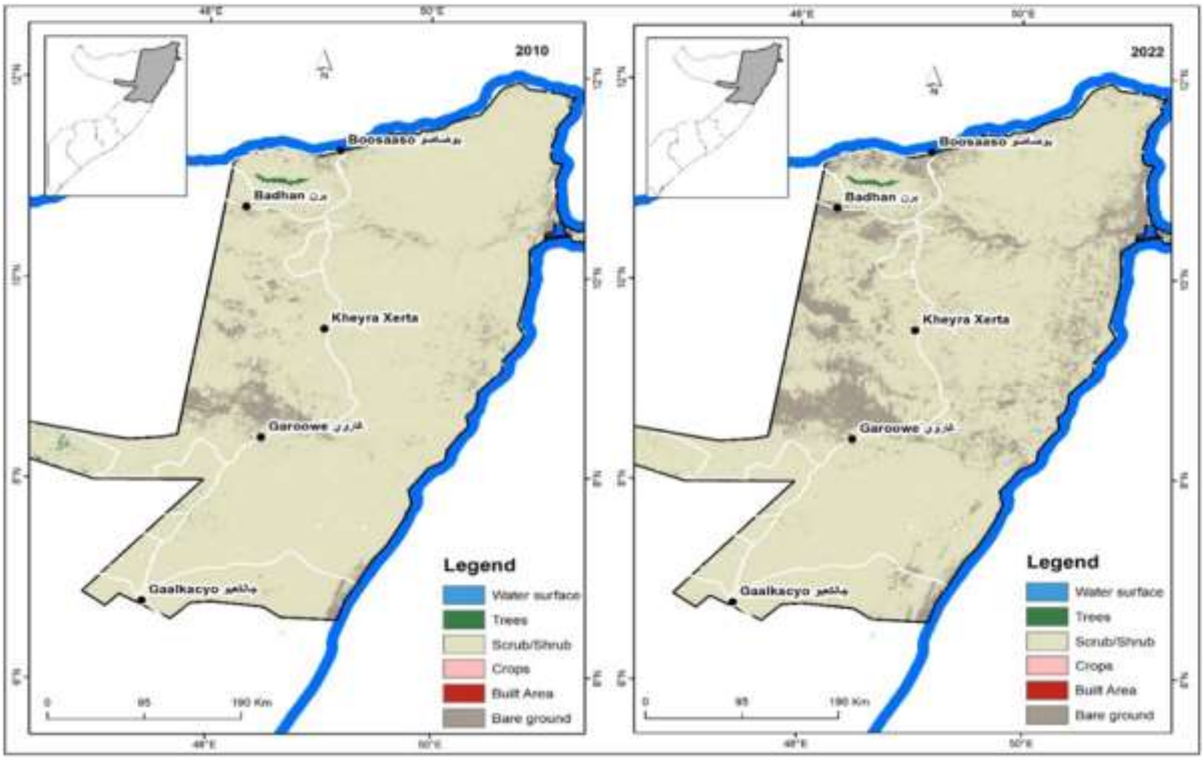

Fig. 1. Land use in Puntland State between 2010 and 2022

Table 2. Annual rate of land cover change in Puntland State (2010 - 2022)

Land cover	Change (ha)	Annual rate of change (%)
Water surface	-163.70	-0.05
Trees	-30,697.30	-6.13
Crops	+3,372.32	+9.43
Built area	+2,857.17	+4.15
Bare ground	+1,516,911.00	+8.83
Scrub/Shrub	-1,492,279.49	-0.94

By 2022, the landscape had undergone substantial transformation. Bare ground expanded dramatically to 2,440,480 ha (15.12%), representing a net increase of 1,516,911 ha, the largest absolute change of any class. Scrub/Shrub declined to 13,623,750 ha (84.41%), a loss of 1,492,279 ha. Tree cover was nearly halved, falling to 31,876 ha (0.20%), a loss of 30,697 ha. Crops increased to 5,224 ha (0.03%), Built Area to 7,789 ha (0.05%), while Water surface remained relatively stable at 30,941 ha (0.19%).

Fig. 1 shows the spatial distribution of land cover change across Puntland, with the most pronounced expansion of bare ground occurring in the central and southern plateaus, while tree cover loss was concentrated in the Golis Mountain foothills where frankincense and myrrh woodlands are located.

Annual rates of land cover change

Table 2 presents the annual rates of change calculated using the Bernier formula. The most rapid expansion occurred for Crops (+9.43% per year), followed by Bare ground (+8.83% per year) and Built Area (+4.15% per year). These high positive rates indicate rapid intensification of human land use despite the region's aridity.

The most striking negative change was for Trees, which declined at -6.13% annually, substantially higher than the national average deforestation rate of -1.03% (World Bank, 2020) and comparable to the most rapid deforestation rates reported in unprotected forest areas of the Congo Basin (Ernst *et al.*, 2013). Scrub/Shrub declined at a modest -0.94% annually, indicating that this class is being converted primarily to Bare ground rather than to other vegetated classes.

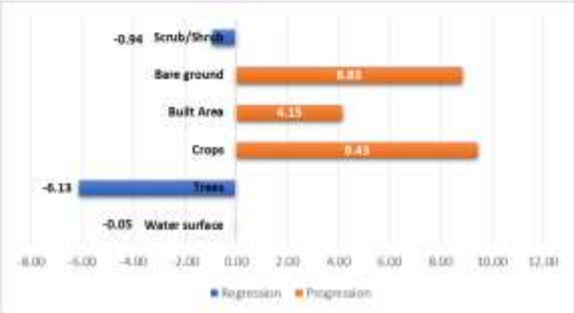

Fig. 2. Annual rate of change in land use categories in Puntland State 2010 and 2022

Fig. 2 illustrates the comparative annual rates of change across classes, highlighting the stark contrast between rapid expansion of bare ground (+8.83%) and cropland (+9.43%) versus sharp decline of tree cover (-6.13%).

Transition patterns between land cover classes

Analysis of transition matrices revealed the specific conversions driving landscape change. Between 2010 and 2022, the largest transitions were from Scrub/Shrub to Bare ground (approximately 1,200,000 ha), indicating widespread degradation of shrubland to exposed soil. Trees were predominantly converted to Scrub/Shrub (approximately 25,000 ha) rather than directly to Bare ground, suggesting a two-stage degradation process: forest degraded to shrubland, followed by shrubland degradation to bare ground. Crops expanded primarily at the expense of Scrub/Shrub (approximately 3,000 ha) and Bare ground conversion to cultivation (approximately 2,500 ha), reflecting agricultural frontier expansion. Built Area expansion occurred through conversion of Scrub/Shrub (approximately 2,000 ha) and Bare ground (approximately 1,500 ha), associated with urbanization and the growth of IDP settlements.

Frankincense and Myrrh value chains

Frankincense (*Boswellia frereana* "Maydi" and *Boswellia sacra* "Moxor") and myrrh (*Commiphora myrrha* "Dhidin") represent the most commercially significant NTFPs in Puntland. Focus group discussions revealed that an estimated 7,000 - 10,000 collectors are involved in resin harvesting, with approximately 300 buyers/traders and over 3,000 women employed in cleaning and sorting. Resins are exported to the United Arab Emirates, other Arabian Gulf countries, and France. In 2020, Somalia exported $25.8 million in resins, ranking 8th globally. Average prices were reported as $18 – 30 per kg depending on quality.

However, 76% of respondents indicated declining resin production due to drought, climate change effects, and poor harvesting techniques. Key informants reported that unsustainable tapping practices, including excessive cuts per tree, tapping young trees, and harvesting during inappropriate seasons, have reduced tree productivity and caused mortality. One frankincense collector in the Bari region explained: "In the past, a single tree could produce 5-10 kg of resin per season. Now we are lucky to get 2-3 kg. The trees are stressed from drought and too many cuts."

Governance of frankincense resources operates through a combination of customary tenure and open access. Family-owned trees are inherited and managed under traditional rules (*xeer*), with boundaries known to community members but not formally demarcated. However, trees growing on communal grazing land are effectively open access, leading to competition and unsustainable harvesting. Conflict over tree access has increased as production has declined and prices have risen.

Perceived drivers of vegetation change

Household surveys revealed that drought is perceived as the primary driver of vegetation change in Puntland. Respondents reported that three consecutive seasons of failed rains have led to massive livestock losses, forcing pastoralists to sell animals at depressed prices and increasing dependence on NTFP harvesting for survival. Overgrazing was ranked as the second most important driver, with respondents noting that reduced rainfall has concentrated livestock around remaining water points, creating zones of extreme degradation.

Table 3. Capacity gaps, training needs, and infrastructure requirements in Puntland

Capacity gap	Priority	Training needs	Infrastructure needed
Sustainable forest management	5	Inventory, regeneration, sustainable harvesting	Nurseries, laboratory equipment
Biodiversity restoration	5	FMNR, enclosures, rehabilitation	Weather stations, monitoring equipment
Climate change response	5	GHG inventories, MRV, adaptation planning	Emission monitoring station
Environmental governance	4	Policy analysis, customary law integration	Office facilities, computers
Value chain development	4	NTFP processing, grading, market access	Processing equipment, storage

scale 1-5; 5=extremely important

Unsustainable wood harvesting for charcoal and firewood was ranked third, followed by expansion of settlements associated with drought-induced displacement. Focus group participants described a downward spiral: drought reduces forage availability, leading to overgrazing of remaining vegetation and increased livestock mortality; loss of livestock reduces household assets, forcing families to harvest wood for charcoal sales; charcoal production degrades the land further, reducing future forage production; and frankincense trees, stressed by drought, are more vulnerable to damage from tapping, reducing resin yields and tree survival.

Institutional capacity gaps

Institutional capacity assessments revealed severe constraints on effective resource management. Over 90% of staff interviewed in Puntland's Ministry of Environment, Agriculture and Climate Change had received no formal environmental management training, although the Director General noted that approximately 90% had basic training compared to near-zero levels in Jubaland and Galmudug. Respondents attributed Puntland's relatively stronger capacity to longer-term security stability, which enabled training by UN agencies and expatriate experts, and the state's status as the oldest federal member state, allowing capacity to accumulate over time. However, critical gaps remain. Table 3 summarizes capacity needs identified by key informants.

DISCUSSION

Deforestation and degradation in comparative perspective

The deforestation rate documented in Puntland (-6.13% annually, representing a 51% loss of existing tree cover in just 12 years) is catastrophic for the slow-growing, long-lived *Boswellia* and *Commiphora* species that are endemic to the region. This rate exceeds deforestation rates reported from most other dryland regions in Africa. For example, in the Sahelian zone of Sudan, Ibrahim *et al.* (2021) reported annual deforestation rates of 0.5–2.0% for Acacia woodlands. In Ethiopia's dry Afromontane forests, Meshesha *et al.* (2014) documented rates of 1.0-1.5% annually. In Kenya's rangelands, Owuor *et al.* (2018) found woody cover loss of 0.3–0.8% per year. The only comparable rates come from unprotected forest reserves in densely populated areas of the Congo Basin, where Ernst *et al.* (2013) reported localized deforestation up to 1.5% annually, and from Cameroonian forest reserves under intense pressure, where Feudjio *et al.* (2023) documented rates of 0.84–1.57% and Temgoua *et al.* (2021) observed progressive forest loss.

The Puntland case differs from these forest contexts in two critical respects. First, the primary driver is not agricultural conversion (which remains limited at 0.03% of state area) but rather climate-induced degradation: drought reduces vegetation cover, overgrazing prevents regeneration, and the combination shifts the system from Scrub/Shrub to Bare ground. Second, the economic importance of frankincense and myrrh creates incentives for maintaining tree cover, but poor harvesting practices and climate stress overwhelm these incentives. The transition pattern from trees to scrub/shrub to bare ground documented in this study suggests that Puntland is experiencing progressive degradation rather than direct deforestation, with the window of opportunity for intervention closing as the system moves toward a bare ground state that may be difficult to reverse.

Implications for Frankincense and Myrrh sustainability

The 51% loss of tree cover in Puntland between 2010 and 2022 has profound implications for the Frankincense and Myrrh value chains. *Boswellia* and *Commiphora* species are slow-growing, with trees requiring 8–15 years to reach tapping maturity and potentially living for over a century (Hassan *et al.*, 2019). The loss of 30,697 ha of tree cover represents not only a reduction in current resin production but also a long-term decline in productive capacity, as lost trees will take decades to replace. Furthermore, the trees that remain are likely those in poorer condition, stressed by drought, damaged by excessive tapping, and growing on degraded soils, further reducing per-tree productivity.

The economic consequences extend beyond Puntland. With Somalia ranking as the 8th largest global resin exporter (World Bank, 2022), continued decline in production will affect national export earnings, estimated at $25.8 million in 2020. More immediately, the 7,000-10,000 collector households and 3,000 women employed in processing face declining incomes, with limited alternative livelihood options in Puntland's arid economy. The gender dimension is particularly concerning: women who dominate the cleaning and sorting stage (90% female) have the fewest alternative employment options and may be pushed into more precarious informal work as resin processing declines.

Similar NTFP declines have been documented elsewhere in Africa. For example, in the dry forests of southern Africa, Paumgarten (2007) found that declining availability of medicinal plants and wild fruits due to land degradation increased household vulnerability. In humid forest contexts in Cameroon, Feudjio *et al.* (2023) reported that local communities depended on non-timber forest products for both subsistence and income, but that deforestation and habitat degradation were reducing availability. However, the frankincense case is unique because the trees themselves are the product, and unsustainable harvesting directly damages the resource base. Interventions must therefore focus on harvesting techniques, restoration, and alternative livelihoods simultaneously.

Governance and capacity constraints

The governance challenges identified in Puntland, customary systems ill-adapted to commercial pressure, weak state institutions, limited technical capacity, mirror findings from other dryland regions (Webersik *et al.*, 2018; Kishor *et al.*, 2015). However, Puntland's relative security stability has enabled some institutional development, with the Ministry of Environment reporting that 90% of staff have basic environmental training, far higher than Jubaland (two trained staff) or Galmudug (none). This differential suggests that security is a prerequisite for capacity building but not sufficient: sustained investment in training, equipment, and infrastructure is also required.

The capacity gaps identified in Table 3 including sustainable forest management, biodiversity restoration, climate change response, environmental governance, and value chain development, are interconnected. Without forest management training, harvesting practices will remain unsustainable. Without restoration capacity, degraded areas will not recover.

Without climate change response, vulnerability to drought will increase. Addressing these gaps requires a systemic approach rather than piecemeal interventions.

Conclusion

This study demonstrates that Puntland State has experienced substantial land use and land cover changes between 2010 and 2022, characterized by extensive vegetation degradation, rapid expansion of bare ground, and a significant decline in tree cover. The findings indicate that the region is undergoing a progressive transition from productive scrubland and woodland ecosystems to increasingly degraded landscapes. Recurrent drought, overgrazing, unsustainable wood harvesting, and weak environmental governance have emerged as the principal factors accelerating ecosystem degradation. Although agricultural land and built-up areas expanded during the study period, their contribution to overall landscape transformation was relatively small compared with the widespread conversion of vegetated land into bare ground.

The continued decline of *Boswellia* and *Commiphora* woodlands poses a serious threat to Puntland's frankincense and myrrh resources, which support thousands of households through resin production and trade. The deterioration of these ecosystems not only reduces biodiversity and ecosystem resilience but also undermines livelihoods, economic opportunities, and the long-term sustainability of dryland natural resources. If current trends continue, the degradation of rangelands and woodland ecosystems may become increasingly difficult to reverse, resulting in further losses of ecological functions and reduced capacity to adapt to climate variability.

The findings highlight the urgent need for integrated land management strategies that combine ecosystem restoration, sustainable grazing practices, improved harvesting techniques for non-timber forest products, and strengthened environmental governance. Enhancing institutional capacity, expanding community-based resource management, promoting climate-resilient livelihood options, and investing in environmental monitoring will be essential for reversing current degradation trends. Such interventions would help restore ecosystem health, safeguard biodiversity, improve the sustainability of frankincense and myrrh production, and strengthen the resilience of dryland communities against future environmental and climatic challenges.

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