**Indigenous agroforestry practices for climate change mitigation and adaptation in Ethiopia: A review**.

**Abstract**

*Agroforestry systems are extensively utilized and play a vital part in reducing the consequences of climate change. This review's objective was to assess Ethiopia's traditional agroforestry practices' effect on climate change adaptation and mitigation. This review was conducted using pertinent data from peer-reviewed research and reviewing books, papers, conferences, and articles. The results were searched, synthesized, and summarized using well-known search engines, exclusion criteria, and inclusion criteria. According to the findings of the reviewed materials, agricultural productivity and community livelihood are at risk when the degree of land degradation increases over time. The effects of climate change, such as prolonged moisture stress, heavy rainfall, floods, seasonal variations in rainfall, etc., were catastrophic events that increased food insecurity and decreased productivity and production. The results showed that one of the most popular options for farmers to respond to climate change was indigenous agroforestry. Among the many benefits of indigenous agroforestry systems are wood, animal feed and vital ecosystem services. This not only makes it easier for farmers to adjust, but it also reduces pressure on indigenous trees in the area. The presence of perennial trees in agroforestry increases its capacity to sequester carbon compared to other land use regimes. It has been demonstrated that agroforestry significantly affects the conservation of soil and water. Agroforestry can conserve soil organic matter and minimize soil erosion by lowering runoff velocity through mulching and biomass exchanges. The deliberate planting, retention, or selection of agroforestry trees requires an understanding of the function and benefits of a species. Particularly to ensure the five functions of trees: fodder/feed, firewood/timber, fiber, food, and fertilizer. Working on carbon finance, enhancing research to encourage the adoption of better agroforestry practices, training farmers and stakeholders, and resolving policy, legal, and infrastructure barriers to the practices' growth are all ways to fully benefit farmers through capacity building.*

*Keywords: Agroforestry; Climate change; Carbon finance; Carbon sequestration; Land degradation*

1. **Introduction**

Land degradation is serious problems that affect agricultural production and productivity which threatens livelihood of the people in Ethiopia. Soil degradation due to soil erosion is the major form of land degradation which results in high economic loss and human wellbeing (Tsegaye, 2019; Asnake, 2024; Tadesse & Hailu, 2024**).** The economic loss due to soil degradation in the form of soil erosion and nutrient depilation accounts 10-11% of agricultural GDP form highlands of Ethiopia. The mean annual soil loss rate is 42 tones/ha on cultivation land and extends up 300 tones/ha in exposed area. The mean total soil loss is estimated as 12 tones/ha/year for the country. The county loses about $106 million annually due to soil and nutrient loss (Tsegaye, 2019). The primary reasons of high soil erosion rates in Ethiopian highlands were recognized as the integrated effect of erosive precipitation, steep slopes, and human impact through deforestation, overgrazing, land use system, and farmer livelihood (Nyssen *et al*. 2015;Tadesse, & Hailu, 2024; Solomon *et al.* 2024). The threat that land degradation poses to biodiversity and climate change, the other two primary components of global environmental change, may be the focus of an alternative strategy for controlling it (Gisladottir and Stocking, 2005). Land degradation is caused by a number of factors, including land use, land cover change, climate change; war, inefficient land management systems, and population increase (Solomon *et al.* 2024).

Several studies revealed that there is significant land use and cover (LULC) change in the country. For example, in Duguna Fango, Southern Ethiopia, the study found that between 2000 and 2018, urbanization and agriculture lands increased at an average annual rate of 92.18 and 366.96 hectares, respectively. While dense forests decreased at a mean annual rate of -228.27 ha/year (Babiso *et al*., 2020). LULC alteration is primarily driven by a variety of primary and underlying causes. The primary proximate causes are the increase of settlement and infrastructure, agricultural expansion, illicit logging, and fuel wood extraction. Demographic, economic, policy, technological, and biological variables are the underlying driving forces (Alemayehu *et al*.2019). Environmental issues have been made much worse by the LULC modifications. Increased soil erosion, sedimentation, degraded lands, and nutrient loads on aquatic bodies are all results of the LULC changes. A decrease in fish populations in Lake Abaya, crop yields, and animal numbers and products were also consequences of LULC alterations. Water bodies, cultivable land, built-up areas, and bare lands have all grown by 0.97, 0.13, 9.27, and 1.36% over the previous periods, respectively. Furthermore, LULC change results from 1985 to 2019, the overall area covered by agroforestry and the area occupied by settlement, including road development, grew at yearly rates of 0.3% and 2.7%, respectively. The highlands of Wonchi District showed more noticeable LULC alterations (Amare *et al.* 2018). But the grazing and woodland areas have shrunk by 3.18% and 8.56 percent, respectively. The production of sloppy lands and extensive land cultivation without proper management have increased soil erosion and sediment yield to water bodies (Demissie, 2022).

The existence of climate change, as demonstrated by decreased precipitation, rising temperatures, and extreme weather events, has been recognized by approximately 94 percent of respondents (Tesfamariam *et al.,* 2020). Approximately 23% of global greenhouse gas emissions (GHGs, such as CO₂, N₂O, and CH₄) originate from forestry, agriculture, and other land uses, such as livestock production, deforestation, and deterioration of soil and biodiversity (IPCC, 2019). According to Meragiaw *et al*. (2022), for a number of reasons, including livelihoods, ecosystem services, and the presence of visually appealing and economically valuable birds, farmers grow native trees. The same household-level factors that account for the adoption of many other agroforestry strategies have also been responsible for the growth of farmland agroforestry (Amare *et al.* 2018). An approach to land use management known as agroforestry, involves growing trees or shrubs in or around pastureland or crops. It creates land-use systems that are more varied, profitable, productive, healthy, and sustainable by combining technology from forestry and agriculture (Misra, 2011). Agroforestry combines forestry and agriculture technology to provide land use systems that are diversified, productive, and integrated. Water and soil conservation is a more general field because reducing water loss through runoff is a key component of soil conservation (Zinabu Wolde, 2015**).** Agroforestry systems are widely used and have a significant role in mitigating the effects of climate change (Solomon, 2019). Thus, the objective of this review was to assess the effect of indigenous agroforestry practice in minimizing the effect of land degradation and climate change adaptation and mitigation in Ethiopia.

1. **Materials and Methods**

Finding and synthesizing pertinent information from peer-reviewed research and reviewing books, papers, conferences, and articles was the process used for this review. Search engines including Google, Google Scholar, Research Gate, Academia, and the websites of the most well-known journals were used to find the pertinent documents. After downloading over 135 PDFs, relevant elements were examined and added to the review. Recent papers in reputable journals (2005–2024) and research on land degradation and agroforestry system generally, with an emphasis on Ethiopia, are among the search criteria.

Keywords pertaining to land degradation trend, extent, and effect on agricultural production were the main focus of the search. "Impact of land degradation, magnitude of land deration, land degradation effect in Ethiopia," “effect of climate change in Ethiopia," "climate change mitigation potential of agroforestry “and” adaptation mechanism of agroforestry in Ethiopia" were the keywords utilized in the literature search. After the literature search, the criteria were used to assess the results from several databases. Literature published before 2005 was eliminated. Additionally, duplicate papers were eliminated from the review. The study's goals, which were mainly to ascertain the extent, trends, and effect of land degradation, the indigenous agroforestry system in climate change mitigation and adaptation role in Ethiopia were assessed thoroughly , taken into consideration when creating the inclusion and exclusion criteria.

The inclusion and exclusion criteria in this review were based on both research and report characteristics. Study parameters like the study location's inclusion and exclusion criteria, the findings' outcome, and the setting were applied in this investigation. The year of publication and the report type which could be full-length research articles, meta-analyses, book chapters, or reports are two examples of report characteristics.

1. **Results and discussions**
   1. **Land degradation trends and effects in Ethiopia**

Land degradation is a major environmental concern in Ethiopia. The primary causes of land degradation in Ethiopia are both human induced and natural (Tadesse, & Hailu, 2024). The study found that land degradation has increased in recent decades, particularly in Ethiopia's highlands (Solomon *et al*. 2024). According to the study, land degradation is a severe issue that has a detrimental impact on the farming community's livelihood in general, as well as the crop and livestock output of household heads, which has been dropping over time due to land degradation. The extent of land degradation in the studied area rises over time (Dakeso, 2024). Furthermore, according to the study, there are 27 million hectares of degraded land in the highlands, of which 14 million hectares have seen severe erosion, with 2 million hectares of that area having reached a point of no return. The soil depth has also decreased to the point where the land can no longer sustain any vegetative cover. Reduced yield, altered land use, altered crops, field abandonment, altered livestock mixes and grazing patterns, flooding, stream flow changes, silting of rivers and dams, unreliable irrigation water flow, declining drinking water and groundwater quality, loss of environmental services, and other costs are indicators of land degradation (Mesene, 2017). There is a negative correlation between livelihood and land degradation. Over 80% of those respondents noted that land degradation affects animal productivity as well as crop yield. The implications of land degradation on agriculture include loss of soil nutrients, and the continuation of poverty. Additionally, it diminishes the resilience of ecosystems and the availability of environmental services (Gashu & Muchie, 2018; Tadesse, & Hailu, 2024). These clearly show the contribution of land degradation for climate change that requires mechanisms to adopt and promote climate smart agricultural practices as strategy to mitigate climate change.

* 1. **Climate change, its effect and coping strategies in Ethiopia**

Ethiopia, Kenya, and other East African nations are experiencing the effects of climate change. The frequent droughts, floods, and famines that have endangered millions of people and cattle in recent decades are examples of climate change in action. The majority of inhabitants in this area, which is distinguished by deteriorated soils, small farm sizes, and low agricultural outputs, rely on subsistence farming methods as their primary source of income (Bishaw *et al.* 2013; Tebkew *et al.,* 2024). Climate change has direct and indirect implications on agricultural production systems. Ethiopia has experienced various climate change effects like extended moisture stress, receiving intense rainfall, occurrences of floods, seasonal fluctuation of rainfall etc. These severe occurrences worsen food insecurity and lower output and productivity (Bouteska *et al*, 2024).

Adaptation and mitigation techniques are two ways to combat climate change brought on by rising CO2 and other GHG concentrations in the atmosphere. The detrimental effects of climate change on ecosystems and people have been reduced by the two main mechanisms. Effective methods and adaptive mechanisms are necessary to reduce anthropogenic GHG emissions and improve sinks in order to prevent the harmful effects of climate change. There is an inherent connection between forests and climate change because they capture and store CO₂, which helps to mitigate the effects of climate change. As a result, forests are cut down, burned, and deforested; these activities can release carbon dioxide, which raises atmospheric concentrations of the gas (IPCC, 2019).

Soil and water conservation, agroforestry, integrated soil fertility management, small-scale irrigation, the use of improved crop varieties, the use of improved livestock, mixed cropping, early and late planting, and income-generating activities are some of the coping mechanisms that farmers have employed in response to climate change (Sinore & Wang, 2024). According to Bishaw *et al*. (2013), home garden agroforestry practices are essential for surviving the anticipated climate change caused by population pressure and poor management that resulted in land degradation. Agroforestry contributes to the production of fuel and building timber, improves soil nutrients, sequesters carbon, and has other ecological benefits (Salve *et al*. 2018; Cheru & Hailu, 2023).

3.3 **Agroforestry system for climate change mitigation and adaptation in Ethiopia**

An ecologically based traditional farming method called agroforestry incorporates trees into farming systems to improve soil fertility, boost agricultural productivity, reduce erosion, preserve biodiversity, and diversify household and community income (Semere *et al.* 2021; Bishaw *et al.,* 2013; Tebkew *et al*., 2024). Indigenous agroforestry emerged as one of farmers' top choices for adapting to climate change, according to the findings. Especially during times of climatic shock, indigenous agroforestry practices provide a variety of advantages, including as wood, animal feed, and essential ecosystem services. In addition to improving farmers' ability to adapt, this also lessens the burden on nearby natural trees. It is noteworthy that on-farm trees significantly improved household income, crop productivity, and overall capacity for adapting to climate change. On-farm trees contributed an astounding 34.35% of the household's total revenue, despite differences seen across various agro ecologies (Berihu *et al.,* 2023)

Smallholder farmers in Ethiopia can benefit from agroforestry by lowering the effects of and adapting for climate change: The term "agroforestry" describes a collection of land-use systems in which herbaceous plants (crops, pastures), woody perennials (trees, shrubs, etc.), and/or livestock are cultivated in a rotational pattern, spatial arrangement, or both. The tree and non-tree plant components interact ecologically and economically in these systems as well. By integrating forestry and agriculture, it produces a land use system that is healthy, productive, economical, and sustainable. It benefits the environment overall, as well as people, animals, and plants. It lessens the trade-off between forests and agriculture. As a result, Agroforestry is seen as the future global land use system (Hagazi *et al*. 2023).

Agroforestry's potential to sequester carbon is higher than that of other land use systems since it contains perennial trees. Furthermore, agroforestry outperformed treeless systems in terms of its capacity to sequester carbon and assist in CO2 mitigation. Comparing agroforestry systems to traditional agriculture systems and forest production techniques can reveal advantages. Increased productivity, food security, economic advantages, and a wider range of ecological goods and services are all possible with them (Solomon, 2019). Agroforestry has been shown to have a significant impact on soil and water conservation. Particularly in southern Ethiopia, planting trees on both agricultural and nonagricultural areas was a common activity. It was unavoidable because the region was hilly; most farmers were small-scale operators who could barely afford to integrate appropriate trees for their crop with intense crop management (Cheru & Hailu, 2023). By conserving soil and water on sloping slopes, agroforestry contributes to environmental rehabilitation and preservation. Tree canopies also protect the soil from the erosive effects of rains, while tree roots keep the soil cohesive, reducing erosion and ultimately the likelihood of floods during the rainy season. In general, one of the greatest land use systems available today is the best method for conserving soil and water, which properly sustains our ecosystem for both the present and the future generations (Zinabu, 2015).

Through mulching and biomass transfers, agroforestry can preserve soil organic matter and reduce soil erosion by reducing runoff velocity, which can help mitigate land degradation. Through the restricting runoff velocity, the contour hedges produced by multipurpose trees reduce soil erosion (Bishaw *et al*., 2013). The study's findings showed that, in the locations under investigation, soil properties were considerably improved under the canopy of Croton macrostachyus compared to the adjacent open space. Under the canopy of Croton macrostachyus, bulk density values decreased by 33.8% while organic carbon, total nitrogen, available phosphorus, CEC, and exchangeable potassium increased by approximately 29.9%, 42.4%, 12.6%, 7%, 14.8%, and 6.1%, respectively. This may be because Croton macrostachyus contributes organic materials as litter falls (Misra, 2011*;* Mamo & Asfaw, 2017).

In the home garden, the topsoil's EC, pH, and CEC were significantly higher than in the parkland and woodlot, while the subsoil's EC, pH, and total nitrogen were significantly greater than in the parkland and woodlot. Through improved accumulation of total nitrogen, good EC, and CEC at all elevation gradients, home gardening is recommended as an effective agroforestry method for the area's sustainable rehabilitation (Aklilu & Mikrewongel, 2016). Furthermore, the study revealed home garden is diverse as compared to other agroforestry practices (Euketu *et al.,* 2014). Soil development under trees and agroforestry systems is in considerable part due to increases in organic matter, whether in the form of surface litter or soil carbon (Misra, 2011). Moreover; The findings showed that there was no significant difference in the overall amount of carbon stocks between the two land uses under study (P > 0.05), with Home garden Agroforestry /HGAFs/ having 148.32 ± 35.76 tons ha⁻¹ and adjacent NFs having 157.27 ± 51.61 tons ha⁻¹. Similar to the NF, HGAFs have the capacity to increase carbon stocks and counteract biomass loss (Siyum & Tassew., 2019).

Understanding the role and advantages of a species is necessary for the purposeful planting, retention, or selection of agroforestry trees. Particularly in order to ensure the five purposes of trees: food, fiber, fertilizer, firewood/timber, and fodder/feed (Bishaw *et al*. 2013; Hagazi *et al.* 2023). According to Tesfamariam *et al*., (2020), 40% of the respondent’s cash revenue came from the trees on the farm. Also, trees on fields are the primary source of fodder for cattle, sheep, and goats during droughts. This is owing to the fact that during periods of drought, it is difficult to gather grasses and as feed from crop wastes (Figure 1)**.** Furthermore,Agroforestry contributes to the environment by preserving biodiversity and has social and cultural significance. As the component interaction is essential for the home garden's sustainable productivity, farmers additionally have indigenous expertise to manage it (Abay & Melese, 2019).

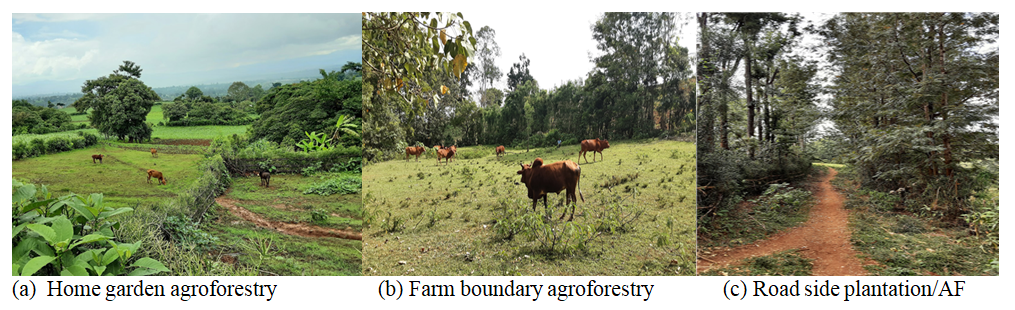
 Figure 1. Indigenous agroforestry practiced (a), (b), & (c) at Gibe Kabala watershed, Southwestern Ethiopia.

Photo credited by the author during field work in 2023.

* 1. **Agroforestry in Line with Sustainable Development Goals (SDGs)**

Agroforestry is considered a sustainable and efficient land management technique integrating crops, trees, and sometimes livestock. According to the report "Achieving the Global Goals through Agroforestry," there is confirmation that agroforestry may help ensure that nine of the seventeen Sustainable Development Goals are implemented. Agroforestry holds the greatest promise for reducing poverty (SDG 1), hunger (SDG 2), climate action (SDG 13), biodiversity conservation, and sustainable land management (SDG 15). Furthermore, the report indicates that agroforestry can contribute to other goals by improving gender equality (SDG 5) and health (SDG 3), as well as by increasing access to clean water (SDG 6), sustainable energy solutions (SDG 7), and responsible agricultural production (SDG 12) (Andersson, 2018).

* 1. **The way forwards**

Agroforestry systems are the primary means of mitigating and adapting to climate change. Agroforestry methods aid in adaptation and mitigation strategies. Improving the technical knowledge and skill gaps by raising awareness among farmers and other stakeholders. Encourage transformation of indigenous agroforestry practice to adoption of enhanced/designed agroforestry practice as better land use systems for the present and future generations, and intensify the testing of novel agroforestry systems that increase and improve production per unit area (Figure 2). Characterizing the current agroforestry system and determining which agroforestry techniques are most appropriate for different agro-ecological bases. Focusing on carbon financing and rewarding small-scale household farmers who take part in agroforestry systems for their role in sequestering carbon. Addressing the policy, legal, and institutional issues that prevent agroforestry systems from being widely adopted and expanded. The strategic coordination of the operations of various governmental and other development organizations involved in natural resource management is another significant aspect that could support the growth of agroforestry.

**** Figure 2*. Promotion and adoption of improved/designed agroforestry practices at Gibe kabala watershed, southwestern, Ethiopia.*

*Photo credited by author during field work in 2022/23.*

1. **Conclusion and recommendation**

A major issue that impacts agricultural productivity and output endangers people's livelihoods, and causes climate change is land degradation. Approximately 94% of respondents acknowledged the presence of climate change, which is characterized by increased temperatures, extreme weather events, and decreased precipitation. Agroforestry is a method of managing land use that includes planting trees or bushes in or near crops or pasture land. Through litter fall, indigenous agroforestry techniques boost organic carbon, decrease soil erosion, and store carbon in the soil, above ground, and below. To enhance soil fertility and health, add organic matter to the soil to improve its nutrients. They provide a greater variety of ecological products and services, economic benefits, increases in production, and food security. In addition to increasing agricultural output, agroforestry practices also decrease erosion, protect biodiversity, and increase household and community income diversification. Therefore, the greatest nature-based approach to climate change adaptation in Ethiopia is indigenous agroforestry, which necessitates the adoption and promotion of better agroforestry practices for the benefit of farmers. It is recommended to use research findings to develop and strengthen innovative agroforestry practices. It is strongly advised that farmers and other stakeholders receive training to fill in their knowledge and skill shortages and connect them to carbon funding.

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