Daagu International Journal of Basic and Applied Research 8(1) (2026): 977-991
doi: 10.20372/dijbar314.v8i1.2026

Research Article

Environmental and socioeconomic impacts of Cactus (*Opuntia ficus-indica*) species in Saesie Tsaeda Emba woreda, Eastern Tigray, Ethiopia

Haftom Teshale Gebre

Adigrat University, College of Social Sciences and Humanities, Department of Geography and Environmental Studies Adigrat, Ethiopia. Email: haftomteshale1@gmail.com

Received: 07/09/2025 *Revised:20/05/2026* *Accepted: 01/06/2026*

Abstract

This study assessed the socioeconomic and ecological impacts of Cactus pear (*Opuntia ficus-indica*) in Saesie Tsaeda Emba woreda, Eastern Tigray, Ethiopia. Data were collected from 129 stratified randomly selected households through structured surveys, complemented by focus group discussions, key informant interviews, field observations, and vegetation transect sampling in 20 Cactus-dominated and 20 Cactus-free quadrats. Results show that Cactus cultivation significantly contributes to household income, with a positive correlation between income and cultivated Cactus area ($r = 0.592$, $p < 0.001$). However, ecological analysis revealed substantial negative impacts, including significant differences in plant species composition between invaded and non-invaded areas ($X^2 = 158.889$, $p < 0.001$) and reduced regeneration of native woody species due to competition for space and light. Overall, while *O. ficus-indica* supports local livelihoods, its spread negatively affects biodiversity, highlighting the need for management strategies that balance economic benefits with ecological conservation.

Keywords: Cactus pear, Invasive species, Biodiversity loss, Socioeconomic resilience, Ecological displacement

1. INTRODUCTION

The genus *Opuntia* exhibits its primary center of evolutionary genetic diversity within Mexico, where it has long been cultivated as a critical agricultural resource for fodder, forage, fresh fruit, and vegetables (Russell and Felker, 1987). Globally, more than 200 distinct Cactus species have been introduced far beyond their native geographic ranges to fulfill anthropocentric needs, notably human consumption, livestock sustenance, pharmacology, and landscape ornamentation (Novoa, 2016). Owing to this widespread utility, the genus has successfully naturalized across extensive multi-continental areas, including Australia, Southern Europe, and numerous African nations (Novoa et al., 2015). Among these taxa, *Opuntia ficus-indica* stands out as the most widely distributed species globally, having successfully established self-sustaining wild populations outside its historical native boundaries across 22 different nations (Novoa et al., 2015). While historically introduced to provide strategic food and agricultural security, *O. ficus-indica* has aggressively crossed ecological boundaries to become a highly destructive invasive weed across several vulnerable

ecosystems worldwide, notably causing widespread rangeland degradation throughout semi-arid zones in Australia and South Africa (Pyšek *et al.,* 2020).

Within the regional state of Tigray, Ethiopia, the Cactus pear (*O. ficus-indica*) is widely known by its vernacular name, "Beles" (Alemseged, 2010). Historically, it has been called the “fruit of dark days” because it ripens during lean summer periods when household cereal stocks are depleted. Since the 1960s, recurring droughts, overgrazing, rangeland degradation, and limited crop residues have increasingly forced rural pastoralists to depend on Cactus stands to feed their livestock. (Desta, 2010). Today, *O. ficus-indica* remains fundamentally indispensable for human survival and livestock preservation during severe famines (Brutsch, 1997). Given that the ecological future of arid and semi-arid landscapes hinges upon the adoption of sustainable agricultural systems utilizing drought-adapted crops, cacti perfectly satisfy these strict criteria (FAO, 2013). Ideal crops must possess specialized physiological mechanisms to endure extreme climatic variabilities, such as severe water scarcity, elevated thermal stress, and nutrient-depleted soils, while requiring minimal management to deliver food and forage (FAO, 1996).

In Tigray, Cactus cultivation is concentrated on steep marginal lands where it has been systematically encouraged by ideal edaphic and microclimatic matchings, leading to its complete naturalization across the regional landscape. The baseline natural resource infrastructure of Eastern Tigray is currently undergoing profound degradation due to shifting macro-climatic patterns that favor increasingly arid conditions. The pristine primary vegetation of Tigray historically characterized by a complex mosaic of savannahs, dense woodlands, and dynamic forest ecosystems dominated by indigenous *Acacia*, *Adansonia* (baobab), and *Juniperus* taxa, has virtually disappeared, leaving behind severely denuded landscapes (Nyssen et al., 2004; Solomon et al., 2017). In response, Cactus pear has proliferated dramatically due to its exceptional tolerance to extreme drought, elevated thermal maximums, thin soils, and its highly efficient Crassulacean Acid Metabolism (CAM) pathway (FAO, 1996; Novoa et al., 2015).

Consequently, the spatial footprint of Cactus pear has expanded rapidly across Eastern Tigray, particularly within domestic backyards and communal hillsides. This expansion has been favorably reviewed in literature as a means of promoting sustainable cultivation frameworks, enhancing landscape conservation, and safeguarding heritage (Mondragón-Jacobo and Chessa, 2010). Economically, Cactus provides fresh and processed fruits for human diets and reliable green fodder for livestock (Barbera, 1995). A broad range of domestic products are derived from it, including artisanal jams, juices, nectars, syrups, and liquors, while the young vegetative cladodes are pickled or minimally processed for human consumption (FAO, 2013). Previous research confirms that the plant is thoroughly integrated into the socioeconomic

fabric of Tigray, serving as a core pillar of seasonal income, rural employment, and ecological stabilization (Lemma et al., 2010).

In Saesie Tsaeda Emba Woreda, the severity of household food insecurity, driven by persistent droughts, severe over-cultivation, and structural deforestation, has led to widespread ecological collapse and a critical shortage of biomass. This chronic vulnerability is worsened by unpredictable environmental shocks, leaving a large portion of the population dependent on regular safety-net relief food assistance, even during years with standard market and weather conditions. Driven by these pressures, many communities have historically migrated to food- secure zones. To mitigate this out-migration and reinforce local food security, development agencies emphasized the intensive cultivation of Cactus pear (Nadaf, etal., 2018). It has consistently become the primary crop of choice over traditional staples like maize or dry beans in drought-ravaged areas, effectively stabilizing household incomes (Dubeux et al., 2017).

Cactus pear was originally introduced to Saesie Tsaeda Emba Woreda from the adjacent eastern zone with the specific directive of securing human fruit supply and livestock feed (BoARD, 2000). Popularly dubbed the "camel of the plant world" due to its extraordinary adaptation to hyper-arid environments, the species quickly occupied natural slopes, communal lands, and rugged rocky massifs (BoARD, 2000; Desta, 2010). While the deliberate introduction of exotic crops globally has significantly enhanced human welfare and accelerated rural societal development (Tessema, 2012), it can trigger unforeseen ecological pressures. In this district, Cactus pear is actively expanding into niches previously dominated by *Eucalyptus* species, yet detailed empirical assessments clarifying the precise dynamics of this vegetation replacement remained completely lacking (Mokria *et al.,* 2018; Wordofa et al., 2020; Belay et al., 2015). Prior localized cultivation efforts were small-scale, mostly restricted to isolated micro-catchment soil conservation works or private residential boundaries (Meles et al., 2009). Because general household incomes remained low and vulnerable, this research was specifically designed to fill the existing knowledge gap by accurately identifying, mapping, and quantifying the dual socioeconomic contributions and environmental ramifications of this critical plant. Therefore, the comprehensive objective of this study was to evaluate the socioeconomic impacts of Cactus species alongside their ecological costs, explicitly balancing its positive financial contributions to household income against its verified negative pressures on indigenous woody plant species diversity and structural forest regeneration.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Saesie Tsaeda Emba Woreda is located within the Eastern Administrative Zone of the Tigray

Regional State in northern Ethiopia. The study area is geographically bounded between latitudes 13°55′00″ N and 14°23′30″ N, and longitudes 39°28′30″ E and 39°53′00″ E (Figure 1) (Ethiopian Mapping Agency, 2017). The district is situated approximately 78 km north of the regional capital, Mekelle, and 37 km south of Adigrat town. In terms of relative location, Saesie Tsaeda Emba lies directly south of Gulomekada Woreda, east of Atsbi-Wenberta Woreda and the Afar Regional State boundary, and north of the Kilte Awlaelo, Hawuzen, and Ganta-Afeshum districts (CSA Plan and Finance of Tigray Region, 2017). The woreda is subdivided into 28 distinct administrative units (kebeles), which primarily span across the "Dega" (temperate highland) and "Weina Dega" (sub-tropical mid-highland) agro-ecological zones, with a few low-lying catchments falling into the arid "Kolla" (lowland) classification, encompassing an altitudinal gradient ranging from 1,500 to 2,950 meters above sea level. The long-term mean annual precipitation of the district is recorded at 596 mm (CSA Plan and Finance of Tigray Region, 2017).

The overarching landscape is characterized by an extensively dissected, rugged, and highly mountainous terrain exhibiting sparse primary vegetation cover (Abera *et al.,* 2025). Reflecting its semi-arid status, the district receives an erratic annual rainfall totaling between 300 mm and 800 mm, subjected to a prolonged, severe dry season spanning from November to February (EMA, 2017). The remaining natural vegetation communities are structurally classified into four distinct formations: desert scrubland, open woodland, bushland, and highly fragmented remnant montane forests (Atinafe et al., 2023). Decades of intense anthropogenic pressures, primarily clear-cut deforestation, chronic overgrazing, and uncontrolled agricultural expansion into marginal slopes, have precipitated severe land degradation, accelerating sheet erosion, widespread loss of indigenous biodiversity, and local desertification (Abera *et al.,* 2025). Demographic assessments indicate a total district population of 162,138 individuals, comprising 76,391 males and 85,747 females, with the primary urban center, Freweyni town, housing 25,895 inhabitants distributed across approximately 5,800 domestic households (CSA, 2017). Public health infrastructure consists of seven core health centers and 26 rural satellite health posts. While an all-weather road traverses the district, access to robust water supply infrastructure remains highly restricted across the majority of rural households.

2.2 Data Collection Framework

A rigorous mixed-methods research design was deployed, drawing from concurrent collections of primary and secondary, quantitative and qualitative datasets. Secondary baselines were extracted from institutional archives at the Saesie Tsaeda Emba Woreda Office of Agriculture and Rural Development. Primary field campaigns utilized a combination of structured household question forms, direct content interviews, key informant inputs,

interactive focus group sessions, and vegetative field measurements.

Socio-economic

Socioeconomic data were collected through a combination of methods. Face-to-face interviews were conducted with regional Development Agents (DAs) to obtain professional insights into long-term agricultural changes and socioeconomic transitions associated with cactus expansion. In addition, structured household questionnaires, comprising both open- and closed-ended questions, were administered to 129 selected household heads. To ensure clarity and accessibility, the questionnaires were prepared in both English and Tigrigna.

Field observations were also undertaken, with the primary investigator maintaining detailed logs on household living conditions, local market activities, and agricultural practices. Furthermore, four focus group discussions (FGDs) were held, involving both cactus-reliant landowners and households from cactus-free areas, to enable comparative analysis of seasonal income patterns and livelihood.

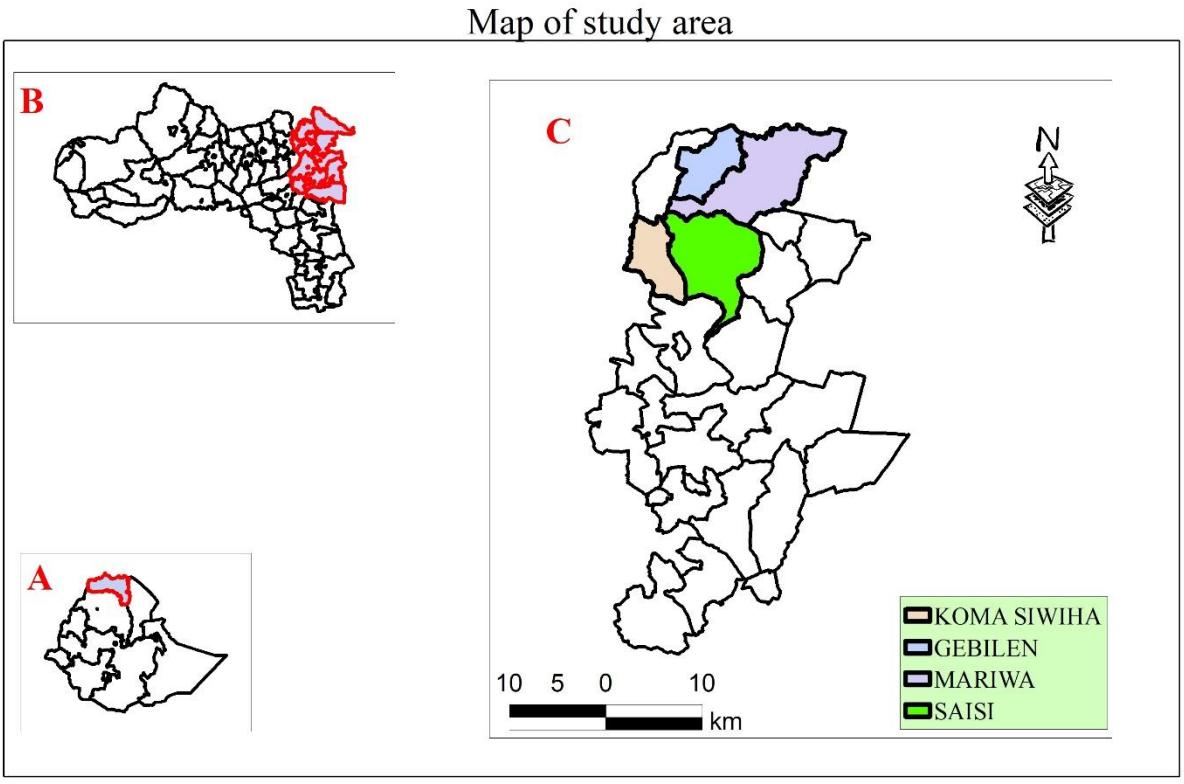


Figure 1. Geographic setting and cartographic layout of the study area within Saesie Tsaeda Emba Woreda, displaying spatial borders and the four focal study kebeles.

Ecological and Vegetative Sampling:

To explicitly verify the environmental pressures exerted by Cactus pear on the baseline structure and taxonomic diversity of the local flora, systematic transect sampling was performed. Two parallel line transects were established across the landscape, spaced exactly

300 meters apart. Along each transect, square vegetation sampling plots measuring 100 m² (10 m × 10 m) were fixed at regular intervals of 100 meters. Field sampling was balanced between conditions, comprising exactly 20 sample quadrants positioned inside hyper-dense stands of *O. ficus- indica* and 20 identical sample quadrants situated in adjacent Cactus-free ecological niches. Inside every individual plot, all woody species were recorded using their local vernacular names (Tigrigna) and subsequently cross- referenced with standard botanical records (Bein.*etal.,* 1996).

The physical collection of data for structural vegetation profiling adhered to a standardized forestry measurement framework: all individual woody trees and shrubs exhibiting an established diameter at breast height (DBH) exceeding 2.5 cm were measured using standardized forestry calipers at a fixed, uniform height of 1.3 meters above the soil surface line, while individual plant heights were systematically recorded using a precision optical hypsometer. For demographic population structure classification, individual woody stems possessing a DBH ≥ 2.5 cm alongside a total vertical height ≥ 2 meters were cataloged as mature adults. Stems displaying a DBH < 2.5 cm and a total vertical height < 2 meters were categorized as juveniles representing active forest regeneration.

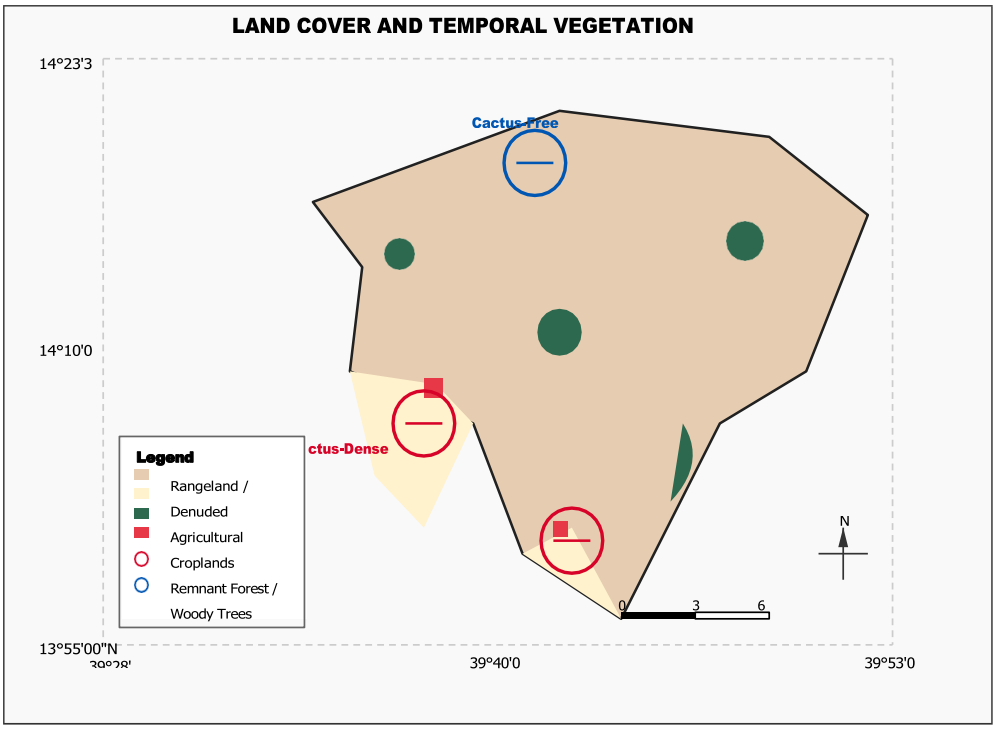


Figure 2. Land cover map

2.3 Household Sampling Framework

The selection of the human sample population was structured around a multi-stage probability and non- probability sampling framework designed to eliminate selection bias. In the initial stage, non-probability purposive sampling was applied to isolate the four specific target kebeles (Koma Siwiha, Gebilen, Mariwa, and Saisi) from the 28 total options within the

woreda, based on secondary administrative registries demonstrating that these catchments maintained the highest densification and overall surface coverage of Cactus landholdings.

In the second stage, probability stratified random sampling was deployed. Stratification was structured around the heterogeneous baseline criteria of household Cactus landholding sizes, establishing clear, homogeneous strata across both owners and non-owners to guarantee proportional group representation. The absolute sample size for the structured questionnaire was determined via the robust statistical framework proposed by Kothari (2004). Assuming a 95% confidence level, an estimated population variance response distribution of p = 0.9, q = 0.1, and an acceptable margin of error precision tolerance limit of e = 0.05, the formula is expressed as follows:

$$n = \frac{Nz^2PQ}{E^2(N-1) + z^2PQ}$$

Substituting the exact empirical baseline values derived from the formalized municipal registries of the four target kebeles (*N = 1,985* total registered households):

$$n = \frac{1985(1.96)^2(0.9)(0.1)}{(0.05)^2(1985-1) + (1.96)^2(0.9)(0.1)}$$

$$n = 129$$

Accordingly, exactly 129 separate household heads were drawn via simple random numbers from the comprehensive stratified frame of 1,985 households to establish the final, statistically representative sample size. Institutional Review Board approval was formally granted by the Adigrat University Research Ethics Panel (IRB Protocol Number: IRB-2023-021), and full written informed consent was verified for all human participants prior to data elicitation.

2.4 Methods of Statistical Analysis

Quantitative analysis was executed using the Statistical Package for the Social Sciences (SPSS) Version 20.0 software. Baseline demographic variables and general household characteristics were evaluated using descriptive summary metrics, including means, medians, standard deviations, and relative frequencies. Inferential statistics were applied to assess socioeconomic and environmental outcomes. To evaluate structural variations in vegetation composition, a paired-sample t-test was deployed to compare absolute plant stem densities between corresponding Cactus-occupied and Cactus-free quadrants. A non-parametric Pearson Chi-Square test was applied to determine changes in baseline species richness, and multi-variable linear regression modeling was executed to isolate the relative predictive power of family sizing, total household landholding, and specific Cactus-producing surface area upon gross seasonal household revenue metrics.

3. RESULTS AND DISCUSSION

The statistical calculations demonstrate a clear positive socioeconomic benefit associated with active Cactus pear production across the study area. Bivariate inferential modeling confirmed a statistically significant positive linear correlation between average monthly household income expressed in Ethiopian Birr and the physical surface area allocated to Cactus cultivation in hectares ($r = 0.592$, $n = 129$, $p < 0.001$), as shown in Table 1. This linear linkage strongly indicates that household financial performance increases along with expansions in the structural scale of Cactus management.

To further isolate the specific predictive power of Cactus production relative to conventional agricultural assets, a multiple linear regression analysis was executed. Three models were isolated to assess the relative changes in total household income based on three distinct predictor variables: household size, total land area, and allocated Cactus land area, as summarized in Table 2.

Table 1. Pearson correlation analysis between household income and allocated Cactus landholdings.

Correlation Variables	Pearson Correlation Coefficient (r)	Sample size	Significance Level (p-value)
Gross Monthly Household Income (ETB) with Total Cactus Farm Area (ha)	0.592	129	0.000

*** *Statistically significant at the alpha level of 0.01.*

The regression results indicate that while universal agricultural landholding size remains the strongest predictor of total income ($R^2 = 0.424$, accounting for 42.4% of total household variance), the dedicated Cactus landholding size exerts a distinct, independent positive effect ($R^2 = 0.118$), explaining 11.8% of the variation in household income. This financial contribution is further supported by model tracking from adjacent regions, which verified that approximately 66% of local agriculturalists are consistently confident in generating regular returns of 300 to 500 Birr annually per harvest unit via localized Cactus commercialization, providing a financial safety net for low-income households (Belay, 2015).

The specific baseline motivations driving local smallholders to cultivate Cactus pear were quantified through descriptive frequencies, as structured in Table 3. Livestock feed emerged as the primary purpose, cited by 35.05% of respondents, followed by dedicated income generation (24.74%) and fresh fruit production for domestic human consumption (22.69%). Focus Group Discussions confirmed that the utilization of specialized Cactus cladodes provides a crucial management strategy to bridge the acute structural livestock feed gaps that occur twice annually: once during the standard winter dry spell lasting 2 to 4 months, and more severely during prolonged summer gaps spanning 5 to 6 months.

Table 2: Multiple linear regression model outputs predicting household income changes

Model Frameworks	Model Predictor Core Variable	Model Fit (R)	Coefficient of Det. (R^2)	Adjusted R^2 Metric	Std. Error Estimate	F-Value Change	Sig. F-Change
Model 1	Total household Family size Members	0.24	0.05	0.05	1866.27	7.79	0.006**
Model 2	Total universal Land Holding Size (ha)	0.65	0.42	0.41	1459.56	93.38	0.000***
Model 3	Specific cactus production area (ha)	0.34	0.11	0.11	1805.44	17.03	0.000***

*** Significant at p < 0.05; *** Significant at p < 0.01.*

Qualitative logs confirmed that during these extended feed gaps, smallholders apply direct thermal processing to remove spines before slicing the cladodes for cattle ingestion. Furthermore, localized marketing channels allow for the commercialization of fresh Cactus fruits during critical lean periods. Beyond direct consumption, literature confirms that Cactus crops can be processed into derivatives such as specialized oils, structural thickeners, and cosmetics, offering further potential for local value-chain integration (Taddele and Workneh, 2010).

Table 3: Empirical smallholder ranking of the primary motivations for Cactus cultivation

Statements	Absolute Smallholder Frequency (count)	Proportional Response (%)
Targeted livestock feed and forage security	34	35.05
Seasonal income source and direct sale	24	24.74
Direct human dietary consumption	22	22.69
Living fences and perimeter homestead security	15	15.46
Domestic fuelwood and thermal extraction	2	2.06
Aggregate totals	97	100

3.1 Environmental Impacts and Taxonomic Biodiversity Alterations

Despite the explicit economic benefits highlighted by smallholders, field data from the systematic vegetation sampling revealed clear environmental trade-offs. The expansion of dense stands of *O. ficus-indica is* associated with a distinct contraction in the structural density and taxonomic diversity of surrounding native woody plant communities.

The paired t-test metrics (Table 4) revealed that the mean number of co-occurring woody plant species per individual plot was significantly lower within Cactus-occupied plots (2.70 ± 1.129) compared to paired Cactus-free quadrants (6.45 ± 1.849, t = -10.364, df = 19, p < 0.001). Similarly, the mean absolute individual stem count recorded per species was sharply depressed within the Cactus-invaded communities (51.71 ± 46.568 individuals) relative to uninvaded zones (248.57 ± 249.564 individuals, t = -2.485, df = 6, p = 0.048). Field inventories identified only seven indigenous woody species capable of surviving inside both conditions: *Becium grandiflorum, Rumex usambarensis*, *Acacia lahai, Maytenus*

senegalensis, Maytenus arbutifolia, Dodonaea angustifolia, and *Acacia etabica*. However, their absolute numerical presence was heavily skewed toward uninvaded plots, as detailed in Table 5.

Table 4. Inferential paired-sample t-test results comparing plant density and species count

Paired Statistical Contrast Groupings	Calculated Mean	Standard Deviation (SD)	Calculated t-value	Degrees of Freedom (df)	Two-Tailed p-value
Pair 1: Cactus-Occupied Plots (Mean Species Count per Plot)	2.7	1.129	-10.364	19	0.000***
Pair 1: Cactus-Free Plots (Mean Species Count per Plot)	6.45	1.849			
Pair 2: Cactus-Occupied Sites (Mean Absolute Stem Count/Species)	51.71	46.568	-2.485	6	0.048**
Pair 2: Cactus-Free Sites (Mean Absolute Stem Count/Species)	248.57	249.564			

Table 5. Quantitative abundance distribution of overlapping native woody species

Botanical Taxonomic Identification	Vernacular Script (Tigrigna)	Abundance in Cactus-Dense Plots	Abundance in Cactus-Free Plots
Becium grandiflorum	Tebeb	127	474
Rumex usambarensis	Mekmeko	100	151
Acacia lahai	Chia	64	160
Maytenus senegalensis	Atat	21	90
Maytenus arbutifolia	Atat	21	75
Dodonaea angustifolia	Tahses	18	51
Acacia etabaica	Seraw	9	33

A non-parametric Pearson Chi-Square analysis confirmed that this structural variation in universal vegetation composition between invaded and uninvaded environments was highly statistically significant ($X^2 = 158.889$, $df = 4$, $p < 0.001$), comfortably exceeding the critical tabular threshold value of 9.49 (Table 6). These empirical findings match historical monitoring profiles indicating that cumulative cover indices of native woody plant canopies systematically decline with increasing dominance of invasive Cactus layers (Lemma et al., 2010).

Table 6: Chi-Square testing framework assessing vegetation divergence across target zones.

Statistical Metric	Calculated Value	Degrees of Freedom (df)	Asymptotic Significance (p-value)	Critical Value (α=0.05)
Pearson Chi-Square	158.889	4	0.000***	9.49

3.2 Native Forest Population Structure and Regeneration Impairments

To determine the long-term ecological trajectory of the remaining forest fragments, a demographic life- stage comparison was performed, balancing structural frequencies between mature adults and juvenile classes, as detailed in Table 7.

Table 7. Demographic plant stage frequencies across structural vegetation zones

Sampling Zone	Adult Stem Freq (DBH ≥ 2.5cm)	Adult Group Prop (%)	Juvenile Freq (DBH < 2.5cm)	Juvenile Prop (%)	Aggregate Zone Counts	Total (%)
Cactus-Free Control Sites	301	28.42	758	71.58	1,059	100
Cactus-Dense Invaded Sites	140	38.89	220	61.11	360	100

The baseline metrics indicate that within the uninvaded Cactus-free landscape, the demographic distribution displays a healthy population structure: juvenile cohorts account for 71.58% of the total stems (758 stems), while mature adults represent 28.42% (301 stems). Conversely, inside the areas heavily invaded by dense stands of O. *ficus-indica*, the proportion of juvenile stems drops sharply to 61.11% (220 stems), which is paired with an artificial relative inflation of mature adults to 38.89% (140 stems). This severe absolute drop in juvenile abundance within invaded areas demonstrates an active inhibition of seedling establishment.

Furthermore, a detailed demographic investigation tracking individual tree frequencies across precise, standardized diameter classes reveals that while native species inside uninvaded zones display a classic, healthy inverted "J"-shaped frequency curve characterized by high numbers of young individuals in lower diameter classes that gradually decline as size increases the population structure within Cactus-invaded zones exhibits a broken distribution, with very low tree frequencies in the 2.5 to 3.5 cm range and an anomalous accumulation of individuals constrained within the 3.5 to 4.5 cm diameter class. This structural distortion indicates that the expansion of dense Cactus stands severely restricts natural regeneration by outcompeting native seedlings for physical space and solar radiation, effectively suppressing long-term forest recruitment (Ferrell *et al.,* 2014; Lemma et al., 2010).

3.3 Physiographic Landscape Context and Land-Use Suitability Analysis

The broader environmental distribution of Cactus was evaluated alongside district-wide landcover and topographical characteristics. Geographic Information Systems (GIS) analysis confirmed that the landscape is dominated by favorable slope classes: "Very gently sloping" surfaces cover 26.47% of the area (1,585.98 ha), followed by "Gently sloping" at 21.74% (1,302.48 ha), and "Level" terrains at 17.14% (1,027.08 ha), as summarized in Table 8.

Table 8. Topographical slope classification and agricultural suitability profile

Topographical Class Identifier	Physical Gradient Range (%)	Spatial Coverage (ha)	Relative Allocation Suitability	Land Use Proportion (%)
Level	0 - 2 %	1027.08	17.14	Highly Suitable: Intensive Agriculture / Housing
Very Gently Sloping	2 - 5 %	1585.98	26.47	Highly Suitable: Mechanical Farming / Cropping
Gently Sloping	5 - 10 %	1302.48	21.74 /	Suitable: Standard Cultivation Agroforestry
Sloping	10 - 15 %	534.60	8.92	Moderately Suitable: Perennial Pastures
Strongly Sloping	15 - 30 %	247.05	4.12	Marginally Suitable: Controlled Terracing
Moderate Steep	30 - 50 %	117.45	1.96	Unsuitable: Restricted Conservation Forestry
Very Steep	> 50 %	38.88	0.65	Unsuitable: Full Strict Ecological Preservation

Cumulatively, these three gentle terrain categories comprise over 65% of the total landscape, representing areas highly suitable for intensive agriculture and infrastructure development. In contrast, steeper gradients such as "Strongly sloping" (4.12%), "Moderate steep" (1.96%), and "Very steep" terrains (0.65%) occupy a much smaller spatial fraction. These steep lands are unsuitable for intensive cultivation and are better reserved for conservation activities, terracing, or controlled perennial grazing. The spatial distribution of regional agro- ecological zones was mapped concurrently in Table 9, establishing that "Weina Dega" constitutes the primary zone covering 43.53% of the territory, followed closely by "Qolla" at 37.38%, while the highland "Dega" zone occupies a minor enclave of 0.09%.

Table 9. Geographic distribution of agro-ecological designations across the woreda

Agro-Ecological Designation	Count	Coverage (ha)	Representation (%)
Qolla (Arid Lowland Enclave)	3,036	2,459.16	37.38
Weina Dega (Sub-Tropical Mid-Highland)	3,536	2,864.16	43.53
Dega (Temperate High-Altitude Massif)	7	5.67	0.09

This physiographic arrangement creates a highly dynamic agricultural matrix. While the flat and gently sloping mid-highlands support primary cereal cropping, the surrounding degraded slopes and arid lowland margins provide the exact ecological conditions that enable *O. ficus-indica to* rapidly colonize and expand across the district landscape.

4. CONCLUSIONS AND POLICY RECOMMENDATIONS

This empirical evaluation clarifies the dual role played by Cactus pear (*Opuntia ficus-indica*) within Saesie Tsaeda Emba Woreda. Socioeconomically, the plant serves as a critical asset for building household economic resilience. It provides a reliable fodder source that addresses recurring seasonal livestock feed gaps and generates supplementary household income during

critical summer periods, as supported by the positive linear correlation between household revenue metrics and allocated Cactus farm sizing.

However, these economic contributions are accompanied by substantial ecological costs. Systematic field sampling confirmed that the unchecked expansion of dense Cactus stands leads to a distinct contraction in indigenous plant species richness and stem abundance. Furthermore, demographic population profiling reveals that the expansion of *Opuntia ficus-indica* alters tree size frequency distributions and restricts the growth of native juvenile flora, threatening the natural regeneration of remnant montane forest fragments. To balance these competing economic and ecological priorities, the following strategic policy interventions are proposed:

- Promote Regulated Cultivation of Cactus on Degraded Slopes: Acknowledge the plant's economic importance by supporting regulated cultivation on heavily degraded, marginal slopes where it can assist in soil stabilization, while strictly prohibiting new plantings near natural forest margins.
- Develop Formal Value Chains for Cactus Products: Support the establishment of local agro-processing facilities capable of converting raw fruit and cladodes into higher-value marketable commodities, such as processed food products, cosmetics, or refined livestock feed concentrates, thereby generating rural employment.
- Invest in Targeted Agro-Industrial Research: Fund collaborative research initiatives to develop optimal, non-invasive management techniques and explore industrial applications for Cactus mucilage and seed derivatives, helping smallholders maximize income from smaller spatial footprints.
- Implement Sustainable Management and Containment Protocols**:** Introduce formal containment strategies to systematically prune wild, encroaching stands from communal lands, preventing unchecked spread into native forest fragments while training farmers in sustainable harvesting practices.

ACKNOWLEDGEMENT

The author sincerely acknowledges all individuals and institutions whose support, guidance, and cooperation made this work possible.

Funding Statement

This research received no specific funding from any public, commercial, or not-for-profit funding agency

REFERENCES

Abera, W. H., Vermaak, C., & Meressa, A. M. (2025). Measuring Multidimensional Poverty in Conflict Zones: A Remote Sensing Method for the Tigray Conflict. *Journal of Sustainable Development*, *18*(4).

Alemseged, T. (2010). The Cactus Development Project (HCDP) and the Role of CPPI as a Regional Platform in Tigray Regional State, Northern Ethiopia. *Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa*, 207. Proceedings of International Workshop held in Mekelle, Ethiopia, 19- 21 October 2009.

Atinafe, E., Weber, O., Friis, I., & Seta, T. (2023). Species diversity and vegetation structure of woody plants in regenerating Juniperus forest replacing Eucalyptus in the conservation area of Gullele Botanic Garden, Addis Ababa, Ethiopia. *Webbia*, *78*(2), 49-71.

Barbera, G. (1995). History, economic and agro-ecological importance. *FAO Plant Production and Protection Paper (FAO)*, (132).

Bein, E., Unit, R. S. C., Habte, B., Jaber, A., Birnie, A., & Tengnaes, B. (1996). Useful trees and shrubs in Eritrea: identification, propagation and management for agricultural and pastoral communities.

Belay, F. (2015). An Assessment on the Economic Benefit of Cactus Crop in the Case of Ganta Afeshum District, Eastern Tigray, Ethiopia. *American Journal of Environmental Protection*, *4*(5), 202-206.

Belay, K. T., Van Rompaey, A., Poesen, J., Van Bruyssel, S., Deckers, J., & Amare, K. (2015). Spatial analysis of land cover changes in Eastern Tigray (Ethiopia) from 1965 to 2007: are there signs of a forest transition?. *Land Degradation & Development*, *26*(7), 680-689.

BoARD. (2000). *Annual resource assessment report*. Tigray Bureau of Agricultural and Rural Development.

Brutsch, M. O. (1997). The beles or cactus pear (Opuntia ficus-indica) in Tigray, Ethiopia. *Journal of the Professional Association for Cactus Development*, 2, 130-141

Central Statistical Agency (CSA) Plan and Finance of Tigray Region. (2017). *Demographic and biophysical inventory data for Eastern Tigray*. Central Statistical Agency.

Desta, T. Y. (2010). Farmers Practice in use of cactus as animal feed-in Tigray. *Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa*, 101. Proceedings of International Workshop held in Mekelle, Ethiopia, 19- 21 October 2009.

Dubeux Jr, J. C. B., Salem, H. B., & Nefzaoui, A. (2017, March). Forage production and supply for animal nutrition. Crop ecology, cultivation and uses of cactus pear. In *Proceedings of the IX International Congress on Cactus Pear and Cochineal: CAM Crops for a Hotter and Drier World, Coquimbo, Chile* (pp. 26-30).

Ethiopian Mapping Agency (EMA). (2017). *Topographical and administrative layout of Seasia Tsaeda Emba Woreda*. Ethiopian Mapping Agency.

FAO. (1996). *Declaration on world food security and world food summit plan of action*. World Food Summit. http://www.fao.org/3/w3613e/w3613e00.htm

FAO. (2013). *Agro-industrial utilization of cactus pear*. FAO Agricultural Services Bulletin. Rome: Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/documents/card/en/c/ca2467en

Ferrell, J., Sellers, B., & Leon, R. (2014). Management of spreading Pricklypear (Opuntia humifusa) with fluroxypyr and aminopyralid. *Weed Technology*, *28*(4), 734-738.

Kothari, C. R. (2004). *Research methodology: Methods and techniques* (2nd ed.). New Age International Publishers.

Lemma, H., Haile, M., Fetene, M., & Belay, T. (2010). Cactus in southern Tigray: Current status, potential use, utilization and threats. *Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa*, 135. Proceedings of International Workshop held in Mekelle, Ethiopia, 19- 21 October 2009.

Meles, K., Nigussie, G., Belay, T., & Manjur, K. (2009). Seed system impact on farmers' income and crop biodiversity in the drylands of southern Tigray. *DCG Policy Brief*, *2*.

Mokria, M., Mekuria, W., Gebrekirstos, A., Aynekulu, E., Belay, B., Gashaw, T., & Bräuning, A. (2018). Mixed-species allometric equations and estimation of aboveground biomass and carbon stocks in restoring degraded landscape in northern Ethiopia. *Environmental Research Letters*, *13*(2), 024022.

Mondragón-Jacobo, C., & Chessa, I. (2010, October). A global perspective on genetic resources of cactus pear; an asset for the future sustainability of semiarid lands. In *VII International Congress on Cactus Pear and Cochineal 995* (pp. 19-26).

Nadaf, S. K., Al-Farsi, S. A. M., Al-Hinai, S. A., Al-Hinai, A. S., Al-Harthy, A. A. S., Al-Khamisi, S. A., & Al-Bakri, A. N. (2018). Potential of forage cactus pear accessions under saline water irrigation in arid areas. *Journal of the Professional Association for Cactus Development*, *20*, 68-81.

Novoa, A., Le Roux, J. J., Robertson, M. P., Wilson, J. R., & Richardson, D. M. (2015). Introduced and invasive cactus species: a global review. *AoB Plants*, *7*, plu078.

Novoa, M. (2016). *The protectors of Indians in the Royal Audience of Lima: history, careers and legal culture, 1575-1775*. Martinus Nijhoff Publishers.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M., & Lang, A. (2004). Human impact on the environment in the Ethiopian and Eritrean Highlands: A state of the art. *Earth-Science Reviews, 64*(3–4), 273–320.

Pyšek, P., Pergl, J., Van Kleunen, M., Dawson, W., Essl, F., Kreft, H., ... & Richardson, D. M. (2020). South Africa as a donor of naturalised and invasive plants to other parts of the world. In *Biological Invasions in South Africa* (pp. 759-785). Cham: Springer International Publishing.

Russell, C. E., & Felker, P. (1987). The prickly-pears (Opuntia spp., Cactaceae): A source of human and animal food in semiarid regions. *Economic botany*, *41*(3), 433-445.

Solomon, N., Birhane, E., Tadesse, T., Treydte, A. C., & Meles, K. (2017). Carbon stocks and sequestration potential of dry forests under community management in Tigray, Ethiopia. *Ecological processes*, *6*(1), 20. https://doi.org/10.1186/s13717-017-0088-2

Taddele, M., & Workneh Negatu, A. G. (2010). Contributions of prickly pear cactus towards achieving household food security in Tigray: The case of Tabia Kihen in Kilte Awlaelo Wereda of Eastern Tigray, Northern Ethiopia. *Improved utilization of cactus pear for food, feed, soil and water conservation and other products in Africa*, 176. Proceedings of International Workshop held in Mekelle, Ethiopia, 19- 21 October 2009.

Tessema, Y. A. (2012). Ecological and economic dimensions of the paradoxical invasive species-Prosopis juliflora and policy challenges in Ethiopia. *Journal of economics and sustainable development*, *3*(8).

Wordofa, M. G., Okoyo, E. N., & Erkalo, E. (2020). Factors influencing adoption of improved structural soil and water conservation measures in Eastern Ethiopia. *Environmental Systems Research*, *9*(1), 13.

Publisher's Note

Daagu International Journal of Basic and Applied Research remain neutral with regard to jurisdictional claims in published maps and institutional affiliations.