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Research article

The role of agroforestry systems for addressing climate change livelihood vulnerability of farmers of Northwestern Ethiopia

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A R T I C L E I N F O

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A B S T R A C T

Farmers in Ethiopia have been vulnerable to climate change in recent decades. In the face of this change, farmers have managed agroforestry systems to maintain their livelihoods. However, studies exploring the role of agroforestry in reducing household vulnerability are lacking in Northwestern Ethiopia. The objectives of the study were to (i) investigate households' livelihoods vulnerability to climate change in Northwestern Ethiopia; (iii) assess the role of agroforestry in mitigating the negative impacts of climate change on farmers livelihoods. Key informant interviews, in-depth interviews, household surveys (387), and focus group discussions were used to collect the data. Descriptive statistics, principal component analysis, the X^2-test, and the *t*-test were run to analyze the data. The findings revealed that households are vulnerable to rising temperatures, rainfall variability, frost, disease and pests, erosion, hailstorms, price hikes, wildlife damage to crops, and health stress. Agroforestry non-practitioners had a higher livelihood vulnerability index (LVI) (0.42 ± 0.081) than practitioners (0.46 ± 0.079). The Livelihood Vulnerability-Intergovernmental Panel for Climate Change Index (LVI-IPCC) showed that AF non-practitioners had a higher exposure (0.58), sensitivity (0.54) index, and a lower adaptive capacity index (0.44) than the exposure (0.34), sensitivity (0.38), and adaptive capacity index (0.51) of practitioners. Plant diversity, income level and diversity, livelihood activities, social network, and food security status of farmers were improved by agroforestry. Farmers were therefore less susceptible to adverse climate shocks. Thus, the AF system could be part of future adaptation and resilience programs that provide dependable tools to minimize households' vulnerability to climate shocks. However, management guidelines, such as understanding local ecosystems, setting clear objectives, choosing suitable species, planning for diversity, considering the market, and regular maintenance and monitoring, are needed for agroforestry to improve its contribution.

1. Introduction

In Ethiopia, evidence indicates that the people are situated under high population pressure, market price hikes, low productivity, natural resource degradation, and other socioeconomic factors [1–3]. Further, farmers are dependent on rain-fed agriculture [4]. A UNDP [5] analysis found that, on average, Ethiopia's mean annual temperature rose by 1.3 °C between 1960 and 2006, or 0.28 °C

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every ten years. In southern Ethiopia, Matewose [6] discovered a decrease in RF trends and an increase in drought occurrences between 1983 and 2014. In Northwestern Ethiopia, the prediction of climate change by Ayalew et al. [7] indicated that the mean maximum and minimum temperature increased from 1.55 °C to 6.07 °C and from 0.11 °C to 2.81 °C, respectively, in the 2080s compared to the base period considered (1979–2008). The amount of annual rainfall and number of rainy days also decreased in the region in the 1980s. As a result, climate change events such as rising temperatures, increasing rainfall variability, hailstorms, and frost strongly affect rural livelihoods [2,8–10]. According to the report, from the 2000s through the 2010s, more than 38 million Ethiopians experienced a major disruption in their way of life due to climate-related issues [11]. Because of the ragged and mountainous terrain, high population growth, large deforestation, and severe land degradation, farmers in northwestern Ethiopia are distinctively vulnerable to climate events [12,13].

There has been a growing interest among academics, researchers, policymakers, and development practitioners to manage vulnerability [14–16]; managing vulnerability is crucial for poverty reduction and sustainable livelihood [15,17,18]. Vulnerability factors are highly influenced by spatial characteristics and livelihood activities [19]. Climate-friendly practices such as agroforestry are the most effective ways to reduce household vulnerability [20,21]. Studies indicate that agroforestry is widely utilized by farmers to improve their food and livelihood security and adapt to and mitigate climate change [22]. For example, Papa et al. [20] in Kedougou, Senegal, reported that farmers increased their food security using agroforestry while mitigating the negative impacts of rainfall variability. Quandt et al. [23] in Isiolo, Kenya, stated that farmers sell and consume agroforestry fruits to recover and resist the impacts of droughts and floods. Hoang et al. [24], in Vietnam and Kenya, stated that local farmers utilize tree-based systems to secure their livelihoods when crops fail. In Sri Lanka, owning a forest garden is the oldest strategy to withstand the prevailing inter-annual and seasonal rainfall variability [25].

Generally, agroforestry practices help households produce a variety of utility and functional food crops, medicinal plants, vegetables, and woodlots, including those sold and consumed by themselves [26,27]. It allows households to maintain their food requirements, minimize their risk of vector-borne disease, secure energy, and maintain their overall wellbeing under diverse challenges [20,28,29]. Environmentally, agroforestry practices promote organic matter addition, nutrient restoration, soil cover, and erosion control [30]. Deep-root trees are able to utilize water and nutrients from deep soil horizons during climate shocks [31,32]. Trees buffer temperature fluctuations, which prevent and nurture the system from moving to undesired conditions [33]. AF can provide habits for species that support considerable diversity compared to monoculture cropping systems [34]. These benefits play a vital role in addressing climate change livelihood vulnerability of farmers to climate change [24,29].

Agroforestry is an integral part of the farming system in the agricultural landscapes of Ethiopia [35]. Some of the multi-functional and prominent agroforestry practices in the country include homegardens, coffee-shaded practices, woodlots, fallows, scattered trees on farms, boundary plantings, live fences, and other farm plantations [35,36]. These agroforestry practices provide various socio-economic and environmental services to households. For instance, homegardens in southern Ethiopia provide food, fiber, fuelwood, construction, medicine, ornamentation, shade, fencing, and environmental services such as biodiversity, soil improvement, and climate change mitigation [37]. Enset-based agroforestry practices in Southern Ethiopia generate fuelwood, timber, poles, fodder, medicines, and honey for households [38]. On-farm trees in drylands of Ethiopia demonstrated a significant positive impact on crop productivity, household income, and the overall climate change adaptation and mitigation capabilities of farmers [39]. *Acacia decurrens*-based practices in the Fagita Lekoma district generate income while improving soil fertility [40]. Despite these benefits, Alambo [3] reported that, being under the pressure of climate and socioeconomic dynamics, the agroforestry-based livelihoods of smallholders is emerging as less and less rewarding and transitioning in a direction that endangers the sustainability of the agroforestry system.

Many studies have been conducted on livelihood vulnerability and agroforestry, with varying conclusions [20,24,25,27,41]. Scholars [10,11,42,43] have examined the different roles of different adaptation strategies, such as soil and water conservation, improving crop and livestock variety, tree planting, crop diversification, planting date adjustment, irrigation, agronomic practices, livelihood diversification, and integrating livestock with crop production. Berhanu et al. [44] in the Upper Blue. Nile, Ethiopia, explored smallholder farmers' vulnerability to climate change and variability in different agro-ecologies. Specifically, Zerihun [28] in South Africa reported that agroforestry improves the livelihood of farmers under climate change. Gnonlonfoun et al. [45] in Benin and Melvani et al. [25] in Sri Lanka showed that agroforestry has a substantial impact on a household's sensitivity and adaptive capacity. However, studies investigating to what extent and how management and use of agroforestry systems improve farmers' vulnerability to climate change, are limited in northwestern Ethiopia. Further, understanding how farmers' cognizance of risks translates into overt action is another potential area of research. Researchers constantly suggest context-and location-specific vulnerability analysis to devise effective response strategies against climate change hazards.

This study aims to address the following objectives: (i) investigate household's vulnerability to climate change in Northwestern Ethiopia; (iii) assess the role of agroforestry in mitigating the negative impacts of climate change on farmers' livelihoods. This study tried to address these objectives by using qualitative and quantitative data. This study provides information about the household's vulnerability to climate change and the processes by which agroforestry reduces household vulnerability. It provides input for evidence-based policies and practices that promote sustainable livelihoods for farmers in Ethiopia.

2. Conceptual framework

Vulnerability is the most widely recognized concept in various disciplines such as climate risk science, ecology, poverty and development, economics, anthropology, psychology, and engineering [46]. However, the human geography and human ecology disciplines have contributed significantly to the theory of vulnerability [47]. Vulnerability, according to Adger [47], is "a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality in social-ecological systems." A social-ecological system is made up of humans, social structures, and nature that are constantly interacting with one another [48]. The social-ecological system is exposed in time and space to different threats, and it can be vulnerable to them [49]. Fig. 1 shows the conceptual framework of the study.

Vulnerability is most commonly associated with external threats that have a negative impact on livelihoods [51–53]. In this context, hazard refers to the probable occurrence of natural and socio-natural events that may pose physical, social, cultural, institutional, economic, and environmental dangers in a specific location and over time [51]. Risk is defined as "the expected probability of harmful consequences or losses resulting from interactions between natural or anthropogenic hazards and vulnerable conditions" [48]. However, the inherent characteristics of households also determine the vulnerability of livelihoods [54,55]. Education, wealth, technology, information, skills, access to resources, stability, and household management abilities are some of the factors that affect vulnerability [56]. Thus, vulnerability is context- and site-specific and varies across scales with reference to social structure, economic status, and administrative boundaries [56].

According to the IPCC [57–59], vulnerability is a function of three dimensions: exposure, sensitivity, and adaptive capacity. Exposure is understood as some external influence that may affect valued attributes of a system by flagging them, supporting them, or driving a new direction [2]. Exposure to a hazard depends on how communities prefer or are forced to live in an environment [60]. Sensitivity describes the response of a given system to threats and may be shaped by the socioeconomic and ecological conditions of the system's exposure [57]. Household sensitivity is affected by a cumulative effect of social and ecological factors [61]. Adaptive capacity is the "ability of a system to adjust to threats (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" [62].

Agroforestry practices are effective win-win strategies that are well known for their ability to improve livelihood systems' vulnerability to climate change [45]. Research suggests that agroforestry practitioners are less adversely affected by stressors associated with climate change than traditional farmers [20]. Nonetheless, there is evidence that agroforestry and agriculture have trade-offs. Farmers who solely depend on agriculture are subject to variations in the weather each year [63]. Agroforestry trees, on the other hand, may negatively affect crops by competing with other trees for available water and by reducing light availability, which may decrease crop photosynthesis [64]. Notably, agroforestry systems themselves are susceptible to the impacts of climate change [45].

Despite this, current research shows that agroforestry can help with agricultural production, climate change adaptation, and mitigation through its biophysical and socioeconomic effects [65,66]. Agroforestry is a promising agroecological approach to improving livelihood vulnerability to climate change because many agroforestry systems offer numerous co-benefits beyond climate change adaptation, such as synergies with climate change mitigation through carbon sequestration, improved food and income security, and biodiversity conservation [64,65,67].

Agroforestry has the ability to pull water from deeper soil layers and assist crop root water uptake, prevent soil loss after heavy rainfall and/or downstream activities, and generate microclimates with lower mean air temperatures ([68]. By augmenting soil nitrogen and carbon [65] and growing the geographical variety of the soil microbial population, agroforestry can strengthen the resilience of agricultural soils. Additionally, agroforestry trees are a valuable tool for farmers looking to reduce risk and uncertainty by accumulating money for difficult times [64,69]. In general, agroforestry practices can help households increase their sources of income. However, a number of factors, such as farm management abilities, the adoption of new varieties, resource consumption patterns, farm size, health, education, and family size, affect the effectiveness of agroforestry operations [45,67]. Thus, this study examines how vulnerable agroforestry practitioners and non-practitioner families are to climate change.

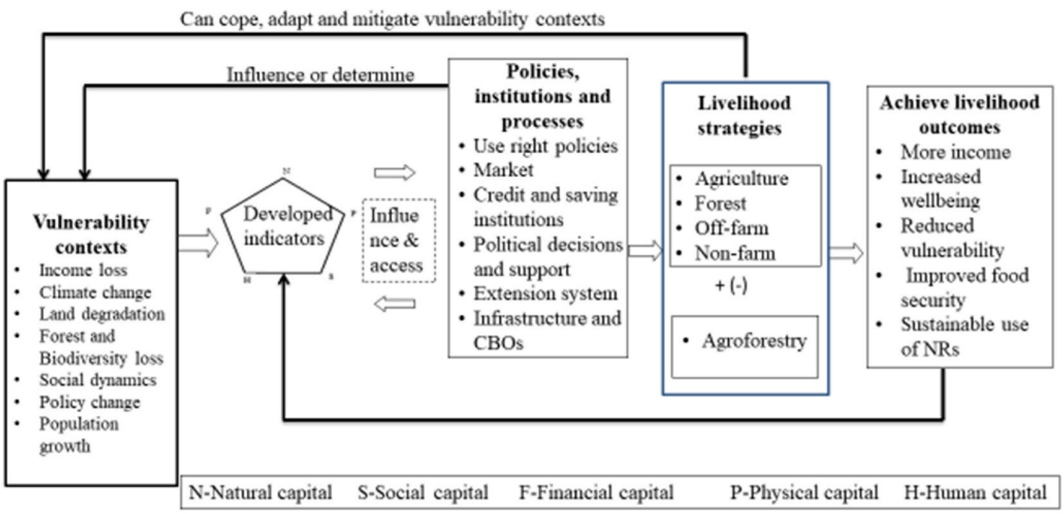

Fig. 1. Conceptual framework of the study (adapted from Ref. [50].

Vulnerability assessment methods employ a variety of ways to objectively investigate and integrate various features and interactions among socioecological systems. There are three commonly used vulnerability assessment approaches: the biophysical approach (BVA), the socioeconomic approach (SVA), and the integrated approach (IVA) [70]. The SVA focuses on individuals' or social groups' variation in socioeconomic and political circumstances and their contribution to vulnerability, including evaluating the nature, distribution, and causes of vulnerability [2,46,54,55,71,72]. However, SVA (i) focuses primarily on societal factors, (ii) overlooks the dynamic interactions and feedback loops between biophysical processes, social susceptibility, and hazards at different scales [73], and (iii) ignores the importance of the natural resource base in mitigating the negative consequences of shocks. The BVA determines the quantitative or qualitative harm that a specific environmental deterioration produced to social and biological systems, such as a financial cost, a change in production or flow, human death, and ecosystem harm [74]. The BVA has the following weakness: (i) it ignores the elements that determine the sensitivity of the system [75]; (ii) it is incompatible with comprehensive and integrated approaches linked with biophysical and social systems [73,75]; and (iii) it overemphasizes extreme occurrences while ignoring underlying causes and regular social processes [76].

The integrated approach to vulnerability assessment combines both SVA and BVA [71,74]. This approach minimizes the limitations of other approaches. However, the IVA lacks a standard method for combining different indicators and accounting for dynamism in vulnerability [71]. To solve these challenges, several scholars used different analytical approaches and tools [51] (section 3.4).

3. Materials and methods

3.1. Study area description

3.1.1. Biophysical set up

This research was conducted in the districts of Lay Armachiho, Bahir Dar Zuria, and Banja of Amhara regional state, Northwestern Ethiopia (Fig. 2). Geographically, the districts are located at 12°35'-12°58' N, 37°10'-37°34' E for Lay Armachiho; 11°16'-11°56' N, 37°6'-37°39' E for Bahir Dar Zuria; and 10°50'-11°05' N, 37°28'-37°46' E for Banja.

The Lay Armachiho (LA hereafter) district covers a total area of 1059.33 Km^2. The Bahir Dar Zuria (BDR hereafter) district had a total area of 2062.62 km^2, whereas the Baja district represents 473.08 km^2. The Lay Armachiho district covers 20552 ha of agricultural crops, 5072 ha of perennial crops, 5166 ha of non-arable land, 5215 ha of future arable land, 8244 ha of forest, 6457 ha of bushlands and shrubs, 5399 ha of grazing land, 1318 ha of wetlands, and 5650 ha of *Cordia africana* plantations. Residents and construction sites

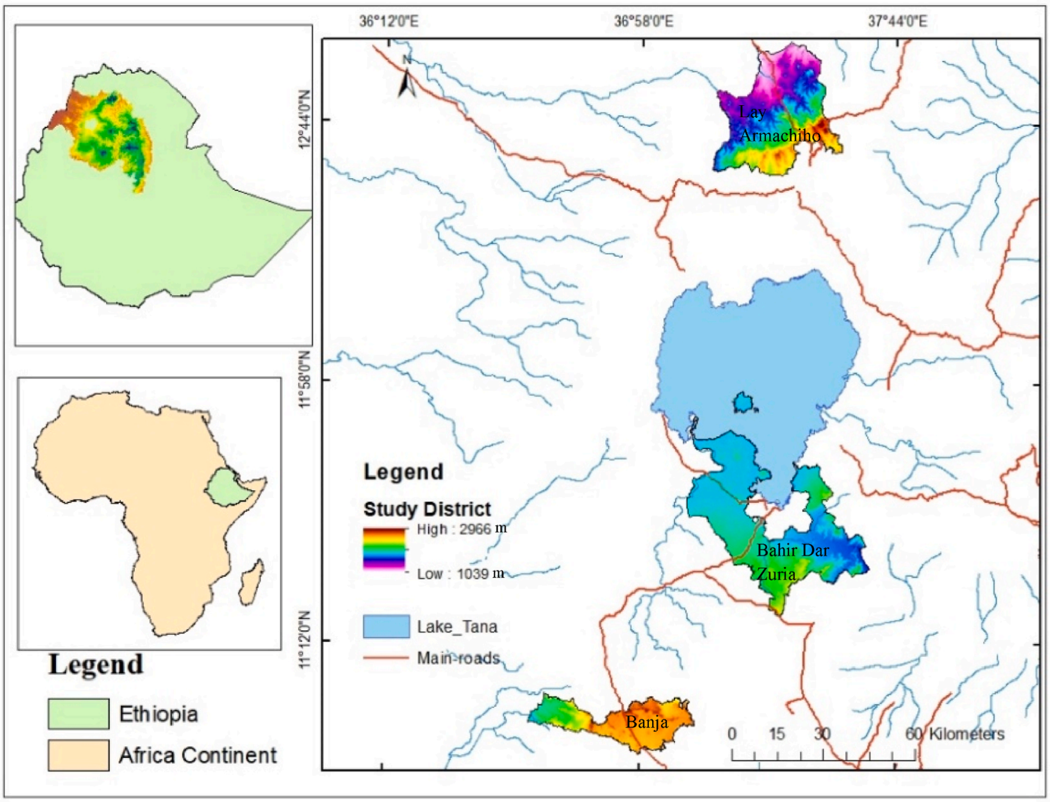

Fig. 2. Map of the study area showing study districts.

cover 7066 ha (Lay Armachiho District Office of Agriculture, 2020). In Bahir Dar Zuria, cropland covers 448,722.00 ha (59.30 %), 83,641.00 ha (11.00 %) grass land, 9982.00 ha shrub and bush, 5451.00 ha wetland, 1320.00 ha waterbody, 2254.00 ha forestland, and 3424.70 ha built-in areas [77]. The Banja district covers 30298.216 ha of cropland, 134 ha of perennial crops, 7891.674 ha of grazing, 7420.8 ha of residence, 8012.512 ha forest, and 180.884 ha protected areas (Banja District Environmental Protection, 2020).

The altitude ranges from 1019 to 2974, 1786–1886, and 1800–2966 m above sea level for LA, BDR, and Banja, respectively. The major soil types in the districts include vertisols, alilosols, leptosols, cambisols, luvisols, and alilosols. The LA has humid and sub-humid agro-climates, whereas the BDR and Banja districts have humid climate zones [77]. The districts' average total annual rainfall (in millimeters) ranges from 995 to 1175 for LA, 895 to 2037 for, and 912.1 to 3741. The mean monthly temperature ranges from 11 to 32 °C for LA, 13–32 °C for BDR, and 9.24–29.36 °C for Banja.

3.1.2. Demography and socioeconomic conditions

The total population of the districts was 194919 for LA, 211051 for BDR, and 100836 for Baja districts [78]. The study sites are composed of Amhara, Kimant, and Agew communities. Kimant communities dominated the LA district. Amhara communities occupy the BDR district, whereas Agew and Amhara communities occupy Banja district. The main livelihood activities of the sites are crop production, livestock rearing, and AF production. Major crops grown in the districts include wheat, barley, teff (*Eragrostis tef Zucc.*), maize (*Zea Mays* L.), millet (*Eleusine coracana* L.), potato, garlic, onion, pepper, and niger seed [77]. Agroforestry practices in the study sites include homegarden, Gesho practice, coffee shade practice, eucalypt woodlots, and *A. decurrens* based tungya systems. According to agricultural offices, AF practices play a key role in maintaining rural livelihoods in the region. The most common woody species

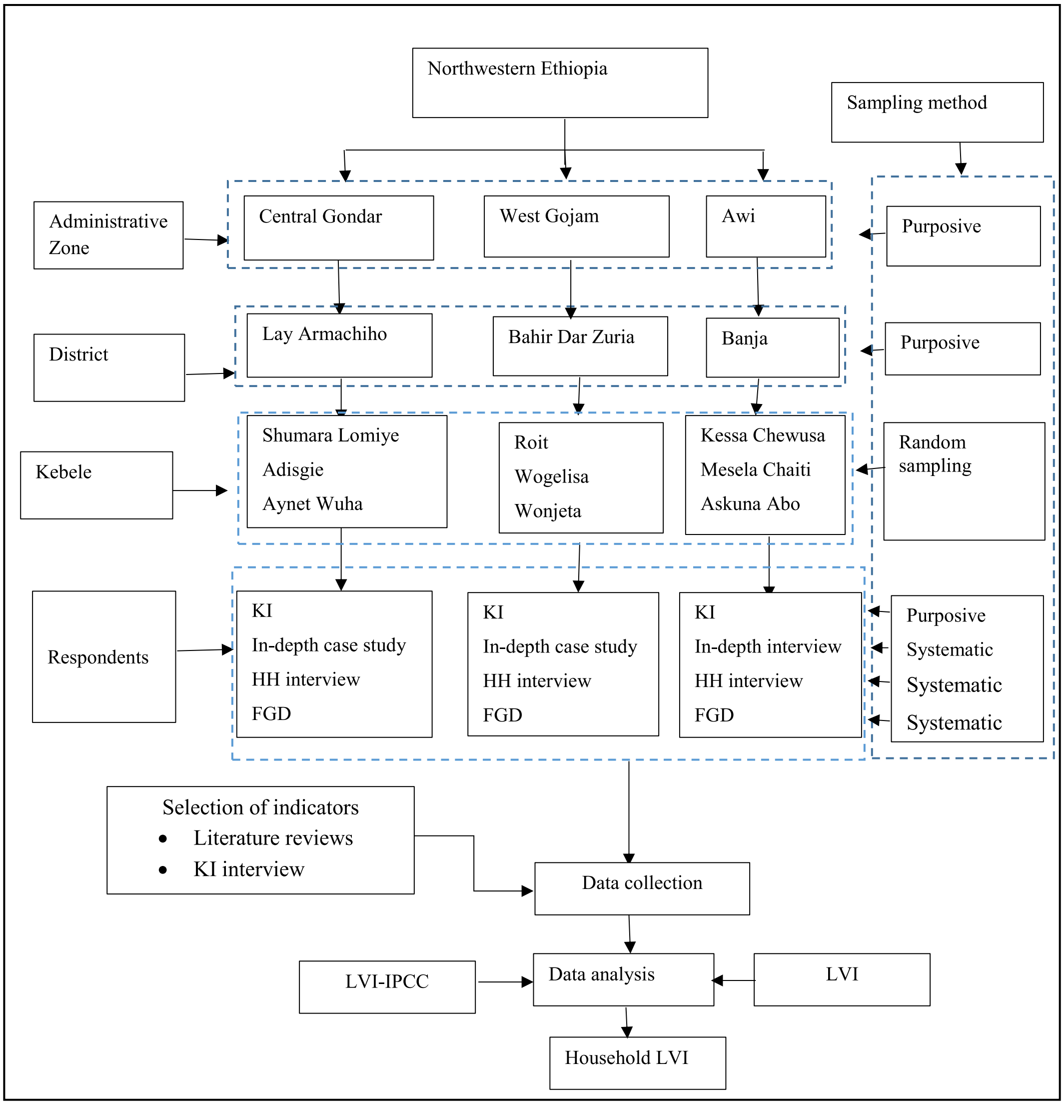

Fig. 3. Sampling procedures of the study.

grown in AFPs are *Rhamnus prinoides* L'Herit (Gesho), *Coffea arabica* (coffee), *A. decurrens*, eucalyptus, bamboo, Mangifera indica, and other indigenous species. *C. Africana, Albizia gummifera,* and *Melitia ferruginia* are examples of multi-purpose shade trees. According to Miller et al. [36], coffee represents 65 % of Ethiopia's total tree-related monetary income. Organic coffee grown in the Banja HGs is referred to as "Awi coffee." It is one of the region's high-quality coffee seed sources. 'Awi coffee' is a well-known exported coffee bean in the region. Gesho is grown in the gardens and farms for economic and cultural reasons. To boost household income, farmers sell AFP products such as dogwood leaves, coffee, fruits, poles, charcoal, and spices.

3.2. Site selection

The sampling procedures for zones, districts, Kebeles, and respondents are shown in Fig. 3. The study districts (Lay Armachiho, Bahir Dar Zuria, and Banja district) were selected purposefully with the heads of agriculture departments. These districts have different agroforestry practices, are accessible to data collection, and have different socio-ethnic groups and vulnerability contexts [77]. Then, three administrative Kebeles, which practice agroforestry, were selected randomly. These Kebeles are Shumara Lomiye, Adisgie, and Aynet Wuha at LA; Robit, Wogelisa, and Wonjeta at BDR; and Kesa Chewusa, Mesela Chaiti, and Askuna Abo at the Banja.

3.3. Data collection

To allow a holistic understanding of livelihoods and their vulnerabilities, both quantitative and qualitative data were collected from primary and secondary sources. The primary data sources include key informant interviews (63), in-depth case studies (27), household interviews (387), focus group discussions (9), and field observations. All KIs, in-depth study participants, and household interviewees were met on a one-to-one basis using Amharic language (local and state language) with their oral consent. Secondary data sources include published and unpublished literature and office documents.

Sixty-three KIs (46 male, 17 female), i.e., seven KIs in each KA, were selected and interviewed. Key informants in this study include both men and women who are knowledgeable about their community's position, climate conditions, culture, and overall growth. Participants in KIs include Kebele's administrative leaders, experts in the KA (three experts in each KA) and district offices, religious leaders, elders, and knowledgeable community members. The age of KIs ranges from 25 to 75 years old. Data collected using KIs comprise livelihood activities such as crops, AF practices, trees, climate and socioeconomic threats, and adaptation strategies. In addition, KIs in each KA were asked to rate major shocks on a scale of one to seven based on importance. A high-impact shock or calamity received a score of seven, while the least important threat received a value of one. Then, scores were summed up to rank the importance of climate shocks.

In an in-depth case study, households were selected from different household groups practicing agroforestry. In each KA, three interviews were selected (one from each wealth group). Hence, in total, 27 interviewees (18 male and 9 female) were selected to conduct the interview. Data collected using this method involves detailed socio-demographic information such as family size, health, wealth status, gender, livelihood strategy determinants, shocks they faced, and adaptation strategies, including the role of AF during shocks.

A stratified random sampling method was used to carry out a household interview. First, the samples representing the target population were determined using the Yamane [79] formula. Sample size using a simplified Yamane formula is calculated as (equ. 1): $n = N/(1 + (N\ (e)2)$ … … … (Equ. 1.), where n is sample size and, N = total household. The selected KAs have 9575 households (N). Using 5 % precision, the sample size of this study was calculated as: $(n) = 9575/(1 + 9575\ (0.05)^2)$. With 10 additional households for replacing missed household the total sample was 387. Second, the list of the target households was received from the agriculture office of KAs. Third, the total sample was allocated to KAs proportionally. Then, with KIs and development agents (DAs), households in each KA were stratified into AF practitioners and non-practitioners. Each stratum was further grouped into poor, medium, and better off using local wealth classification criteria. Key informants confirmed that wealth is a source of variation in livelihood strategies at our study sites. Major criteria include the size of livestock, land, and woodlot. Finally, using the proportional allocative method, sample households were selected randomly in each wealth class. The data collected at this level include households' demographics such as number of family members, age, sex, household livelihood portfolios, off-farm work, households' capital assets such as farm experience, educational status, farm tools and house utensils, belongingness, food and water security, shocks and their impacts, households' local climate perception, and the role of AF practices during shocks. The respondents were interviewed with their oral consent. About 30–50 min were taken to collect the individual household data. To get additional data and check the reliability of household data, nine focus group discussions (FGDs) (one from each KA) were held. The FGD participants involved 8–15 members of diverse social groups (sex, age, and wealth). The time taken to conduct the FGDs was 50–60 min.

3.4. Selection of indicators and assessment approaches

Vulnerability analysis must integrate and examine interactions between humans and their physical and social surroundings. Thus, vulnerability studies designed to inform adaptation policies should examine future development priorities, generate information that is useable for more local-level decisions, and consider the full range of socioecological systems that shape people's current and future vulnerability [80]. However, there is no clear rule that specifies the criteria to assess vulnerability and give development priority [46]. As a result, vulnerability assessment approaches will continue to differ and function based on aims and levels of attention. This makes it incredibly difficult to generate meaningful and trustworthy measurements of vulnerability [47].

Recently, almost all researchers have used indicators to characterize and quantify the different dimensions of vulnerability [81].

Most researchers used the sustainable livelihoods approach (SLA) and the IPCC definition to organize indicators [82–84]. Sustainable livelihood approaches focus on access to capital assets (financial, physical, natural, human, and social), the ways in which people combine these capital assets to create livelihoods, and how they are able to enlarge their asset base through interactions with social structures (actors and institutions) [85]. It identifies vulnerable environments, institutions, policies, and processes that either enable or impede a household's capacity to exercise its capabilities by using a variety of indicators.

Using the sustainable livelihood approach (SLA), Hahn [86] has developed a pragmatic livelihood vulnerability index (LVI) within the broader IPCC framework. A livelihood vulnerability index is a useful instrument for understanding how physical, social, and demographic factors affect households' vulnerability to climate change ([86]; Panthi et al., 2015). Utilizing SLA, Hahn et al. [86], and the IPCC criteria, this study computes LVI among smallholder farmers and its drivers.

Dimensions and indicators were set referring to literature [9,23,26,49,87,88]; [45]]; [25,29,53,55]. Indicators set through a review of literature were modified with key informants to fit the context of our study area. Then, questioners were prepared and tested through a pilot household interview. Finally, the data gathered from the household survey was grouped into major components and dimensions using the Hahn [86] and IPCC [62] definitions. For example, the impacts of climate disasters, i.e., floods, rainfall, frost, hailstorms, theft, wildlife, and epidemics, on household livelihoods were grouped into exposure dimensions (Tables 1 and 2).

3.5. Data analysis

The data were analyzed using statistical software programs (STATA Version 14.0). Qualitative data were organized, described qualitatively, and presented in texts. Quantitative data were analyzed using descriptive and inferential statistics and presented in figures and tables. The chi-square test was used to compare households' perceptions among districts and between practitioners and non-practitioners to climate change and variability. A T-test was run to compare household groups using socioeconomic and demographic variables.

There are different methods suggested to combine different variables. The first is to assume that all indicators of vulnerability are equally important, therefore, give them the same weights [89]. This approach is disregarded since different indicators typically influence vulnerability in different ways [55]. Giving distinct weights is one technique to prevent uncertainty. Several methodological strategies have been proposed to compensate for the weight variations in indicators in accordance with the second approach. Principal component analysis (PCA) is one of the appropriate analysis methods to attach weights, according to several vulnerability studies [2,54]. However, principal component analysis has two major limitations. First, it assumes that the associations between variables are linear. Second, its interpretation is only functional if all the variables are supposed to be numerical. To solve these limitations, standardizing all indicators to a 0–1 value is taken as a suitable technique [2,18,63,80]. Thus, this study employed PCA to reduce dimensions and attach weights to indicators (Table 2).

3.5.1. Calculating the LVI composite index

In this study, the LVI is constructed in steps, beginning with indicator selection and progressing to component aggregation and the final index. Each of the sub-components was measured on a different scale; therefore, it was first necessary to standardize them for comparability. The data collected on continuous, nominal, and ordinal values were normalized to come up with standard values (0–1). Indicators measured using metric scales were normalized by applying the min-max method of Fritzsche et al. [80] (Table 3, Equ. 2). Dummy variables, e.g., any 'yes' answer was assigned a 1 and any 'no' answer was assigned a 0.

Then the major component indices of vulnerability for livelihoods were calculated (Table 3, equ. 3). Major components include disaster/stress impact, land, health, food, water, infrastructure, sociodemographic profile, livelihood strategies, and social networks (Table 1). The relative effects of each threat on the livelihood strategies (crop, livestock, and agroforestry) of a particular household were used to measure the impact or exposure level. The relative effect or impact was scaled: 0 = no impact; 1 = low impact; 2 = medium impact; and 3 = high impact as perceived by a household. Then the average impact of each threat on the livelihoods of each household was estimated before running the PCA. Indicators and their scale of measurement to create land, health, food, water, infrastructure, sociodemographic profile, livelihood strategies, and social network components are shown in Table 1. An index for each major component was created by assigning weight to each indicator. Principal component analysis was used to generate object scores across the principal components. The numbers of components to be extracted were determined through the Kaiser Rule, the Scree plot rule, and the interpretability of the rotated component matrix criteria [90]. Once values for each of the nine major vulnerability components for districts are calculated, they are averaged using Eq. (4) in Table 3 to obtain the district-level LVI.

3.5.2. Calculating LVI-IPCC

The LVI-IPCC uses the same individual components as the LVI to create the index. The index value is different from the LVI in how the major components (dimensions) are combined [9,29,53,55]. Instead of merging the dimensions into the LVI together, they are combined into exposure, sensitivity, and adaptive capacity [62] (Table 3, equ. 5). In this study, we used climatic impact indicators to measure households' exposure dimension; the current state of land, health, food and energy, infrastructure, and water to measure the sensitivity dimension; and indicators of socio-demographic profiles, livelihood strategies, and social networks to measure adaptive capacity dimensions. Adaptive capacity reduces vulnerability. Accordingly, the inverse of the components was used to calculate this major dimension composite index. After calculating the contributing factors, the LVI-IPCC is calculated using Equ. (6), Table 3. The vulnerability index for each household ranges from −1 (least vulnerable) to 1 (most vulnerable), which is standardized between 0 and 1, inclusive. According to the ICC [62], households with an LVI value less than 0.45 are low vulnerable, whereas those with an LVI between 0.45 and 0.7 and >0.70 are medium and severely vulnerable, respectively. Based on the IPCC [62] and local context, the

Table 1
Dimensions, major components, subcomponents, data sources and their functional relationship.

Dimensions	Major component	Sub-components/Indicators	Assumed functional relationship/Measures of construct	Source
Exposure	Exposure	Effect of delay RF on crops Effect of delay RF on AF Effect of delay RF on livestock and fodder Effect of erratic nature of AF on crops Effect of erratic nature of AF on AF Effect of erratic nature of AF on livestock and fodder Effect of early offset of RF on crop Effect of early offset of RF on AF Effect of early offset of AF on livestock Effect of Late rainfall offset on crops Effect of Late rainfall offset on AF Effect of Late rainfall offset on livestock Effect of frost on crop Effect of frost on AF Effect of frost on livestock Effect of hailstorm on crop Effect of hailstorm on AF Effect of hailstorm on livestock Effect of disease and pest on crops Effect of disease and pest on AF Effect of disease and pest on livestock Effect of wildlife damage on crop and fruits Effect of productive family member death Asset loss Effect of erosion on land Effect of erosion on yield Effect low yield price on livelihoods Effect of high input price on farming practice Inflation on livelihood	Exposure level is measured by the relative effects of a threat on particular household (0 = no impact; 1 = low impact; 2 = medium impact; and 3 = high impact) as perceived by a household	[9,23,26,49,87,88]; [45]; [2] [25,29,53,55].
Sensitivity	Land	Land capability class (1–6)	High capability implies higher sensitivity	[2]
		Location of farms to shocks (1 = far, 2 = medium, 3 close to shock)	Farms located in hill areas, close to forests etc implies higher sensitivity	[2] [55]
		Land fragmentation (# of different plots)	High land fragmentation implies low sensitivity	[55]
	Food and energy	This year food insufficient months	High value implies higher sensitivity	[53]
		Last year food insufficiency months (# of months)	High value implies higher sensitivity	[9]
		Feeding condition (1 = decreased, 2 = same, 3 = increased)	High value implies lower sensitivity	[9]
		Food consumption score (sum of score)[a]	High implies low sensitivity	[9]
		Energy security (1 = yes; 0 = otherwise)	High implies lower sensitivity	[9]
	Health	Family health status (1 = better; 2 = medium = poor)	Better health status implies low sensitivity	[2]
		Health impact (1 = low; 2 = medium; 3 = high)	High health impact implies high sensitivity	[2]
		Health insurance (1, yes; 0 = otherwise)	High implies low sensitivity	[2]
	Water	Access to safe water (1 = Have access pipe, hand well, stream water access within 1.5 km; 0 = otherwise)	Access to safe water implies low sensitivity	[2]
		Access to river (1 = yes; 0 = otherwise)	Access to river implies low sensitivity	[2]
		Irrigation access (1 yes; 0 = otherwise)	Access to irrigation implies low sensitivity	[23].
	Infrastructure	Road access (1 yes; 0 = otherwise)	Access to road implies low sensitivity	[2]
		Road condition (1 = asphalt; 2 = Pista; 3 = soil)	better road implies low sensitivity	[27]
		Road in rain (1 = good; 2; medium; 3 = bad)	Good implies low sensitivity	
		Produce market access(1 = yes; 2 = otherwise)	Access to market implies low sensitivity	[2]
		Farm input market access (1 = yes; 2 = otherwise)	High implies low sensitivity	[2]
		Livestock market access (1 = yes; 2 = otherwise)	High implies low sensitivity	[2]

(continued on next page)

Table 1 (*continued*)

Dimensions	Major component	Sub-components/Indicators	Assumed functional relationship/Measures of construct	Source
		Access health center (1 = yes; 2 = otherwise)	High implies low sensitivity	[27]
Adaptive capacity	Sociodemographic profile	Age in Years	Age increase experience	[2]
		Sex (1 = male, 0 = otherwise)	Females are usually more vulnerable than men	Mekonen et al., 2019;
		Education in years	Education makes people more aware and able to adjust to change	[55]
		Place attachment ratio (years lived in the area divided by age of respondent)	High place attachment ratio implies high adaptive capacity	[2]
		Family size	Family size increase adaptive capacity	[2]
		Dependency ratio (age under 15 and above 65 based on Ethiopian rural labor low)	High implies low adaptive capacity	[2][53];
	Livelihood strategy	Farm experience in years	High implies high adaptive capacity	[55]
		Land size in ha	High implies high adaptive capacity	[25,55]
		Land fertility (1 = low, 2 = medium, 3 = high)	High implies high adaptive capacity	[80]
		Soil and water conservation (1 = low, 2 = medium, 3 = high)	High implies high adaptive capacity	[2]
		Land certificate (0 = no, 1 = in process, 3 = yes)	High implies high adaptive capacity	[23]
		Farm equipment (# of equipment)	High implies high adaptive capacity	[23]
		Total belongingness (# of belongingness)	High implies high adaptive capacity	[23]
		Credit access (1 = yes, 0 = otherwise)	High implies high adaptive capacity	[54]
		Saving in Birr	High implies high adaptive capacity	[54]
		Extension contact per week (1 = no; 2 = one times; 3 = 3 times; 4 = 4 times; 5 = 5 times and above)	High implies high adaptive capacity	[55]
		Technology adoption (1 = yet; 0 = otherwise)	High implies high adaptive capacity	[56]
		Total annual income in Birr	High implies high adaptive capacity	[2]
		Total farm income in Birr	High implies high adaptive capacity	[2]
		Total non-farm income in Birr	High implies high adaptive capacity	[2]
		Livelihood diversification index measured by Simpson index ($SI = 1 - \sum_{i=1}^{n} pi^2$)	High index better adaptive capacity	[2]
		TLU[a]	Livestock reduces the risk of major losses	[55]
		Crop diversity (# of crop species)	High implies high adaptive capacity	[45]
		Woody species diversity (# of woody species)	High implies better adaptive capacity	[45]
	Social capital	Total farm cooperative membership (# of farm cooperative participated)	High social activity implies better adaptive capacity	[2]
		Strength of social bond (# of social activity done with neighbor)	High social activity implies better adaptive capacity	[2]
		Participation in Kebele leadership (0 = no; 1 = low; 3 = medium; 4 = high)	High implies better adaptive capacity	[2]

[a] TLU = Tropical livestock unit. Conversion factor used to calculate TLU is 1 for cows, 0.75 for heifer and bull, 0.45 for calf, 0.15 for goat and sheep, 0.5 for donkey, 0.005 for chicken, 1.15 for mule/horse, and 0.0019 for beehive. Household's food item weight = item weight times consumption frequency response/score per month. Household food consumption score (FCS): FCS $= \sum_{i=0}^{n} \textit{food item weight}$. Weight for each food item or food group was given as: grain = 2, pulses = 3, vegetables = 1, fruits = 1, egg and meat = 4, dairy product = 4, sugar or honey = 0.5, and oil, fat, butter = 0.5.

LVI-IPCC value of each household's major dimension (exposure, sensitivity, and adaptive capacity) was categorized into low (0 ≤ LVI-IPCC ≤0.45), medium (0.45< LVI-IPCC ≤0.70), and high (0.70 < LVI-IPCC ≤1.00) to compare the vulnerability status of agroforestry practitioner and non-practitioner households.

4. Results

4.1. Respondents demographic and socio-economic characteristics, livelihood strategies and agroforestry practices

A total of 255 practitioners and 132 non-practitioners were interviewed. Of which, 81 respondents were from LA (55 practitioners and 26 non-practitioners) and 181 from BDR (125 AF practitioners and 56 non-practitioners). In Banja, 125 respondents (75 practitioners and 50 non-practitioners) were interviewed. Most of the household respondents (90 %) were male. Socio-ethnically, 56 % of interviewees were Amhara, 22 % were Kimant, and 21 % were Agew. Respondents were Kinamt in LA, Amhara in Bahir Dar Zuria, and 70 % Agew and 30 % Amhara in Banja district. The average age of household heads was 47.26 years (47.89 ± 11.19 in LA, 45.45 ±

Table 2
Dimensions, major components, subcomponents, and their weights in the study areas.

Dimensions	Sub-components	Indicators/variables	Weight scaled to sum unit one	Mean	STD DEV.	Variable loadings/ scores	Indexed value of the variable/contribution
Exposure	Impact of shocks	Delay RF impact (Av.)	0.7140	0.4823593	0.1706606	0.2704	0.12470
		Early offset of RF impact (Av.)	0.7673	0.4324675	0.2054778	0.3043	0.14404
		Late RF impact (Av.)	0.5746	0.3753247	0.1895024	0.2409	0.08076
		Erratic RF impact (Av.)	0.6621	0.3819264	0.1827296	0.2495	0.10724
		Frost impact (Av.)	0.6060	0.2427489	0.2034068	0.2801	0.08984
		Hill storms impact (Av.)	0.5196	0.1886364	0.1399153	0.2089	0.06606
		Disease impact (Av.)	0.6960	0.4834416	0.2511925	0.2922	0.11851
		Wild life damage (Av.)	0.5220	0.2928571	0.2255945	0.2506	0.06665
		Death of productive family member	0.3995	0.4344156	0.3499684	0.2493	0.03905
		Asset loss	0.3624	0.4266234	0.332641	0.2605	0.03213
		Erosion on land	0.2903	0.3681818	0.2359198	0.2975	0.02062
		Erosion on yield	0.4785	0.4006494	0.2577564	0.2844	0.05602
		Low yield price	0.1727	0.3922078	0.2689516	0.1995	0.00730
		High input price	0.3655	0.625974	0.2332418	0.2559	0.03269
		Inflation	0.2425	0.6090909	0.265377	0.1976	0.01439
Sensitivity	Land	Land capability	0.0297	0.4640827	0.15975	0.0441	0.00026
		Location of farms to shocks	0.0942	0.378553	0.302374	0.0445	0.00259
		Land fragmentation	0.7033	0.7984496	0.1409046	0.3373	0.14436
	Food and energy	This year food insufficiency	0.8034	0.237907	0.3016501	0.4098	0.18836
		Last year food insufficiency	0.8138	0.1871232	0.2412725	0.4119	0.19331
		Feeding improvement	0.6275	0.2764858	0.3559852	0.2726	0.11491
		Food consumption score	0.8197	0.538468	0.1850073	0.3931	0.19612
		Energy security	0.3008	0.1472868	0.3548504	0.1825	0.02642
	Health	Family health status	0.1916	0.2338501	0.3161727	0.2069	0.01072
		Health impact	0.2124	0.2226563	0.3566339	0.2148	0.01317
		Health insurance	0.1636	0.126615	0.3329716	0.0946	0.00782
	Water	Access to safe water	−0.1033	0.2764858	0.4478389	−0.0917	0.00311
		Access to river	−0.029722	0.6124031	0.4878324	−0.0517	0.00026
		Irrigation access	0.438485	0.372093	0.4839887	0.2961	0.05612
	Infrastructure	Road access	−0.048333	0.1808786	0.3854158	−0.1084	0.00068
		Road condition	0.122037	0.5155039	0.2718769	−0.0285	0.00435
		Road in rain	0.122037	0.2997416	0.2405794	0.1423	0.00435
		Produce market access	−0.241240	0.5374677	0.4992396	−0.1706	0.01699
		Farm input market access	−0.004902	0.4134367	0.4930873	−0.0233	0.00001
		Livestock market access	0.136754	0.7829457	0.4127735	0.0249	0.00546
		Access health center	−0.191075	0.8423773	0.3648586	−0.151	0.01066
Adaptive capacity	Socio-demography profile	Age	0.95428	0.52247	0.2141258	0.14070	0.29372
		Sex	−0.10469	0.0935065	0.2915198	0.18870	0.00354
		Education	−0.33252	0.7864935	0.2367849	0.10540	0.03566
		Place attachment ratio	0.88966	0.4384263	0.1905399	0.12030	0.25529
		Family size	0.32689	0.5827627	0.1837702	0.28980	0.03447
		Dependency ratio	0.22591	0.4001882	0.2039865	0.00650	0.01646
	Livelihood strategy	Farm experience	0.92407	0.543085	0.194097	0.14840	0.27542
		Land size	0.33177	0.7263162	0.1617235	0.34710	0.03550
		Land fertility	0.07375	0.4688312	0.2847055	0.12650	0.00175
		Soil and water conservation	0.08417	0.6363636	0.3231152	0.10360	0.00229
		Land certificate	0.08599	0.6909091	0.4556308	−0.11270	0.00239
		Farm equipment	−0.00280	0.7231911	0.154734	0.27620	0.00000
		Total belongingness	0.02317	0.7605728	0.1391318	0.27380	0.00017
		Credit access	0.10583	0.6545455	0.476135	0.11750	0.00361
		Saving	0.03462	0.9541558	0.1122637	0.13850	0.00039
		Extension contact	0.12574	0.5490909	0.2763329	0.00350	0.00510
		Technology adoption	−0.01752	0.1272727	0.3337119	0.16270	0.00010
		Total annual income	0.13389	0.7893564	0.1464528	0.30520	0.00578
		Total farm income	0.14718	0.809456	0.1421529	0.30450	0.00699

(*continued on next page*)

Table 2 (*continued*)

Dimensions	Sub-components	Indicators/variables	Weight scaled to sum unit one	Mean	STD DEV.	Variable loadings/ scores	Indexed value of the variable/contribution
		Total non-farm income	−0.02429	0.8876773	0.1655043	0.06300	0.00019
		Livelihood diversification index	0.08498	0.4467819	0.1508553	0.13540	0.00233
		TLU	0.08641	0.6575909	0.2046942	0.19120	0.00241
		Crop diversity	0.15479	0.6165584	0.1603935	0.15690	0.00773
		Woody species diversity	0.06239	0.7833766	0.1954358	0.24520	0.00126
	Social capital	Total farm cooperative membership	0.12251	0.4557261	0.1576596	0.22780	0.00484
		Total social support	−0.00905	0.2344156	0.2246249	0.14540	0.00003
		Participation in *Kebele* leadership	0.08958	0.6813853	0.3377525	0.19950	0.00259

Note: Av. in bracket implies average.

Table 3
list of equations used to calculate vulnerability indexes.

Equation	Equation no.	Description
$X_{i,0to1} = \frac{X_i - X_{min}}{X_{max} - X_{min}}$	Equ. 2	Xi represents the individual data point, XMin the lowest value for that indicator, XMax the highest value for that indicator, and $X_{i,0\ t\ o1}$ the normalized data point within the range of 0–1.
$Mv = \frac{\sum_{i=1}^{n} \text{indexSi}}{n}$	Equ. 3	Mv is one of the nine major components for each district, Si represents the sub-components indexed by i that make up the major component, and n is the number of sub-components in each major component.
$LVI = \frac{\sum_{i=1}^{9} \text{WMi Mvi}}{\sum_{i=1}^{9} WMi}$	Equ. 4	LVI is livelihood vulnerability index, WMi is the weight of one of the major contributing factors
$CFV = \frac{\sum_{i=1}^{n} \text{WMi Mvi}}{\sum_{i=1}^{n} WMi}$	Equ. 5	CFV is one of the contributing factors to LVI-IPCC (exposure, sensitivity, or adaptive capacity) for a district, WMi is the weight of one of the major contributing factors, and MVi is the major component for a district vulnerability indexed by i.
LVI-IPCC= (Exposure– Adaptive) *Sensitivity	Equ. 6	LVI-IPCC refers Livelihood vulnerability intergovernmental panel for climate change

11.14 in BDR, and 49.472 ± 11.37 in Banja). About 38.76 % of respondents were unable to read and write, and 39.28 % had basic educational status. The remaining households had elementary (18.35 %) and secondary (2.07 %) educational status. The mean family size of the study districts was 5.51 ± 1.98 for LA, 5.88 ± 2.09 for BDR, and 5.15 ± 1.96 for Banja. The average land size was 1.59 ± 0.88 ha in LA, 1.47 ± 0.82 ha in BDR, and 1.03 ± 0.56 ha in Banja district. Agroforestry practitioners had an average land size of 1.98 ha, whereas AF non-practitioners owned 0.68 ha. T-test analysis shows that AF practitioners owned larger land sizes than non-practitioners in all districts ($P < 0.05$).

On average, farmers at the study sites had 3.63 farm plots. The mean number of plots in each district was 3.48 ± 1.47 for LA, 3.98 ± 1.67 for BDR, and 2.94 ± 1.07 for Banja. Most household respondents (93.37 %) had a landholding certificate. Most respondents (81.48 % in LA, 83.98 % in BDR, and 96 % in Banja) have health insurance. Major farm labor resources include drought power (livestock), family members, and hired workers (either daily or contract workers). The main farm equipment includes an axe, plough, generator, machete, saw, and local digging tools.

Crop production, livestock husbandry, AF activities, forests, paid income, private enterprise, employment, remittances, and seasonal migration are major livelihoods for farmers. Almost all respondents in the study area cultivate crops. Major agricultural staples and cash crops in LA district include teff, maize, sorghum, and millet. In BDR, agricultural crops comprise teff, maize, millet, and wheat. Cash and staple crops in Banja include maize, wheat, teff, barely, and potato. About 94 % of respondents in LA, 99 % in BDR, and 92 % in Banja owned livestock. On average, households in LA owned 5.13, 6.85, and 5.04 tropical livestock units (TLU), respectively. In LA, 40.74 % of the respondents received remittance income. About 11 %, 19 %, 17.28 %, and 6 % of farmers in LA obtain income from natural forest, paid labor work, business, and employment, respectively. About 33 %, 25 %, and 8.84 % of household respondents in the BDR district obtain income from natural forest, business, and remittance, respectively. In Banja, more than half of respondents collect income from nearby natural forests and daily labor employment, respectively. Moreover, 30 %, 18 %, and 9 % of respondents get remittance, business, and employment income, respectively.

The average household's total income (ETB) in the study sites was 68,845 in LA, 78,592 in BDR, and 47,262 in Banja. Agricultural crops (35.67 %), AF (28.43 %), and livestock rearing (22.79 %) were the three most important income sources in the study area. These livelihood activities contribute 81–91 % of the total household income in the study sites. Crop yields and byproducts like thresh, stalks, and leaves were the primary goods produced by agriculture. Major income sources included in the estimation of livestock income include dairy products, selling dung, selling animals, and rental income. Fruits, leaves, seeds, fuel wood, fodder, and medicines were major income-generating products in agroforestry. In LA, agricultural crops constituted 37.78 % (26009.64 ETB) of the total income, followed by AF, which contributes 35.2 % (24233.44 ETB), and livestock rearing (18.44 %). In the BDR district, crop production, AF, and livestock rearing contribute 37.5 %, 30 %, and 20 % of the total income, respectively. However, livestock rearing is the most important income source for Banja's total income (33.4 %). Crop production (29.30 %) and AF practices (18.4 %) were the second and third important income sources in the Banja district, respectively.

The aggregated result shows AF practitioners had significantly higher mean crop income (23699.02 ETB± 16448.48) than non-practitioners (21048.54 ± 17098.02) ($t = 1.4780$, $p = 0.07$). Moreover, AF practitioners' livestock income was substantially larger ($t = 2.55$, $p = 0.005$) than that of non-practitioners (17148.25 ± 15057.03) (12738.7 ± 16851.1). The findings show that AF practitioners earned considerably more money from crops and animals ($p < 0.05$).

The major agroforestry practices in the study sites include homegardens, shaded coffee, Gesho agroforestry, eucalyptus woodlots, and A. decurrens woodlots. Homegardens were implemented by 45 (55.56 %) farmers in LA, 118 (65 %) in BDR, and 35 (28 %) in Banja. About 46 % and 35 % of respondents in the LA district carried out Gesho and coffee-shade practices, respectively. About 44 % of households in BDR, 33 % in Banja, and 15 % in LA planted eucalyptus woodlots on their farms. Thirty-four percent of farmers in the Banja district planted *A. decurrens.*

Agroforestry practices comprised cash and non-cash trees, shrubs, and herbs. Major cash trees and shrubs include *Gesho, C. arabica* L.*, Citrus sinensis (L.) Osb., Citrus aurantiifolia (Christm.) Swingle, Mangifera indica* L., *Percia americana Mill., Eucalyptus, A. deccurens*, *Z. mays* L., and *Capsicum frutescens* L. Products of homegardens include fruits, crops, leaves, fuelwood, fencing materials, and fodder for livestock. Herbaceous components like cereals (*Z. mays* L., *E. coracana* L.*)*, and vegetables and spices (*Brassica carinata A. Br.*, *Lycopersicon esculentum Mill.*, *Solanum tuberosum* L., *C. frutescens* L., etc.), are integrated in the farm mostly for household use. Species such as *Gesho, C. arabica, C. aurantiifolia, M. indica, and P. americana* are planted mainly to generate cash income.

Production of Gesho leaf is the primary objective for farmers practicing Gesho. Gesho leaf is useful to prepare "Tela, Areki, and Teji." Tela, Areki, and Teji are local alcoholic drinks in Ethiopia, where the first two are prepared from gesho and cereals, and the latter is prepared from Gesho and honey. Agricultural crops grown in the early stages of Gesho practice, such as teff, maize, and millet, are useful for supplementing household food. *Coffea arabica* is the preferred cash crop under multipurpose shade trees in coffee-shade practices. Common multi-purpose shade trees involve *Cordia africana* L.*, Albizia gummifera (J. F. Gmel.) C. A., Ficus sycomorus* L.*, Ficus sur Forssk, and M. indica*. Other benefits collected in this practice include timber, wood fuel, construction, and fencing materials. Eucalyptus is a multi-purpose tree planted by farmers in study districts to collect fuel wood, timber, house and farm tools, and generate income. It is widely planted on degraded lands, farm boundaries, and farmlands. *Acacia decurrens* is an exotic plant introduced to Banja in 1988. This plant is a fast-growing species that rapidly expands in the agricultural landscapes of Banja district to produce charcoal, generate income, and improve soil fertility.

4.2. Livelihood threats and households perception

The results indicate the climate faced by communities in the study area. Rising temperatures, the unpredictability of rainfall, hailstorms, frosts, and disease and pest outbreaks are all examples of climate events. Most respondents perceived a rapid change in climate during the last three decades (Table 4). Most respondents (84 % in LA, 77 % in BDR, and 69.11 % in Banja) perceived the rising temperature compared to three decades ago. Further, most respondents (43 %) reported a decreasing rainfall amount. About 57 % of respondents reported a later commencement and shorter rainy seasons. In the BDR and Banja districts, households confirmed that rainfall over the last 30 years has fluctuated. However, non-negligible farmers perceived no change on rainfall or frost occurrence.

The Pearson X^2-test showed that the perception of households regarding climate change ($X^2 = 32.34$, Pr = 0.000), rainfall amount ($X^2 = 80.85$, Pr = 0.000), rainfall distribution ($X^2 = 46.94$, Pr = 0.000), rainfall predictability ($X^2 = 22.68$, Pr = 0.000), temperature condition ($X^2 = 32.96$, Pr = 0.000), and frost occurrence ($X^2 = 59.089$, Pr = 0.000) varied among districts. However, there was no significant statistical variation between AF practitioners and non-practitioners within districts. The mean maximum and minimum temperatures of the three districts varied greatly (Table 5). The LA district has greater rainfall variability than the other districts.

Key informant ranking exercises indicate that the relative importance of major livelihood problems varies among districts (Table 6). Rainfall variability is the most important problem in Lay Armachiho and Bahir Dar Zuira districts, whereas it is second in Banja district. Erosion is a first, second, and third-ranked problem in Banja, Bahir Dar Zuria, and Lay Armachiho districts, respectively. Disease and pests are the third-most important problems at all sites. The rising temperature was second in Lay Armachiho but fourth in Bahir Dar and Banja districts. Frost and hailstorm damage had little relative importance in all study districts.

Case study respondents confirmed that rainfall variability, rising temperatures, frost, hailstorms, soil erosion, and disease and pest occurrences are predominant climate-induced events for households. They cited that rainfall was erratic and did not follow historic patterns, and extreme weather events occurred more frequently. A male agroforestry practitioner in the Lay Armachiho district remarked on climate variability and its effect: "The volume and timing of rain are inconsistent and unpredictable; in some years, it is too early, while in others, it is too late. We find it very difficult to plan ahead and schedule the planting of crops. For instance, during the 2019–2020 season, heavier and later rain was recorded, which harmed crops. Their quality was also lost." This indicates how the variability of climate parameters influences farmers' livelihoods. The principal climatic change and variability-induced human epidemics reported by the households in the study area were malaria, cholera, and animal illnesses. Farmers are pleading with the government and scientific community to find a solution to their difficulties. Tsedey is a production season in Ethiopia that extends from the end of September to November.

Socioeconomic conditions that disturb the livelihoods of the study areas include land and forest degradation, price hikes, wildlife damage to crops, health stress, family death, and asset loss. Government reforms and population growth were the contributing factors for land degradation in the study area. Natural forests have been removed since the era of imperialism in order to increase the amount

Table 4
Perception of local communities to climate change and variability in the study districts.

Climate variable	Response	LA (N = 81)			BDR (N = 181)			Banja (N = 125)		
		Practitioner	Non-practitioner	Total	Practitioner	Non-practitioner	Total	Practitioner	Non-practitioner	Total
Climate changes	Yes	83.64	92.31	86.42	62.40	60.71	61.88	89.33	84.00	87.20
	No	16.36	7.69	13.58	37.60	39.29	38.12	10.67	16.00	12.80
2019/2020 rainfall amount vs. 10 years before	Decreased	40.00	50.00	43.21	4.00	17.86	8.29	60.00	28.00	47.20
	Same	23.64	26.92	24.69	23.20	41.07	28.73	4.00	6.00	4.80
	Increased	36.36	23.08	32.10	72.80	41.07	62.98	36.00	66.00	48.00
2019/2020 rainfall distribution vs. 10 years before	Changed	36.36	38.46	37.04	32.00	37.50	33.70	6.66	8.00	6.800
	Not changed	63.64	61.54	62.96	68.00	62.50	66.30	93.33	92.00	93.00
Rainfall predictability	Yes	52.73	34.62	43.21	30.40	23.21	28.18	50.67	56.00	53.66
	No	47.27	65.38	56.79	69.60	76.79	71.82	49.33	44.00	46.34
Temperature	Increasing	78.18	96.15	83.95	79.20	73.21	77.35	68.00	72.00	69.11
	Decreasing	16.36	00.00	11.11	3.20	5.36	3.87	26.67	14.00	21.95
	Same	5.45	3.85	4.94	17.60	21.43	18.78	5.33	14.00	8.94
Frost occurrence	Same	38.18	57.69	44.44	67.20	76.79	70.17	20.00	36.00	26.83
	Increased	41.82	30.77	38.27	26.40	16.07	23.20	64.00	38.00	53.66
	Decreased	20.00	11.54	17.28	6.40	7.14	6.63	16.00	26.00	19.51

Table 5
Agro-climate of Lay Armachiho, Bahir Dar Zuria, and Banja districts, Northwestern Ethiopia.

Parameter	Lay Armachiho	Bahir Dar Zuria	Banja
Maximum Temperature variability	1.10	0.56	0.60
Minimum temperature variability	0.71	0.77	0.72
Rainfall variability	High	Less	Less
Aridity	Humid + sub-humid	Humid	Humid
Frost	Slight	None	Slight
Av. Potential Evapotranspiration mm/year	1497.5	1243	1270.1
Length of growing period (Number of days)	156–171	156–171	191–221

NB: **Rainfall variability index class**: >30 % ~ highly variable; 20 % <X ≥ 30 % ~ moderately variable; and <20 % ~ less variable. **Aridity index classification**: Hyper arid: AI < 0.05; Arid: 0.05 < AI < 0.20; Semi-arid: 0.20 < AI < 0.50; Dry sub humid: 0.50 < AI < 0.65; Sub humid: 0.65< AI<1; humid: AI >1. **Frost severity category**: <0 °C Sever, 0 °C-5 °C Moderate, 6–8 °C Slight and >10 °C none. AV ~ average.
Data source: Land use bureau of Amhara region agro-climate assessment, 2015.

Table 6
Key informants ranking exercise of the relative importance of household's livelihood problems in the study sites.

Problems	Lay Armachiho		Bahir Dar Zuria		Banja	
	Total score	Rank	Total score	Rank	Total score	Rank
RF variability	144	1	140	1	113	2
Erosion or soil acidity	89	4	110	2	124	1
Disease and pest	105	3	107	3	104	3
Rising temperature	112	2	97	4	87	4
Price hike	72	5	69	5	62	6
Frost	38	6	28	7	78	5
Hailstorm	32	7	26	8	35	7
Wildlife damage	26	8	34	6	33	8

of land used for agriculture and to gather forest products like building materials and fuel wood. Key informants state that free grazing aggravates forest degradation by disrupting the regeneration of woody plants. In the Derge regime, forest management and plantation had been improved slightly. However, a significant amount of forest was lost during the transition period (1983–1987). This spurred the Ethiopian People's Revolution Demographic Front (EPRDF) administration to launch a new forest development campaign, including agroforestry on private farms. Following this, different agroforestry practices such as *A. decurrens*, eucalypts, and fruit trees were expanded on farmers' farmlands.

Key informants also remarked that continued cultivation, erosion, and free grazing are the main problems that reduce the productivity and fertility of the soil. They mentioned that it is too difficult for them to attain yield without adding chemical fertilizer. The yield is decreasing year over year, even with the addition of chemical fertilizer. As a result, farmers convert their farms to tree- and perennial crop-based farming practices, resulting in a convergence of natural forests with agriculture and agroforestry populations.

Crop disease and fungal infestations are another production problem in the studied locations. The diseases have a major and harmful impact on mango and citrus fruits. As a result, fruit production is becoming increasingly difficult for producers. The Temch (American worm) infestation of farmers' maize crops in 2017 also shocked them. Surprisingly, a new fungus infestation occurred on *A. decurrens* plants during data collection in the Banja district.

The principal climatic change and variability-induced human epidemics reported by the households in the study area were malaria, cholera, and animal illnesses. Farmers are pleading with the government and scientific community to find a solution to their difficulties.

4.3. Vulnerability status of livelihoods

4.3.1. Livelihood vulnerability index (LVI) of households

The composite LVI showed there were variations between household groups and among study sites (Table 7). AF non-practitioners had a higher LVI than AF practitioners. The LVI of both AF practitioners and non-practitioners was higher in LA than in other districts.

Based on nine major components, the score for the impact of climatic and socioeconomic threats on the livelihoods of AF non-practitioners was 24 % higher than that of AF practitioners (Fig. 4). The average impact of rainfall variability, disease, and erosion

Table 7
LVI (±SD) of households in the study districts, northwestern Ethiopia.

Household category	Lay Armachiho	Bahir Dar Zuria	Banja	Overall mean LVI
Non-practitioner	0.49 (0.09)	0.45(0.09)	0.45(0.05)	0.46(0.079)
Practitioner	0.44(0.82)	0.40(0.08)	0.43(0.08)	0.42(0.081)
Difference	0.05	0.05	0.02	0.04

was higher on non-practitioners than on practitioner households. In addition, AF non-practitioners had a high loss score in terms of soil, produce, and productive family members. The livelihood strategies of AF non-practitioners were more vulnerable (by 17 %) to climate and socioeconomic threats than the livelihood strategies of AF practitioners (Fig. 4). Agroforestry non-practitioners had lower land size, crop diversification, woody species diversity, soil fertility, farm equipment, total income, farm revenue, livelihood diversity, and TLU (Table 2). Food and energy vulnerability score for AF non-practitioners was 17 % higher than the score for AF practitioners. The food insufficiency months and the impacts of health problems on livelihoods are higher for AF non-practitioner households than practitioner households. Non-practitioners also had lower energy and food consumption score, and farm plots than practitioners.

The health, sociodemographic, social capital, and land LVI scores of non-practitioners were 13 %, 8 %, 6 %, and 3.48 % higher than AF-practitioners, respectively (Fig. 4). AF non-practitioners had lower human capital assets (age, place attachment ratio, farm experience, education, extension contact, and high dependence ratio) than practitioners did Furthermore, AF non-practitioners did not adopt modern agricultural technology and techniques such as improved seed, line sowing, soil conservation, and water conservation measures as practitioners did. AF non-practitioners had low social capital such as low participation in *Kebele* leadership, social activity, and farm cooperatives or groups.

The major components of LVI for practitioners and non-practitioners across the three districts are shown in Fig. 5. Except for the water and infrastructure components, AF non-practitioners had higher exposure, land, health, food, sociodemographic, livelihood strategy, and social capital LVI than practitioners in LA district (Fig. 5 a). The results in Fig. 5 (b and c) showed there was a difference between household groups in the LVI values exposure, health, food, sociodemographic, and livelihood strategies in the BDR and Banja.

4.3.2. Livelihood vulnerability index-IPCC

Principal components with four, seven, and nine factors explained 61.46 %, 62.05 %, and 66.78 % of the variation in the dataset for exposure, sensitivity, and adaptive capacity, respectively. This meets the tolerable value of explained variance for further investigation. According to the overall LVI-IPCC findings, non-practitioner households had a higher vulnerability index value (0.473) than AF practitioner homes (0.316) (Fig. 6).

Within districts, AF non-practitioner households had a higher LVI-IPCC value to threats than AF-practitioners (Fig. 7 a, b, and c). In the LA district, AF reduced the sensitivity and exposure index values of AF practitioners by 28 % and 22 %, respectively (Fig. 7 a). Agroforestry practitioners had a 14 % higher adaptive capacity index value than non-practitioners. In the BDR district, the exposure and sensitivity index values for AF non-practitioners were 19 % and 11 % higher than the values for AF practitioners, respectively. However, the adaptive capacity was 7 % lower for non-practitioners than AF practitioners (Fig. 7 b). In Banja district, non-practitioners had a 31 % higher exposure index, a 10 % higher sensitivity index, and a 5 % lower adaptive capacity value than practitioners (Fig. 7 c).

The aggregate LVI IPCC index indicates that the majority (80 %) of the AF practitioners have a value between 0 and 0.40, inclusive (Fig. 8). However, 46.51 % and 47.28 % of non-practitioners, respectively, have an index value between 0 and 0.40 (low) and 0.41–0.70 (moderate).

In the LA district, 63.64 % of AF practitioners have a low LVI IPCC index, whereas 57.69 % of non-practitioners have a moderate index value. In the BDR district, the majority (84 %) of AF practitioners had a low vulnerability level. Yet, 52 % of non-practitioners have a low index value. Similarly, in the Banja district, more than 85 % of AF practitioners had a low LVI-IPCC index, whereas 44.9 % and 46.94 % of non-practitioners had a low and moderate index value, respectively (Fig. 8).

4.4. How do agroforestry reduce farmer's livelihood vulnerability?

The results revealed that agroforestry reduces households' livelihood vulnerability in several ways. These include diversification of income sources, enhanced food security, improved soil health and water conservation, sustainable resource management, and social and community benefits. Agroforestry practices in the study area involve trees, crops, and/or livestock. We found 83 woody species and 30 herbaceous species from agroforestry practices. These species provided households with diversified income sources, such as

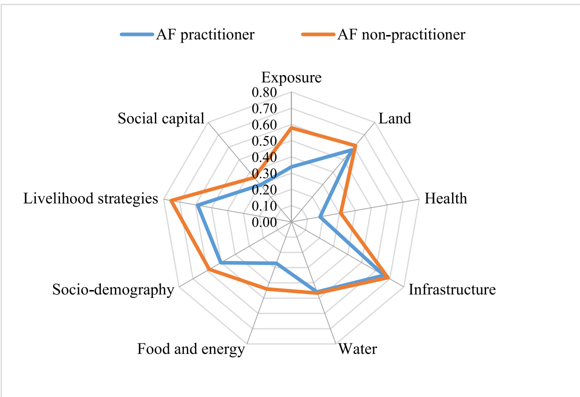

Fig. 4. LVI of agroforestry practitioner and non-practitioner households in Northwestern Ethiopia.

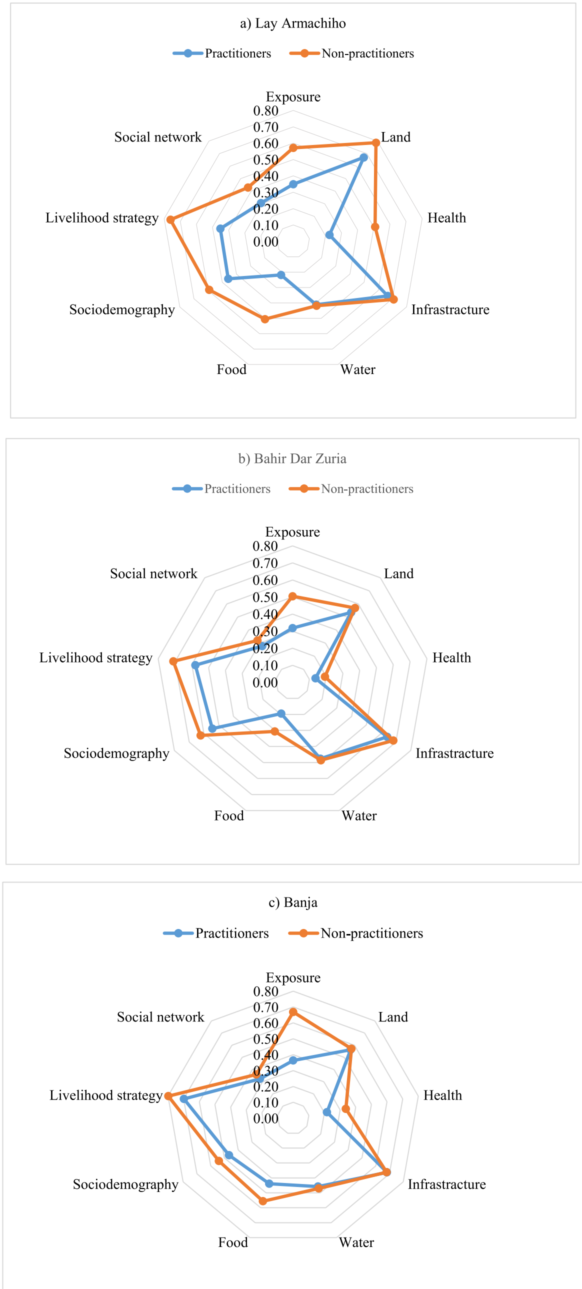

Fig. 5. LVI of agroforestry practitioner and non-practitioner households across study districts.

fuel wood, wood, fruits, food, medicines, honey, fodder, etc. (Table 8).

Thirty-five plant species provide food and fruits for households. Some of the woody plants providing fruit and food include *Carica papaya* L., *Citrus aurantiifolia (Christm.) Swingle, Citrus medica* L., *Citrus reticulata Blanco, Citrus sinensis (L.), Cordia africana Lam., Ficus sur Forssk., Ficus sycomorus* L., *Malus sylvestris Miller., Mangifera indica* L., *Persea americana Mill., Phoenix reclinata Jacq., Prunus africana (Hook.f.), Prunus persica* L., *Psidium guajava* L., *Citrus aurantiifolia (Christm.), Citrus aurantium* L., *Citrus medica* L., *Citrus reticulata Blanco, and Citrus sinensis (L.) Osb*. Herb food species include *Ensete ventricosum (Welw.), Cyperus dichroostachyus A.Rich., Kalanchoe densiflora Rolfe., Lycopersicon esculentum Mill., Stephania abyssinica (Dillon & A. Rich.), Portulaca oleracea* L., *Solanum tuberosum* L., *Brassica carinata A. Br., Capsicum annuum* L., *Capsicum frutescens* L., *and Chloris gayana Kunth,* etc. Households described that using these species, they can cope with food shortages and price fluctuations, increase food security, and reduce vulnerability to food-related shocks.

Agroforestry practices and trees in the study area, such as homegardens, coffee-shade practices, Gesho, woodlots, and decurrens,

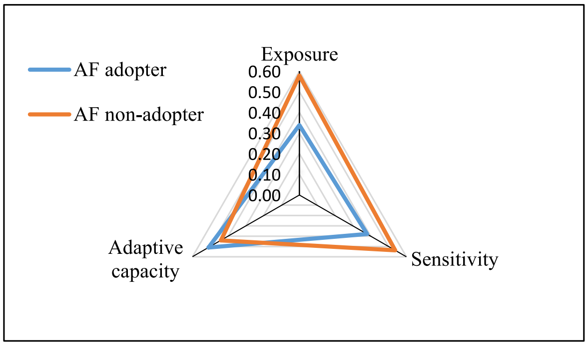

Fig. 6. LVI-IPCC vulnerability of households' livelihoods in Northwestern Ethiopia.

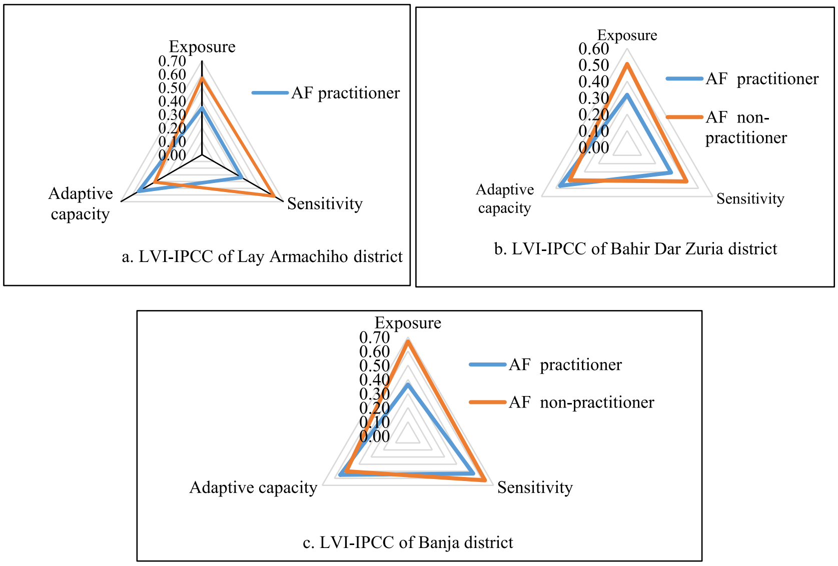

Fig. 7. LVI-IPCC of AF practitioner and non-practitioner households in Lay Armachiho (a), Bahir Dar Zuria (a) and Banja (c) districts, Northwestern Ethiopia.

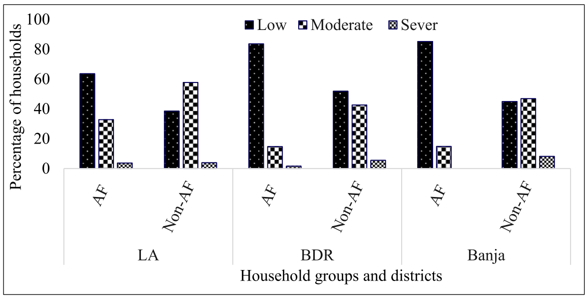

Fig. 8. Percentage of households in different vulnerability category in Lay Armachiho, Bahir Dar Zuria and Banja districts, Northwestern Ethiopia.

- KI interview

provide more than nine environmental benefits, such as erosion control, soil and water conservation, soil fertility, windbreaks, and gully rehabilitation (Table 8). About 56 % of the respondents reported that woody plants (32 species) were playing a vital role in breaking the wind near their homes and farms. The majority of respondents (≥83 %) stated that many woody plants on our farms prevent soil erosion (55 % plants) and conserve water (52 % plants). Approximately 83 % and 68 % of respondents said that trees and shrubs improved the fertility of the land. Nearly 32 % of farmers reported that trees and shrubs (24 species) planted on their degraded

Table 8
Number of household respondents mentioning agroforestry uses, and species cited in each use.

Plant use categories	Percentage of respondents	Proportion of species				Total number of species
		Tree	shrub	Tree/shrub	Herbs	
1. Environment						
Farm demarcation	16	0.43	0.43	0.14	–	7
Erosion/flood control	93	0.70	0.14	0.10	0.06	50
Water conservation	88	0.68	0.15	0.11	0.06	47
Wind break	56	0.78	0.13	0.13	–	32
Gully rehabilitation	32	0.71	0.17	0.08	0.04	24
Carbon storage	78	0.73	0.13	0.13	0.02	64
Coffee shade	52	0.86	0.05	0.09	–	22
Climate regulation	83	0.76	0.13	0.07	0.02	54
Soil fertility	68	0.73	0.13	0.13	–	30
2. Socioeconomic and cultural						
Fuel wood	84	0.73	0.21	0.06	–	48
Timber/pole	78	0.96	–	0.04	–	27
Household utensil	64	0.75	0.25	–	–	4
Farm tools	64	0.75	0.08	0.17	–	12
Honey production	14	0.79	0.12	0.09	–	33
Fruit	70	0.67	0.15	0.15	0.04	27
Food	6	0.13	0.13	–	0.75	8
Fence	76	0.68	0.23	0.09	–	57
Fiber	24	0.75	0.25	–	0.25	4
Medicinal	1	0.40	0.40	0.07	0.13	15
Detergent	11	0.25	0.50	0.25	0.00	4
Spice	1	–	–	–	1.00	2
Fodder	23	0.61	0.06	0.22	0.11	18
Stimulant	62	–	1.00	–	–	2
Flavor	71	–	1.00	–	–	1
Cash income	83	0.72	0.12	0.12	0.04	25
Shade	41	1.00	–	–	–	19
Social bonding	28	0.67	0.11	0.22	–	9

gullies had repaired them. Both key informant and household respondents noted that agroforestry practices help to manage their natural resources, such as soil, water, and trees (Table 2 and Fig. 4).

Better community Social capital is the social benefit of agroforestry practices for households. Respondents confirmed that they exchange and share vegetables with their neighbors to strengthen social ties. For example, during the holidays, people exchange coffee beans with their neighbors and relatives. In order to strengthen social ties, practitioners offer wood or poles to friends, family, and neighbors when they build homes. Farmers can socialize and work out problems on their farms by meeting under trees that are close to their residences and farms.

All respondents (key informants, in-depth study participants, and household interviewees) confirm that the income flows it offered, including fruit, timber, and fuel wood sales, were the main advantages of AF that used to cope with climate and other socioeconomic problems such as crop failure and damage by climate and social crises. A female-headed household in LA said, "B*efore engaging in agroforestry, my house was very small, and I live with my livestock because I have no separate room. I became ill and suffered from asthma as a result; I was unable to obtain medication. I did not have enough money to visit health centers and buy medicine. Following my involvement in AF,*

Table 9
Comparison of livelihood assets between agroforestry practitioners and non-practitioners in study districts, Northwestern Ethiopia.

Demographic variable	Lay armachiho		Bahir dar Zuria		Banja	
	AF	No-AF	AF	No-AF	AF	No-AF
Farm experience in years	32.26(11.17)[a]	26.30(10.76)[a]	29.22(10.98)[b]	24.35(10.22)[b]	30.68(11.61)	27.84(10.97)
Land size (ha)	1.98(0.84)[b]	0.68(0.38)[b]	1.65(0.86)[b]	1.04(0.54)[b]	1.188(0.60)[b]	0.78(0.409)[b]
Bank account (1 = yes, 0 = otherwise	0.57(0.50)[b]	0.13(0.34)[b]	0.736(0.44)	0.66(0.47)	0.46(0.50)[b]	0.10(0.31)[b]
Use irrigation (1 = yes, 0 = otherwise)	0.67(0.47)[b]	0.22(0.47)[b]	0.90(0.85)[b]	0.57(0.49)[b]	0.54(0.50)	0.52(0.50)
# of livelihood activity	3.89(0.81)[b]	3.0(0.85)[b]	4.048(0.95)[b]	3.32(0.79)[b]	4.49(1.34)[b]	3.4(1.21)[b]
Diversity of species (richness)	12.46(3.52)[b]	5.08 (1.68)[b]	7.97(2.90)[b]	4.88(1.95)[b]	6.15(1.97)[b]	5.14(1.58)
Diversity of trees (richness)	8.51(2.89)[b]	2.95(1.52)[b]	5.06(2.38)[b]	2.27(1.44)[b]	2.94(1.38)[b]	1.98 (0.92)[b]
# of food sufficient months	11.22(1.31)[b]	7.34(2.16)[b]	11.904(1.89)	11.76(2.61)	7.52(2.74)	7.52(2.55)
Food consumption score	39.44(9.54)[b]	25.48(6.46)[b]	40.43(6.75)[b]	34.66(6.68)[b]	34.65(7.57)[b]	28.83(5.95)[b]
TLU	6.16(3.41)[b]	2.53(2.63)[b]	7.43(3.74)[b]	5.55(2.57)[b]	5.60(3.02)[b]	4.22(3.28)[b]
Total Annual income (ETB)	93163.07[b]	25364.19[b]	91203.55[b]	61883.11[b]	58735.76[b]	30052.08[b]

Number of food sufficient months last year is ommitted.
[a] significant at 0.05 significance level.
[b] Significant at 0.01 significance level.

I earned money, bought my asthma medication, and recovered my health. I have built separate rooms for the family and the animals using the wood and wood products from AF *farms. Right now, my fa*mily is eating a variety of food items, such as fruits, vegetables, cereals, and pulses, from *my homegarden*". Similarly, "a male case study respondent in Banja district noted that his engagement in the AF practices of homegarden and *A. decurrens* could enable him to manage soil acidity, land degradation, and soil erosion while maintaining soil organic matter and soil fertility through biomass transfers." This case study shows the role of AF in helping households recover from shocks and stresses such as disease, and improve their wellbeing.

Table 9 summarizes the effect of AF practices on farmers' livelihood activities and household assets in study districts. Agroforestry practitioners had more ($t = 7.4936$, $p < 0.000$) land fragmentation (number of plots) (4.09 ± 0.12) than non-agroforestry practitioners (2.69 ± 0.102). The number of households that have bank accounts and use irrigation was higher for AF practitioners than non-practitioners. In all districts, AF practitioners had a higher number of livelihood activities, woody plant diversity, number of food-sufficient months, food consumption score, TLU, total annual income (ETB), and social network than non-practitioners.

5. Discussion

The study confirms that households at our study sites are vulnerable to climate change. Similar findings were reported by other studies in Ethiopia [1–3,9,55] and elsewhere [20,45,63,91]. Households perceive changes in climate. However, some farmers still perceive that climate events are not changing. In line with our findings, other studies indicate the existence of changes in the climate, as evidenced by low rainfall, higher temperatures, and severe weather conditions [39,55]. Studies demonstrate that farmers' perceptions of climate change significantly influence a household's response decisions and adaptive capacity [9,45]. Hence, comprehending farmers' perceptions of climate change patterns is crucial for decision makers in determining the most vulnerable households. The cognitive skills of farmers influence their ability to select and apply adaptive strategies, which are determined by demographic and socioeconomic characteristics such as sex, age, education, assets, and location.

We applied the LVI composite index and VI-IPCC approaches to identify the contributing factors for vulnerability and the most vulnerable households in the studied areas. Households in the Lay Armachiho district were more vulnerable. This might be due to a high (>30 % increase) annual rainfall and a 0.7–1.10 °C rise in temperature variability. More extreme climate events lead to a high exposure value [63]. Factors such as socioeconomic status, geographical location, and access to resources also contribute to a household's vulnerability.

The findings demonstrated that vulnerability scores differ between agroforestry practitioners and non-practitioner families. Similar to our findings, Papa et al. [20] in Senegal and Thangjam et al. [63] in India found that households that do not use agroforestry are more vulnerable to climate and socioeconomic threats. This indicates the role of agroforestry systems in reducing overall livelihood vulnerability. The studies of Gnonlonfoun et al. [45] and Melvani et al. [25] also showed a substantial impact that agroforestry has on household sensitivity and adaptive capacity. Thorlakson [61] found that farmers' participation in agroforestry in Kenya increased household farm productivity, off-farm incomes, wealth, and farm environmental conditions. Zeratsion et al. [39] report that in Tigray, Northern Ethiopia, farmers are adapting crop varieties, livestock breeds, and tree species in a deliberate manner to counteract the impacts of climate change. They act this way because they feel the changes will boost their ability to adapt.

5.1. LVI of the exposure component

The AF non-practitioners experience a greater impact (exposure value) on threats. According to Dendir and Simane [9], households' ability to react to shocks is determined by the nature or strength of their livelihood system, as well as field planning and management. Households in our study confirm that agroforestry practices are less affected by climate threats compared to crops and livestock. Tree-dominated and properly managed systems can tolerate and adjust to climatic events [45], which can help households deal with climate and socioeconomic risks. Agroforestry provides diversity on the farm that may respond very differently to disturbances than traditional crops. Pests, for example, may damage one type of cash crop while leaving others intact, allowing the farmer to continue relying on the unaffected crop for cash and non-monetary revenue. Papa et al. [20] showed that farmers are constantly changing management strategies to mitigate negative disturbances. Similarly, to maintain trees, crops, animals, and associated socioeconomic and environmental benefits, farmers in our study sites have actively implemented a range of management strategies [92].

5.2. LVI of households to the sensitivity component

Households without AF practice were more vulnerable to the sensitive components of infrastructure, food, water, land, and health than those practicing AFPs. Both key informant and household respondents noted that agroforestry practices are important in maintaining natural resources, such as soil, water, and biodiversity, such as trees. Households can more easily endure environmental shocks like deforestation, land degradation, and water scarcity if these essential resources are maintained. Diversified agroforestry has been shown to offer significant potential as a sustainable and multifunctional land use [25,61,93].

Agroforestry is vital for maximizing nitrogen cycling, organic matter production, lowering erosion, and external fertilizer input [26]. Trees in agroforestry landscapes minimize erosion while maintaining farm productivity. Fertile soil improves farmland's health and ability to hold water. Soil erosion is a critical issue for agricultural productivity and long-term viability [94]. Ethiopian highlands, particularly the upper Blue Nile River Basin, are considered soil erosion hotspots [94,95]. Evidence exists [25,26,61] that agroforestry systems maintain farm productivity. For instance, farmers in Kenya obtained 43 % more output due to planting trees on their farm [61]. Thus, trees in the agroforestry practices of our study can make crops and the farming system more resilient to droughts and floods. This reduces the vulnerability of households to climate-related shocks.

Our study found that households practicing agroforestry have higher food availability and energy security status than non-practitioners do. Indigenous knowledge and tribal tree and crop management provide a diverse range of food types, including cereals, pulses, oilseeds, fruits, vegetables, medicinal plants, and aromatic plants. Similarly, Wana et al. [96] in Wollega Zones, Western Ethiopia, reported that farmers traditionally practiced homegardens and coffee-based agroforestry to collect fruits like mango, papaya, orange, avocado, lemon, lime, beans, and various spices and to supplement the household's major food and income. Gnonlonfoun et al. [45] in Benin discovered that palm trees produce palm fruits regardless of climatic change. Handa et al. [26] and Quandt [27] suggest that the presence of diverse plant species in AFPs could help households maintain their food requirements and food security during shocks. Kiptot et al. [97] highlighted that agroforestry makes a substantial contribution to food security in Africa. Medicinal plants using agroforestry techniques can lower their risk of vector-borne disease. Households that plant trees on their land have a safe and more consistent fuel wood supply [61]. On the contrary, households that rely solely on forest-based energy for cooking and lighting are more vulnerable to climate extremes [55].

Market failure, inaccessibility to infrastructure, and lack of agricultural inputs were major concerns for smallholder farmers' implementation of AFS [63]. Thus, improving market and infrastructure access for smallholders is required to encourage agroforestry production and improve households income, food security, and livelihood resilience.

5.3. LVI of households to adaptive capacity

Results indicate that agroforestry practitioners were in a better position in terms of adaptive capacity for varied risks and shocks. The socio-demographic profile, livelihood strategies, and social network of AFPs practitioners were less vulnerable than those of non-practitioners. Agroforestry practices can help farmers enhance their agroecology management knowledge and skills. People's wisdom is important in the development of agroforestry techniques for both livelihood and environmental sustainability [96]. This means that agroforestry, by boosting farmers' adaptive capability and knowledge, reduces livelihood vulnerabilities. Gnonlonfoun et al. [45] in southern and central Benin confirmed this that agroforestry systems have a diverse degree of adaptive capacity to climate change. On the contrary, in monoculture crop production systems, rainfall and temperature fluctuation have a substantial impact on periodic or annual revenues or yields, reducing the system's contributions during climate shocks.

AF practitioners in Northwestern Ethiopia employed a wider range of livelihood activities, income diversities, a high diversity of plants (83 woody and 30 herbaceous species), and plant uses (more than 18 socioeconomic and 9 environmental benefits) to cope with climate variability. Agroforestry species provided households with diversified income sources, such as fuel wood, wood, fruits, food, medicines, honey, fodder, etc. Farmers in the study area remarkably acknowledged economically high value and marketable trees during shocks because they compensated for the loss of crop yield.

The diverse benefits of agroforestry are crucial for households' increasing adaptability and minimizing their vulnerability. Diversity at the farm level and along agriculture-forestry landscape gradients was a key strategy for farmers to deal with climate variability in Vietnam and Kenya [24]. According to MEA [98], livelihoods endowed with high farm diversity have a more functional redundancy and small changes in livelihood assets due to disturbances. Redundancy is the substitutability of species function during disturbances [98]. In agreement with our findings, a number of researchers have reported that agroforestry derives numerous ecosystem services and livelihood strategies to reduce climatic risk [3,20,27–29,61]. For example, Zeratsiona et al. [39] in Northern Ethiopia reported that indigenous AFPs provide multiple functions to farmers, notably wood, livestock fodder, and essential environmental services, especially during climate shocks. This reduces pressure on surrounding natural forests and improves farmers' ability to respond. Similarly, Melvani et al. [25] in Sri Lanka concluded that agroforestry's ecosystem services improve practitioners' adaptive capacity and household assets. Thangjam et al. [63] in India found that AF practices play a key role in improving household total income. Hoang et al. [24] found tree-based homegarden systems in Kenya were safety nets for farmers when crops fail. The authors stated that several plants produced in home gardens, such as tea, acacia, eucalyptus, jackfruit, and rattan, are resistant to adverse weather and can be marketed to offer year-round money. This implies that agroforestry plays a key role in income diversification and can help farmers reduce their reliance on a single source of income.

We found huge variation among the indicators of social adaptation. Households that participated in agroforestry production showed higher participation in farming groups, social networks, trainings, and external support. Similarly, Thangjam et al. [63] in India found greater participation in AFS results in higher social adaptation, better AF management vis-à-vis productivity, and a better livelihood. Participation in farming groups and external support is vital for resource-poor households, as this will enable communities to adapt to climate shock (Ostrom, 2007). Social ties in the community can assist households in obtaining resources and support when they are in need [45]. As a result, households practicing agroforestry are less vulnerable to social and economic shocks. Generally, agroforestry has a direct and cascading impact on the climate vulnerability status and overall wellbeing of households in Ethiopia and elsewhere in the world. Agroforestry practices, such as homegardens and coffee systems, strike a balance between economic sustainability and environmental health, enhancing biodiversity, resilience, and overall socio-ecological solutions for climate change adaptation and sustainable development.

6. Limitation and research recommendation

This study investigates the general contribution of agroforestry practices in improving farmer's livelihood vulnerability to climate change. However, different species of crops and trees have varying capacities to adapt to environmental variables and growth environments. This limitation hinders the implementation and effectiveness of trees and agroforestry practices in adaptation strategies.

Hence, further research should be conducted to predict the adaptation capacity of each agroforestry practice and tree species under various climate change scenarios. Moreover, the current research is based on cross-sectional data to analyze vulnerability and agroforestry. Nevertheless, collecting real-time data over longer periods is needed to analyze the dynamic and long-term effects of agroforestry on farmers' livelihood vulnerability. This can be captured by setting up long-term research sites and special funding sources.

7. Conclusions

Our findings found that households' livelihoods in Northwestern Ethiopia are vulnerable to climatic factors such as rising temperatures, rainfall variability, hailstorms, and erosion risks. The study provides a useful understanding on farmers' perception of climate change. Despite climate change, farmers who manage agroforestry systems have successfully reduced their livelihood vulnerability. The study discovered that the AF system improves farmers vulnerability by diversifying livelihood options, boosting household income and food availability, ensuring energy security, and providing numerous ecosystem services such as soil fertility and erosion protection during hazards. The study results recognize the different socio-cultural, economic, and ecological aspects of agroforestry, which play an important role in risk mitigation, adaptation, recovery, and management. Based on our findings, agroforestry methods could be integrated into future adaptation initiatives to assist farmers in reducing their vulnerability to climatic risks. This study can shed light on the impact of agroforestry-based land management policies and activities on the livelihoods of households in the research area, which can then be extended to similar geographical locations. The study also recognizes the importance of biophysical and socio-economic features of farmers' in implementing agroforestry and other livelihood strategies. Thus, policy support is essential to develop and strengthen farmer's infrastructure and institutions, market linkages, and livelihood assets such as social networks.

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Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

CRediT authorship contribution statement

Mekuanent Tebkew: Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Zebene Asfaw:** Writing – review & editing, Supervision, Conceptualization. **Adefires Worku:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no any claimed conflicts of interest.

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References

[1] W. Bewket, M. Radeny, C. Mungai, Agricultural Adaptation and Institutional Responses to Climate Change Vulnerability in Ethiopia, 2015, Issue 106.
[2] Z. Mekonnen, T. Woldeamanuel, H. Kassa, Socio-ecological vulnerability to climate change/variability in central rift valley, Ethiopia, Adv. Clim. Change Res. 10 (2019) 9–20.
[3] F.I. Alambo, Agroforestry-based livelihoods in the face of cultural and socio-economic dynamics in rural gedeo, southern Ethiopia, Journal of Rural and Community Development 15 (3) (2022) 113–132.
[4] OECD-FAO, Agriculture in Sub-saharan Africa: Prospects and Challenges for the Next Decade, Part 1:In Agricultural Outlook 2016-2025, 2016, p. 39.
[5] UNDP, UNDP Ethiopia:framework for UNDP Ethiopia's climate change, Environment and Disaster Risk Management Portfolio (2011) 24.
[6] T. Matewos, Climate change-induced impacts on smallholder farmers in selected districts of sidama, southern Ethiopia, Climate 7 (70) (2019) 1–17.
[7] D. Ayalew, K. Tesfaye, G. Mamo, B. Yitaferu, W. Bayu, Outlook of future climate in northwestern Ethiopia, Agric. Sci. 3 (4) (2012) 608–624.
[8] T.M. Adgeh, Characterization of present day climate trend over Ethiopia for impact study, in: W.L. Filho, B. Simane, J. Musiyiwa, K. Menas, W. Pantaleo, M. Kumbirai (Eds.), Climate Change Adaptation in Africa. Fostering Resilience and Capacity to Adapt, 2017, p. 746.
[9] Z. Dendir, B. Simane, Livelihood vulnerability to climate variability and change in different agroecological zones of Gurage Administrative Zone, Ethiopia, Progress in Disaster Science 3 (2019) 100035.
[10] T. Gashaw, G.W. Belay, A.W. Worqlul, T. Yihun Dile, et al., Local and regional climate trends and variabilities in Ethiopia: implications for climate change adaptations, Environmental Challenges (2023) 100794.
[11] M.D. Shibabaw, Impact and adaptation of climate variability and change on small-holders and agriculture in Ethiopia: a Review, Heliyon 9 (2023) (2023) e18972.

[12] G. Gebreselassie, O.K. Kirui, A. Mirzabaev, Economics of land degradation and improvement in Ethiopia, in: E. Nkonya, et al. (Eds.), Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development, 2016.
[13] BoEPLAU. Tana sub basin Land Use Planning and Environmental Study Project Technical Report Volume V : Agro-Climatic Assessments (V), 2015.
[14] M.M. Masud, F. Kari, S.R.B. Yahaya, A.Q. Al-Amin, Livelihood assets and vulnerability context of marine park community development in Malaysia, Soc. Indicat. Res. 125 (3) (2016) 771–792.
[15] M.D. Jakariya, M.S. Alam, M.A. Rahman, et al., Assessing climate-induced agricultural vulnerable coastal communities of Bangladesh using machine learning techniques, Sci. Total Environ. (2020), https://doi.org/10.1016/j.scitotenv.2020.140255.
[16] UNFCCC, Climate change: impacts, vulnerabilities and adaptation in developing countries, in: United Nations Framework Convention on Climate Change, 2007.
[17] M.d. Jakariya, N. Islam, Evaluation of climate change induced vulnerability and adaptation strategies at Haor areas in Bangladesh by integrating GIS and DIVA model, Model. Earth Syst. Environ. (2017), https://doi.org/10.1007/s40808-017-0378-9.
[18] S. Kumar, A.K. Mishra, S. Pramanik, S. Mamidanna, A. Whitbread, Climate risk, vulnerability and resilience: supporting livelihood of smallholders in semiarid India, Land Use Pol. 97 (2020) 104729.
[19] M.D. Jakariya, A. Rahman, M. Sayem, S. Saman, S. Alam, S. Sarker, M.S. Ali, D. Akter, Development of livelihood vulnerability index for the coastal fishermen communities of Bangladesh using spatial information technique, Groundwater for Sustainable Development 11 (2020) 100475, https://doi.org/10.1016/j.gsd.2020.100475.
[20] C. Papa, P. Nzokou, C. Mbow, Farmer livelihood strategies and attitudes in response to climate change in agroforestry systems in Kedougou , Senegal, Environ. Manag. (2020) 218–231.
[21] UNDP, Peoples' climate vote, United Nations Development Programme 1 (2021) 1–68.
[22] D.A. Ofori, A. Gyau, I.K. Dawson, E. Asaah, Z. Tchoundjeu, R. Jamnadass, Developing more productive African agroforestry systems and improving food and nutritional security through tree domestication, Curr. Opin. Environ. Sustain. 6 (2014) 123–127.
[23] A. Quandt, H. Neufeldt, J.T. Mccabe, The role of agroforestry in building livelihood resilience to floods and drought in semiarid Kenya 22 (3) (2017).
[24] M.H. Hoang, S. Namirembe, M. van Noordwijk, D. Catacutan, I. Öborn, A.S. Perez-Teran, H.Q. Nguyen, M.K. Dumas-Johansen, Farmer portfolios, strategic diversity management and climate-change adaptation - implications for policy in Vietnam and Kenya, Clim. Dev. 6 (3) (2014) 216–225.
[25] K. Melvani, M. Bristow, J. Moles, B. Crase, M. Kaestli, Multiple livelihood strategies and high floristic diversity increase the adaptive capacity and resilience of Sri Lankan farming enterprises, Sci. Total Environ. 739 (2020) 139120.
[26] A.K. Handa, O.P. Toky, S.K. Dhyani, S. Chavan, Innovative Agroforestry for Livelihood Security in India, World Agriculture, June, 2016, pp. 7–16.
[27] A. Quandt, Measuring livelihood resilience: the household livelihood resilience approach (HLRA), World Dev. 107 (2018) 253–263.
[28] M.F. Zerihun, Agroforestry Practices in Livelihood Improvement in the Eastern Cape Province of South Africa, 2021.
[29] N.M. Heming, Cabruca Agroforestry Systems Reduce Vulnerability of Cacao Plantations to Climate Change in Southern Bahia, 2022.
[30] T.S. Rosenstock, K.L. Tully, C. Arias-Navarro, H. Neufeldt, K. Butterbach-Bahl, L.V. Verchot, Agroforestry with N2-fixing trees: sustainable development's friend or foe? Curr. Opin. Environ. Sustain. 6 (1) (2014) 15–21.
[31] L. Verchot, M. Van Noordwijk, Kandji, S.,et al., Climate change: Linking adaptation and mitigation through agroforestry, Mitig. Adapt. Strat. Glob. Change 12 (2007) 901–918.
[32] L. Verchot, M. Van Noordwijk, S. Kandji, et al., Climate change: linking adaptation and mitigation through agroforestry, Mitig. Adapt. Strat. Glob. Change 12 (2007) 901–918.
[33] World Agroforestry, Corporate Strategy 2017-2026, 2017.
[34] R.P. Udawatta, L.M. Rankoth, S. Jose, Agroforestry and biodiversity, Sustainability 11 (2019) 2879.
[35] T. Abebe, F.J. Sterck, K.F. Wiersum, F. Bongers, Diversity, composition and density of trees and shrubs in agroforestry homegardens in Southern Ethiopia, Agrofor. Syst. 87 (6) (2013) 1283–1293.
[36] D.C. Miller, J.C. Muñoz-Mora, L. Christiaensen, Prevalence, economic contribution, and determinants of trees on farms across Sub-Saharan Africa, For. Pol. Econ. 84 (2017) 47–61.
[37] F. Woldeyes, Z. Asfaw, S. Demissew, B. Roussel, Of the Basket People of Southwestern Ethiopia : sustainable agro-ecosystems characterizing a traditional landscape, Ethnobot. Res. Appl. 14 (2016) 549–563.
[38] M. Negash, Trees management and livelihoods in gedeo's agroforests, Ethiopia, For. Trees Livelihoods 17 (2) (2007) 157–168.
[39] B.T. Zeratsiona, A. Manayeb, Y. Gufia, M. Tesfaye, A. Werkud, A. Anjulo, Agroforestry practices for climate change adaptation and livelihood resilience in drylands of Ethiopia, For. Sci. Technol. 20 (1) (2024) 47–57.
[40] Z. Nigussie, A. Tsunekawa, N. Haregeweyn, E. Adgo, M. Nohmi, M. Tsubo, D. Aklog, D.T. Meshesha, S. Abele, Factors affecting small-scale farmers ' land allocation and tree density decisions in an Acacia decurrens -based taungya system in Fagita lekoma, Small-Scale Forestry 16 (2016) 219–233.
[41] E. Luedeling, R. Kindt, N.I. Huth, K. Koenig, Agroforestry systems in a changing climate-challenges in projecting future performance, Curr. Opin. Environ. Sustain. 6 (1) (2014) 1–7.
[42] N. Zeray, A. Demie, Climate change impact, vulnerability and adaptation strategy in Ethiopia: a review, J. Environ. Earth Sci. 5 (21) (2015) 45–56.
[43] F.T. Kobe, Understanding climate change in Ethiopia: impacts and solutions, International Journal of Big Data Mining for Global Warming (2023) 16, https://doi.org/10.1142/S2630534823300014.
[44] A. Berhanu, B. Ayele, D.C. Dagnew, A.B. Fenta, K.E. Kassie, Smallholder farmers' vulnerability to climate change and variability: Evidence from three agroecologies in the Upper Blue Nile, Ethiopia, Heliyon 10 (7) (2024).
[45] I. Gnonlonfoun, A.E. Assogbadjo, C.P. Gnanglè, R.L. Glèlè Kakaï, New indicators of vulnerability and resilience of agroforestry systems to climate change in West Africa: west African agroforestry systems and climate change, Agron. Sustain. Dev. 39 (2) (2019).
[46] H.M. Füssel, Vulnerability: a generally applicable conceptual framework for climate change research, Global Environ. Change 17 (2) (2007) 155–167.
[47] W.N. Adger, Vulnerability, Global Environ. Change 16 (3) (2006) 268–281.
[48] Commission European, Generic conceptual framework for vulnerability measurement deleiverable (D5). EUROPEAN COMMISSION DG ENVIRONMENT seventh framework programme cooperation theme 6 – environment (including climate change). Methods for the Improvement of Vulerability Assessem, 2011.
[49] L.M. Berrouet, J. Machado, C. Villegas-Palacio, Vulnerability of socio—ecological systems: a conceptual Framework, Ecol. Indicat. 84 (2018) 632–647.
[50] DFID, Sustainable Livelihoods Guidance Sheets, Department for International Development, 2000.
[51] C. Roxana, D. Schroter, T. Glade, Conceptual frameworks of vulnerability assessments for natural disasters reduction, in: Approaches to Disaster Management - Examining the Implications of Hazards, Emergencies and Disasters, 2013, pp. 3–32.
[52] T. Takama, E. Aldrian, S.D.A. Kusumaningtyas, W. Sulistya, Identified vulnerability contexts for a paddy production assessment with climate change in Bali, Indonesia, Clim. Dev. 9 (2) (2017) 110–123.
[53] A. Asfaw, A. Bantider, B. Simane, A. Hassen, Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin), Heliyon 7 (4) (2021) e06761.
[54] G. Tesso, B. Emana, M. Ketema, Econometric analysis of local level perception, adaptation and coping strategies to climate change induced shocks in North Shewa, Ethiopia, International Research Journal of Agricultural Science and Soil Science 2 (8) (2012) 2251, 44.
[55] D.A. Yimam, N. Holvoet, Assessing climate change vulnerability of smallholder famers in northwest Ethiopia: application of a household intrinsic vulnerability index, International Journal of Climate Change Strategies and Management 15 (2) (2022) 24.
[56] K.U. Shah, H.B. Dulal, C. Johnson, A. Baptiste, Understanding livelihood vulnerability to climate change: applying the livelihood vulnerability index in Trinidad and Tobago, Geoforum 47 (April 2013) (2013) 125–137.
[57] IPCC, Climate change 2007: mitigation of climate change. Contribution of working group III to the fourth assessement report of the IPCC, in: Cliimate Impacts, Adaptation and Vulnerability, 2007.
[58] IPCC, Climate change 2014 Part A: global and sectoral aspects: impacts, adaptation, and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2014.

[59] IPCC, in: V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Pēan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, B. Zhou (Eds.), Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2021.
[60] N. Brooks, A Conceptual Framework Vulnerability , Risk and Adaptation : A Conceptual Framework, 2003.
[61] T. Thorlakson, Reducing subsistence farmers' vulnerability to climate change: the potential contributions of agroforestry in western Kenya, in: Agriculture and Food Security, vol. 1, 2011. Issue 1.
[62] IPCC, Climate change 2001: impacts, adaptation, and vulner- ability, in: J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, K.S. White (Eds.), Contribution of Working Group II to the Third Assessment Report, Cambridge University Press, Cambridge, UK, 2001.
[63] U. Thangjam, P. Thong, U.K. Sahoo, Climate change threat on socio-economic condition of agroforestry managers : a vulnerability study in eastern Himalayan state of Mizoram , Northeast India, Climate Risk Management 40 (2023).
[64] A. Quandt, H. Neufeldt, K. Gorman, Climate change adaptation through agroforestry: opportunities and gaps, Curr. Opin. Environ. Sustain. 60 (2023) 101244.
[65] P. Benebere, O.D. Divine Odame Appiah, R. Aabeyir, A. Abass, L. Guodaar, Climate change mitigation potential of agroforestry farms in West African Savanna, Environmental Challenges 10 (2023) 100678.
[66] G.W. Sileshi, J.C. Dagar, A.J. Nath, E. Kuntashula, Agroforestry as a climate-smart agriculture: strategic interventions, current practices and policies, in: J. C. Dagar, S.R. Gupta, G.W. Sileshi (Eds.), Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa. Sustainability Sciences in Asia and Africa, Springer, Singapore, 2023, https://doi.org/10.1007/978-981-19-4602-8_18.
[67] J. Schwarz, F. Schnabel, J. Bauhus, A conceptual framework and experimental design for analysing the relationship between biodiversity and ecosystem functioning (BEF) in agroforestry systems, Basic Appl. Ecol. (2021), https://doi.org/10.1016/j.baae.2021.05.002 (2021).
[68] Lin, The role of agroforestry in reducing water loss through soil evaporation and crop transpiration in coffee agroecosystems, Agric. Meteorol. 150 (2010) 510–518, https://doi.org/10.1016/j.
[69] A. Thiesmeier, P. Zander, Can agroforestry compete? A scoping review of the economic performance of agroforestry practices in Europe and North America, For. Pol. Econ. 150 (2023) 102939.
[70] S. Satapathy, I. Porsché, D. Rolker, S. Bhatt, S. Tomar, S. Nair (Eds.), A Framework for Climate Change Vulnerability Assessments, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, New Delhi, India, 2014, p. pp182.
[71] T. Deressa, Analyzing the Determinants of Farmers ' Choice of Adaptation Methods and Perceptions of Climate Change in the Nile Basin of Ethiopia, 2008. September, 36.
[72] A. Hammill, L. Bizikova, J. Dekens, M. McCandless, Comparative Analysis of Climate Change Vulnerability Assessments: Lessons from Tunisia and Indonesia, vol. 41, Competence Center for Climate Change, 2013.
[73] B.L. Preston, Climate Change Vulnerability Assessment: from Conceptual Frameworks to Practical Heuristics, CSIRO Climate Adaptation Flagship, 2012. Working paper No. 16.
[74] K. O'Brien, S. Eriksen, A. Schjolen, L. Nygaard, What's in a word? Conflicting interpretations of vulnerability in climate change research, CICERO Working Paper 2004:04 (2004).
[75] B.L. Turner, R.E. Kasperson, P.A. Matsone, J.J. McCarthyf, R.W. Corell, L. Christensene, A. Schillerb, A framework for vulnerability analysis in sustainability science, in: Proceedings of the National Academy of Sciences of the United States of America, vol. 100, 2003 (14).
[76] R.S. Pulwarty, W.E. Riebsame, The political ecology of vulnerability to hurricane related hazards, Hurricanes: Climate and Socio-Economic Impacts (1997) 185–214.
[77] BoEPLAU, The Federal Democratic Republic of Ethiopia Amhara National Regional State Bureau of Environmental Protection , Land Administration and Use Tana Sub-basin Land Use Planning and Environmental Study Project Technical Report VI: Crop Resource Assessement, 2015.
[78] Ceneral Statistical Agency, Population Projection of Districts and Kebeles in Amhara Region, 2019. Addis Ababa Ethiopia.
[79] Yamane. Determination of appropriate Sample Size, 1967, p. 28.
[80] K. Fritzsche, S. Schneiderbauer, P. Bubeck, S. Kienberger, M. Buth, M. Zebisch, M.&W. Kahlenborn, The Vulnerability Sourcebook: Concept and Guidelines for Standardised Vulnerability Assessments, 2014.
[81] V.T. Tran, G. Cockfield, S. Mushtaq, Assessing livelihood vulnerability of minority ethnic groups to climate change : a case study from the northwest mountainous regions of Vietnam, Sustainability 13 (7106) (2021).
[82] P. Antwi-agyei, P. Antwi-agyei, A.J. Dougill, E.D.G. Fraser, L.C. Stringer, Characterising the nature of household vulnerability to climate variability: empirical evidence from two regions of Ghana, Environ. Dev. Sustain. (2013) 1–27.
[83] S. Poudel, S. Funakawa, H. Shinjo, B. Mishra, Understanding households' livelihood vulnerability to climate change in the Lamjung district of Nepal, Environ. Dev. Sustain. 22 (8) (2020) 8159–8182.
[84] A.O. Basiru, A.O. Oladoye, O.O. Adekoya, L.A. Akomolede, V.O. Oeba, O.O. Awodutire, F. Charity, E.K. Abodunrin, Livelihood vulnerability index: gender dimension to climate change and variability in REDD + piloted sites, cross river state, Nigeria, Land 11 (Issue 8) (2022).
[85] R. Chambers, G. Conway, Sustainable Rural Livelihoods: Practical Concepts for the 21st Century, IDS Discussion Paper 296, Institute of Development Studies, Brighton, UK, 1992.
[86] M.B. Hahn, A.M. Riederer, S.O. Foster, The Livelihood Vulnerability Index: a pragmatic approach to assessing risks from climate variability and change - a case study in Mozambique, Global Environ. Change 19 (1) (2009) 74–88.
[87] C. Mbow, M. Van Noordwijk, E. Luedeling, H. Neufeldt, P.A. Minang, G. Kowero, Agroforestry solutions to address food security and climate change challenges in Africa, Curr. Opin. Environ. Sustain. 6 (1) (2014) 61–67.
[88] J. Panthi, S. Aryal, P. Dahal, P. Bhandari, N.Y. Krakauer, V.P. Pandey, Livelihood vulnerability approach to assessing climate change impacts on mixed agro-livestock smallholders around the Gandaki River Basin in Nepal, Reg. Environ. Change 16 (4) (2016) 1121–1132.
[89] S.L. Cutter, J.T. Mitchell, M.S. Scott, Revealing the vulnerability of people and places: a case study of Georgetown County, South Carolina, Ann. Assoc. Am. Geogr. 90 (2000) 713–737.
[90] T. Dalton-Greyling, F. Tregenna, Construction and Analysis of Composite Quality of Life Index for a Region of South Africa, ERSA (Economic Research Southern Africa) Working Paper, 2014, p. 481.
[91] M.d. Jakariya, M.F. Ahmed, T. Sikder, Vulnerability analysis of the cyclone aila affected community in the SouthWest belt of Bangladesh, Journal of Health and Environmental Research 2 (2) (2016) 5–12, https://doi.org/10.11648/j.jher.20160202.11.
[92] M. Tebkew, Z. Asfaw, A. Worku, Management strategies and floristic diversity in agroforestry practices of northwestern Ethiopia, Heliyon 9 (11) (2023) e20963.
[93] A. Willmott, M. Willmott, I. Grass, B. Lusiana, M. Cotter, Harnessing the socio-ecological benefits of agroforestry diversification in social forestry with functional and phylogenetic tools, Environ. Dev. 47 (2023) 100881.
[94] D.A. Mhiret, D.C. Dagnew, T.T. Assefa, S.A. Tilahun, B.F. Zaitchik, T.S. Steenhuis, Erosion hotspot identification in the sub-humid Ethiopian highlands, Ecohydrol. Hydrobiol. 19 (2019) 146–154.
[95] H. Hurni, Land degradation, famine, and land resource scenarios in Ethiopia, in: D. Pimentel (Ed.), World Soil Erosion and Conservation, Cambridge University Press, 1993, pp. 27–61.
[96] H. Wana, G. Kudama, A. Tilahun, et al., Indigenous knowledge and traditional agroforestry practices and their implications for food security: the case of Wollega Zones, Western Ethiopia, Geojournal 88 (2023) 2787–2798.
[97] E. Kiptot, S. Franzel, A. Degrande, Gender, agroforestry and food security in Africa, Curr. Opin. Environ.l Sustain. 6 (2014) 104–109.
[98] MEA, Ecosystems and human wellbeing, in: Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, 2005.