Analysis of land suitability for apple-based agroforestry farming in Dire and Legedadi watersheds of Ethiopia: implication for ecosystem services

Simeneh Admasu\(^a,b\,*\), Hayal Desta\(^a\), Kumelachew Yeshitela\(^a\), Mekuria Argaw\(^c\)

\(^a\) Ethiopian Institute of Architecture, Building Construction and City Development, Ethiopia
\(^b\) GFA Consulting Group, Biodiversity and Forests Programme in Ethiopia, Ethiopia
\(^c\) Addis Ababa University, College of Natural Science, Center for Environmental Science, Ethiopia

**ARTICLE INFO**

**Keywords:**
- Agroforestry
- Ecosystem services
- Apple
- Land suitability
- Watersheds

**ABSTRACT**

This study was conducted to evaluate land suitability for apple farming in the Dire and Legedadi watersheds of the central highlands of Ethiopia. Attributes that determine apple growth were categorized into environmental, soil, climate, and land management factors. The land evaluation methodology developed by FAO (1976) was applied in six steps. First, nine thematic layers are prepared. Second, pair-wise comparison matrices were performed using AHP. Third, thematic layers are reclassified. Fourth, weights are assigned to each class. Fifth, weighted overlay analysis was performed to produce a land suitability map. Finally, the land suitability map was classified into high, moderate, marginally suitable, and unsuitable categories. Soil type received the highest weight of 1.98 followed by elevation and LULC of 1.51 each. The mean temperature, rainfall, soil pH, and soil drainage weight were 1.41, 0.94, 0.56, and 0.52 respectively. Whereas the slope and aspect weighted the lowest at 0.38 and 0.19 respectively. Out of the total area of the watersheds, about 14 km\(^2\) (6.7\%) and 12.34 km\(^2\) (13.1\%) are highly suitable for apple farming in the Legedadi and Dire watersheds respectively. Whereas, about 113.35 km\(^2\) (53.8\%) and 42.54 km\(^2\) (45.2\%) of land are not suitable in the Legedadi and Dire watersheds respectively. Landholders who play a pivotal role should be incentivized to grow perennial crops (e.g., apple-trees) to enhance environmental income and alleviate poverty.

1. Introduction

Agroforestry is providing numerous environmental and socioeconomic benefits which have larger local and regional importance (Jose, 2009). It is a highly recognized tool for integrated and sustainable land use schemes that enhance ecological and economic viability (Mbow, 2015; Pande et al., 2021a,b). Agroforestry has also directly influenced agricultural productivity through the reduction of soil erosion, maintaining moisture and organic matter of soil, controlling pests, enhancing pollination, and increasing resilience to climate impacts (Hooper et al., 2005; Mbow, 2015; Roointan et al., 2018; Do et al., 2020). Moreover, agroforestry systems have a multifunctional ecosystem role, which provides multiple ecosystem services; including the provision of food and fiber; regulating climate, water, and soil; enhancing water and air quality; improving nutrient recycling which increases soil, and maintain fertility; critical species for ecological functioning and aesthetic values are among the principal ecosystem services of agroforestry (McAdam et al., 2009; Torralba et al., 2016; Pande et al., 2021a,b).

The application of an agroforestry system plays an important role in the conservation of natural resources, especially soil and water conservation (Pande and Moharir, 2015; Rajesh et al., 2021). Despite its principal component of soil and water conservation, integrated watershed management is also critical to maintaining biodiversity resources, and enhancing crop production and livestock development (Abhijit et al., 2013). Thus, it can be considered as an invaluable tool for watershed management in which it backstops sustainable use of natural resources and enhances the well-being of people. The appropriate application of agroforestry practice can increase the productivity of the agricultural landscape which has a greater implication for ecological functioning and biodiversity conservation (Rohit et al., 2019). Moreover, agroforestry provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. It has been increasingly recognized as a useful tool to mitigate climate change impacts (Verchot et al., 2007; Shahid et al., 2021) and provides an unparalleled contribution to enhancing ecosystem resilience.

* Corresponding author.

E-mail address: simeneh2009@yahoo.com (S. Admasu).

https://doi.org/10.1016/j.heliyon.2022.e11217

Received 23 August 2022; Received in revised form 20 September 2022; Accepted 19 October 2022

2405-8440/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Apple is a deciduous fruit tree that grows in temperate climate zones where most commercial varieties fulfill their required chilling temperature. Although apple trees originated and their environmental requirement is appropriate in temperate regions, many tropical and subtropical countries are adopting the tree (Williams and Tzoc, 1990). The lower temperatures in much higher altitudes allow the fruit to reach of its chilling requirement (Osborne, 2000). The applications of apple-based agroforestry systems have significant contributions to biomass production and mitigate climate change impacts (Zahoor et al., 2021; Pande et al., 2021).

In Ethiopia, the apple tree was introduced six decades ago by European missionaries (Bezabih, 2009; Ashebir et al., 2010; Girmay et al., 2014). Later, the agricultural-led economic growth strategy provides massive emphasis on the introduction of temperate fruits to different parts of the country (Handoro and Gemu, 2007). Most farmers typically produce apples to supplement their meager household income (Zerihun et al., 2019). Hayesso (2008) and Girmay et al., (2014) reported that the annual apple fruits production is about 50 metric tons in Ethiopia which is below the demand; consequently, Ethiopia imports about 350 metric tons of apple fruits annually (Hayesso, 2008; EHDA, 2012). This indicates the presence of a promising market for apple growers in Ethiopia.

The rapidly growing populations coupled with environmental and social changes such as devastating habitat destruction and degradation for cultivation practice and expansion of urbanization are adversely affecting the characteristics of the upper headwaters of Addis Ababa in particular the Dire and Legedadi watersheds (AAWSA, 2011, 2016; Gebreegziabher et al., 2021). Consequently, the widespread alteration and fragmentation of the natural land cover became the greatest threat to the ecosystems. The application of a properly designed apple-based agroforestry system in both watersheds will largely contribute to the improvement of ecosystem services (e.g., water quality and quantity through reducing siltation) in the watersheds.

More recently, several land evaluation studies were made that assessed land suitability for various crops in Ethiopia including Agidew (2015) for sorghum and barley crops; Girma et al. (2015) for maize, wheat, and sorghum; Hailu et al. (2015) for barley and wheat; Nahusenay and Kibebew (2015) for barley, wheat, faba bean, and lentil; Liambila and Kibret (2016) for sorghum, maize, bread wheat, sweet potato, and soybeans; Motuma et al. (2016) for wheat and sorghum and; Hamere and Teshome, (2018) for wheat and barley. More recently, Getachew et al., (2022) have assessed land suitability for apple (*Malus domestica*) production in Sentele watershed of southern Ethiopia. Further several studies have demonstrated the socioeconomic benefits of apple farming in Ethiopia including Handoro and Gemu (2007); Hayesso (2008); Bezabih (2009); Ashebir et al., (2010); Lemlem et al., 2013; Fetena et al. (2014); Girmay et al., 2014; Girmay et al., 2014; Sintayehu et al., 2017; Behnul and Kebede (2018); Tamirat and Muliken (2018); Zerihun et al., 2019; Tesfaye and Amene, 2022. The Addis Ababa Water and Sewage Authority (AAWSA) has grown apple trees along the buffer areas of water reservoirs. However, this was practiced without land suitability evaluation. Therefore, this study aims to assess the land suitability to provide the first comprehensive information for apple farming in the study area for robust intervention to enhance the ecosystem service of the watersheds.

2. Materials and methods

2.1. The study area

The Legedadi and Dire are critical watersheds; they are covering an area of 215 km$^2$ and 97.5 km$^2$ respectively. They are situated between 09$°$00’–09$°$13’ 00’’ N latitude; and 38$°$50’–39$°$07’ 00’’ E longitude in Oromia regional state; about 35 km northeast of Addis Ababa (Figure 1). They are sub-catchments of the Akaki river basin which flows in a northeast-southwest direction and are part of the drainage system that forms the northwest corner of the Awash River basin.

2.2. Methods

2.2.1. Methodological approach

The methodological approach for the land evaluation procedure was designed based on the Food and Agriculture Organization (FAO) land suitability guideline (FAO, 1976, 2007b) and a review of similar works such as the study made by Karma and Gibji (2021) and Getachew et al., (2022) land evaluation assessment for apple tree (Figure 2). Land suitability is a multi-criteria analysis that involves a number of parameters; therefore, the evaluation process requires a multi-criteria approach (Rabia and Fabio, 2013). Accordingly, based on expert opinion from
Holeta Agricultural Research Centre (HARC), Addis Ababa Water and Sewage Authority (AAWSA), and field observation and review of literature; apple tree was chosen for land suitability evaluation in the watersheds as the practice will enhance ecosystem services and income for the local economy.

2.2.2. Factors affecting apple growth

The identified influential factors were categorized into the soil, topographic, land management, and climate data (Kim and Shim, 2018; Karma and Gibji, 2021; Getachew et al., 2022) for the assessment of land suitability evaluation. A total of nine factors that influence apple growth were selected and prioritized. These are soil type, soil drainage, soil pH, rainfall, current land use, land cover, mean temperature, elevation, slope, and aspect (Table 1; Figure 2).

2.2.3. Creation of thematic maps

All these files were extracted for the study watersheds before running the spatial analysis model in ArcGIS 10.5. The input raster's were reclassified into different classes. Once all the criteria were recalculated, the "Weighted Overlay" tool was used to produce the suitability classes. For each criterion, a weight factor was assigned when producing the final result. Finally, the Weighted Overlay Analysis (WOA), an effective technique to resolve spatial complexity in suitability analysis was applied to generate the land suitability map (Girvan et al., 2003; Pramanik 2016; Taddese 2014). The final suitability map was reclassified based on FAO (1976): these are highly suitable, moderately suitable, marginally suitable, and not suitable. Highly suitable areas show the most favorable/the best biophysical conditions for apple growth in the study area. The moderately and marginally suitable areas indicate the next priority areas which need scrutiny of factors and decisions on the feasibility of investment over other opportunities. The unsuitable area represents those sites constrained by reservoirs, settlements, and other land use types (Table 2).

2.2.4. The application of AHP and predictors weight determination

The integration of the AHP method with ArcGIS provides a powerful and accurate analysis of land suitability for agroforestry (Chuma et al., 2021). The AHP method provides a structural basis for quantifying the
comparison of decision elements and criteria in a pairwise technique (Arabinda, 2003). The method evaluates the relative significance of all parameters by assigning weight to each of them in the hierarchical order to ensure the credibility of the relative significance. AHP also provides measures to determine the inconsistency of judgments mathematically (Saaty, 1980). The AHP employs an underlying nine-point recording scale to rate the relative preference on a one-to-one basis of each factor (Saaty, 1980; Saaty and Vargas, 2000). This nine-point scale used in analytical hierarchy studies is ranging from 1 (indifference or equal importance) to 9 (extreme preference or absolute importance) (Table 3).

The information from key actors was used to derive the relative importance of one criterion to another using the AHP (Saaty, 1980; Saaty and Vargas, 2000), which has been used in a pairwise comparison technique to assign individual parameter weights for each factor (Table 4). Thus, all the layers were overlaid by recognizing cell values to the same scale, giving a weight value to the individual criterion, and integrating the weight cell values together as given below:

$$LS = \sum_{i=1}^{n} W_i X_i$$  \hspace{1cm} (1)

where LS indicates the total land suitability score, $W_i$ denotes the weight assigned to each selected land suitability criteria; $X_i$ indicates the factor score (cells) of i land suitability criteria, and n denotes the total number of land capability criteria.

The consistency of the judgment matrix is examined with the calculation of the consistency index (CI) as defined by the equation (Mansouri, 2014):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$ \hspace{1cm} (2)

where CI is the consistency index, $\lambda_{max}$ is the most significant or principal eigenvalue of the matrix that could be calculated from the matrix and n is the order of the matrix (Ying et al., 2007).

### Table 1. Indicators and their proxy variables used for assessing land suitability for apple farming in the study watersheds.

| Parameters   | Indicators | Proxy layers | Data source                                                                 |
|--------------|------------|--------------|-----------------------------------------------------------------------------|
| Topography   | Slope      | Slope        | Extracted from DEM using spatial analysis tool in ArcGIS 10.5              |
|              | Elevation  | Elevation    |                                                                             |
|              | Aspect     | Aspect       |                                                                             |
| Soil         | Soil drainage | Soil drainage | Obtained from Oromia Water Works Design, Construction and Supervision Enterprise (OWWDCSE) |
|              | Soil type  | Soil type    |                                                                             |
|              | pH         | pH           |                                                                             |
| Climate      | Rainfall   | Rainfall     | Obtained from NMA then interpolation algorithm performed using spatial analysis tool in ArcGIS 10.5 (Figure 3) |
|              | Mean temperature | Temperature     | Obtained from NMA then interpolation algorithm performed using spatial analysis tool in ArcGIS 10.5 (Figure 4) |
| Land management | Land use | LULC         | Land classifications and analysis were made in the ArcGIS 10.5 tool         |

### Table 2. Land suitability classification, descriptions and numerical scale (FAO, 1976).

| Classes | Suitability | Description                                                                 | Scale |
|---------|-------------|-----------------------------------------------------------------------------|-------|
| S1      | Highly suitable | Land without significant limitations. This land is not perfect but is the best that can be obtained. | 1     |
| S2      | Moderately suitable | Land that is clearly suitable but has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land. | 2     |
| S3      | Marginally suitable | Land with limitations so severe that benefits are reduced, and/or the inputs needed to sustain production is increased so that this cost is only marginally justified. | 3     |
| N       | Not suitable  | Land that cannot support land use on a sustained basis, or land on which benefits do not justify necessary inputs. | 4     |
Also, in the AHP, a measure of consistency ratio (CR) was calculated to indicate the randomized probability of matrix judgments as follows:

\[
CR = \frac{CI}{RI}
\]

where CI is the average of the resulting consistency index, depending on the order of the matrix given by Malczewski (1999, 2000), RI (Random Index) values for matrices of different sizes (Saaty, 2003).

3. Results

3.1. Suitability of evaluation criteria

The ranking of the nine evaluation criteria showed the importance of each criterion in the order of soil type, elevation, LULC, temperature, rainfall, pH, soil drainage, slope, and aspect (Table 4). Soil type received the highest weight (1.98) followed by elevation and LULC (1.51). The mean temperature, rainfall, soil pH, and soil drainage weight were 1.41, 0.94, 0.56, and 0.52 respectively. Whereas the slope and aspect weighted the lowest at 0.38 and 0.19 respectively. The major soil types in both watersheds are loam and clay. Thus, about 64% and 36% are highly and moderately suitable for the apple tree in the Dire watershed; while about 73.5% and 26.5% are highly and moderately suitable in the Legedadi watershed. The highly suitable elevation of 2500–3000 m.a.s.l constitutes 41.9% and 29.3%; moderately suitable elevation constitutes about 58.1% and 70.7% in the Dire and Legedadi watersheds. On the other hand, 57% and 89% of the watersheds are not suitable for apple growth with the current land use practices in the areas. The mean annual temperature in the Dire and Legedadi watersheds was 15.19°C and 15.02°C in 2020. Thus, favorable mean annual temperature constitutes about 19.59% and 22.79% of the Dire and Legedadi watersheds respectively; while moderately suitable rainfall constitutes about 22.68% of the Dire and 29.77% in the Legedadi respectively; while moderately and marginally suitable rainfall constitutes about 36.08% and 38.14% in the Dire and about 34.42% and 35.81% in the Legedadi. The pH value of the study watersheds ranges from 4.4 to 7.9. Thus, the results show that about 84% and 62.15% of the Dire and Legedadi watersheds are unsuitable for apple growth from the soil pH perspective respectively. About 43.3% and 56.7% of the Dire and 44.65% and 55.35% of the Legedadi watersheds were found highly and moderately suitable respectively which is highly required for the successful growth of the apple tree. With regards to the slope factor, about 38.85% and 34.88% of the Dire and Legedadi watersheds fall under the unsuitable slope category. The aspect factor results showed that the east-facing slope has covered about 26.80% and 20.93% of the Dire and

---

**Table 4.** Land suitability criteria classification for apple cultivation.

| Category | Criteria | Unit | Land suitability classes | Eigenvector weight | Significance (%) | References |
|----------|----------|------|--------------------------|-------------------|----------------|-----------|
| Topography | Elevation | MSL | 2500–3000 | <2000 and >2500 | 1.51 | 12.73 | Manandhar et al. (2014); Getachew et al., (2022) |
| Climate | Rainfall | Mm | 1000 | <500 and >2000 | 0.94 | 12.73 | Chada (2009); Getachew et al., (2022) |
| Soil | Soil pH | log (H+) | 6.5–6.5 | <5.6 and >6.5 | 0.56 | 8.49 | Roots of Peace (2008); Manandhar et al. (2014); Madrigal-Martínez and Puga-Calderon (2018); Sharma et al. (2015); Getachew et al., (2022) |
| | Soil Drainage | % | Well-drained and medium aeration | <35 and >16 | 0.52 | 6.37 | Chada (2009); Manandhar et al. (2014); Madrigal-Martínez and Puga-Calderon (2018); Sharma et al. (2015); Getachew et al., (2022) |
| | Soil type | Texture | Sandy loam and fine sandy clay loam | | | | Chada (2009); Manandhar et al. (2014); Madrigal-Martínez and Puga-Calderon (2018); Sharma et al. (2015); Getachew et al., (2022) |
| | Land Use/Land Cover | Level terraces | | | | | Roots of Peace (2009); Manandhar et al. (2014); Madrigal-Martínez and Puga-Calderon (2018); Sharma et al. (2015); Getachew et al., (2022) |
Legedadi watersheds which is highly suitable for apple production, and about 34% of the watersheds have a southeast-facing slope, which is moderately suitable for apple production (Table 5).

3.2. Land suitability analysis

A total of 305 km² of land was computed for apple-based agroforestry practices in both watersheds using the criteria established. Out of this about 14 km² (6.7%) and 12.34 km² (13.1%) of land is highly suitable for apple farming in the Legedadi and Dire watersheds respectively. About 29.29 km² (13.9%) and 19.05 km² (20.3%); 53.86 (25.6%) and 20.12 km² (21.4%) are moderately and marginally suitable for apple-based agroforestry farming in the Legedadi and Dire watersheds, respectively. However, about 113.35 km² (53.8%) and 42.54 km² (45.2%) of land is not suitable in the Legedadi and Dire watersheds respectively (Table 6; Figure 5). The proportion of highly suitable land in the Dire watershed is more considerable (13.1%) than Legedadi watershed (6.7%). This could be due to the smaller settlement and infrastructure development in the Dire watershed. However, the highly suitable areas were mainly occurring in the higher elevation of both watersheds.

The Dire watershed has more moderate suitable land (20.3%) than Legedadi watershed (13.9%). These areas are mainly located adjacent to the highly suitable areas in both watersheds. More specifically areas adjacent to the reservoirs, and farmland stretched out to the periphery of the watersheds. The marginally suitable and unsuitable areas are widely observed in both watersheds. They consisted of about 66.6% and 79.4% in the Dire and Legedadi watersheds respectively. Unsuitable areas were located in areas where land was used for other development such as the reservoir, intensive farmland, unpaved and paved roads, and congested settlement areas. Since these areas are already occupied by other land uses; we consider these areas inappropriate for apple farming in both watersheds.

4. Discussion

4.1. Factors evaluation

Soil is one of the important parameters that determine plant growth (Mustafa et al., 2011). Apple growth can be influenced by soil types. Clay loam and clay soil characteristics are classified as the most suitable and moderately suitable soil textures for apple production (Roots of Peace, 2008; Manandhar et al., 2014; Madrigal-Martínez and Puga-Calderón, 2018). The loam and clay soil types in the watersheds provide higher suitability for apple growth watersheds. Altitude is also an important factor affecting plant growth (Bzdak et al., 2016). High altitudes characterized by lower average temperatures allow faster chilling conditions (Osborne, 2000). Apple tree can be cultivated at an elevation ranging between 1800 and 3000 m.a.s.l (Karma and Gibji, 2021; Getachew et al., 2022); but the altitude ranges between 2500 to 2700 m.a.s.l is highly suitable (Getachew et al., 2022; Admasu et al., 2022; Admasu and Jenberu, 2022; Abele et al., 2017; Beyene et al., 2022; Calderon-Zavala et al., 2004; Gebrerufael et al., 2014; Nigussie et al., 2019; Roots of Peace, 2008; Udawatta et al., 2002; Williams and Tax Tzoc, 1990; Yohannes and Soromessa, 2018) as the crop gets its chilling requirement to overcome its dormancy (Fadon et al., 2020). The northern parts of the watersheds are the highest peaks which are suitable locations to fulfill the chilling requirement of the tree.

The natural vegetation has been replaced by settlement and agricultural land uses in both watersheds; particularly in the Legedadi watershed (Awarris, 2017; Simeneh et al., 2022). Thus, 90% of the Legedadi watershed is unsuitable for apple growth based on the current land use practices. Temperature affects the net carbon exchange, carbon balance, and carbon partitioning in the apple tree (Zavalda, 2004; Calderon-Zavala et al., 2004). The apple tree requires a temperate climatic regime for growth and fruit development (Krishna, 2014). Low temperature is the most significant factor in affecting dormancy completion (Ramirez and Kallarakal, 2014). Temperature also influences the photosynthesis and respiration processes of the apple (Hester and Cacho, 2003). The result revealed that the moderate temperature of the study watersheds could be the most favorable for the apple tree.

The other most important factor affecting the growth of apple trees are rainfall. Both excessive and lower rainfall is harmful to apple growth. Although, the annual rainfall in the Dire (1406.1 mm) and Legedadi (1886.4 mm) watersheds is a little bit over the optimum range for apple production of 1000–1250 mm (Randev, 2009); the entire watersheds are suitable for apple farming. A wide range of soil pH could be favorable for apple tree; however, the highly suitable soil pH ranges between 6.0–6.5 (Anderson, 2015). The soil pH in the study area ranges between 4.4 to 7.9 which resulted in the majority of the watersheds being unsuitable for apple trees. Well-drained soils are considered as the best for apple cultivation (Chada, 2009; Chattopadhyay, 2009). Thus, the soil drainage in the study watersheds is well-drained which is favorable for the cultivation of apples.
The slope is also an important indicator of land suitability since it influences drainage, irrigation, and soil erosion (Wu et al., 2009). An increase in slope degree slows down the development of soils and decreases soil depth and fertility (Atalay, 2006). The higher slope areas of the watersheds are converted to farmlands, growing annual crops which have contributed to the decreased ecosystem services (Simeneh et al., 2022). The aspect factors determine sunlight availability for the growth of a particular crop. Thus, aspect is an important factor that affects apple yield (Aggelopoulou et al., 2010). Further, the quality of fruit is greatly determined by the availability of sunlight (Lakiso, 1980; Morales-Quintana et al., 2020). Thus, the availability of suitable aspect conditions could be important for apple growth in the study watersheds.

4.2. Land suitability

Sustainable watershed management interventions are vital to improving ecosystem services through restoring ecological integrity and maintaining the biodiversity resources of important landscapes. The practice of agroforestry could also help to improve the well-being of societies at all levels (Jose, 2009). Agroforestry has been recognized as an invaluable tool to control soil erosion by reducing the rate of soil runoff as canopy interception increases (Tyagi et al., 2002) and can retain a large volume of rainfall (Bundela, 2007). The higher infiltration capacity of trees considerably improves the recharge of groundwater, the perennial flow of the stream, and enhanced soil moisture availability through micro-climatic interventions.

The land policy of Ethiopia prohibits practicing farming lands steeper than 30% slope (Lakew, 2005). Thus, the growing of perennial crops (e.g., apple tree) could be invaluable not only for improving ecosystem services but also for ensuring food security. Ranjith et al., (2002) reported that agroforestry combined with contour strips has a significant effect on maintaining soil organic nutrients. The inclusion of trees in soil conservation and erosion control is one of the most widely acclaimed and compelling reasons for including trees on farmlands prone to erosion hazards. Sustainable watershed management practices have generated promising improvements in farm incomes and food security in some of the piloted watersheds in the Tigray, Amhara, and Oromia regions of Ethiopia (Gebreselasie et al., 2016). Therefore, effective and participatory watershed management undertakings are essential in order to alleviate the complex socio-ecological problems in the catchment.

Considerable land is suitable for apple farming practices in the Legedadi and Dire watersheds. Therefore, the application of apple farming as a watershed management intervention could significantly contribute to improving water quality and quantity by largely reducing silt in the water reservoirs. As the city of Addis Ababa is highly reliant on ecosystem services (e.g., water provision) from the surrounding central highlands of Ethiopia, water availability is becoming the most important intensively growing constraint in the city (Anteneh et al., 2019). The unsustainable land use practice in the upper catchment has increased soil erosion and significant sediment load to the water reservoirs; for example, in the Legedadi alone the annual soil loss was estimated between 69.9 and 138.4 tons/ha (Gebreegziabher et al., 2021). The annual siltation rate of the reservoir was estimated at about 110,500 m³ and reduced the capacity by 2.1 MCM between 1979 and 1998 (AAWSA, 2011; AAWSA, 2016).

Moreover, Zerihun et al., (2019) reported that the apple-based agroforestry system largely improved the livelihoods of small-scale farmers in the drought-prone areas of north-western Ethiopia. Girmay et al., (2014) indicated that apple grower farmers in southern Ethiopia are earning an average of US$ 272.89 yr⁻¹. Similarly, the practice of apple-based agroforestry farming has contributed to higher net revenue for apple growers in Dendi district of west shoa Ethiopia (Lemlem et al., 2013). More recently, Tesfaye and Amene (2022) reported that the livelihood status of apple-producer farmers in the Chencha woreda of southern Ethiopia has greatly improved compared to the previous living condition. Therefore, with the presence of huge unmet market demand for apple fruits, apple growers can make an additional income to improve their livelihood. Thus, properly designed apple farming could play a critical role in the improvement of the overall socio-economic and
ecological conditions of farmers and reduce their vulnerability to climate-related natural disasters.

5. Conclusion

The study area is the most important headwaters of Addis Ababa city which suits ecosystem services that are vital for the inhabitants of Addis Ababa and surrounding communities are benefiting. The growing apple tree has been practiced by AAWSA along the buffer areas of water reservoirs without assessing the land suitability for the crop, thus this study will provide information on apple-based agroforestry farming in the study watershed in order to support landscape restoration endeavors by key actors in the study watersheds. The result revealed that considerable land is suitable for apple-based agroforestry farming. Thus, the apple tree can be used as a critical watershed management tool to halt the rapid deterioration of the watershed ecosystem. A sustainable watershed management scheme will provide multitude of benefits; such, first, it contributes to watershed services through improving agroecosystems; second, enhances the local economy through increased income; third contributes to household food security and wellbeing. However, landholders who play a pivotal role in sustainable watershed management practices should be incentivized to grow economic highland fruits (e.g., apple tree) further sustainable and efficient value-adding supply chain needs to be created to enhance environmental income to households and thereby contributes to alleviating poverty. Although the study demonstrates that apple can be used as a tool to improve watershed services; further investigations are required to improve the harvest of quality apple fruit such as identifying key site-specific factors including soil amenability, electrical conductivity (EC) of soil and water, wind speed during pollination, and the amount of lime in the soil, selecting appropriate apple varieties that are compatible for cross-pollination, trees healthiness, fruit thinning and local pests and diseases are amongst the most important factors that determine the success of apple farming.

Declarations

Author contribution statement

Simeneh Admasu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Hayal Desta; Kmelachew Yeshiteila; Mekuria Argaw: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by Addis Ababa University Integrated Landscape-based Management (ILM) Approach for Improving Ecosystem Services, Agricultural Productivity and Water Availability in the Central Highlands of Ethiopia (ILM-ESAW).

Data availability statement

Data will be made available on request.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors are thankful for the financial support provided by Addis Ababa University under the thematic research project on Integrated Landscape-based Management (ILM) Approach for Improving Ecosystem Services, Agricultural Productivity and Water Availability in the Central Highlands of Ethiopia (ILM-ESAW). The authors are also grateful for the kind cooperation of Holeta Agricultural Research Centre (HARC) and Addis Ababa Water and Sewage Authority (AAWSA) to conduct the study. The two anonymous reviewers and Editor of the journal are also thanked for their critical comments that improved the manuscript.

References

Addis Ababa Water and Sewerage Authority (AAWSA), 2011. Master plan review, catchment rehabilitation and awareness creation for Gofersa, Legedadi, and Dire catchments. Addis Ababa, Ethiopia.

Addis Ababa Water and Sewerage Authority (AAWSA), 2016. Urban Water Supply and Sanitation; Legedadi and Dire Dam Rehabilitation Project. Addis Ababa, Ethiopia.

Admasu, Tsegaye G., Jembera, Amanze A., 2022. The impacts of apple-based agroforestry practices on the livelihoods of smallholder farmers in southern Ethiopia. Trees, For. People 7, 100205.

Admasu, Simeneh, Yeshiteila, Kmelachew, Argaw, Mekuria, 2022. Assessing the Impact of Land Use and Land Cover Changes on Habitat Quality and Ecosystem Services in the Dire and Legedadi Watersheds, central highland of Ethiopia. Manuscript under review.

Aggelopoulos, K.D., Wolfoh, D., Fountas, S., Gemtos, T.A., Ananos, G.D., Blackmore, S., 2010. Spatial variation in yield and quality in a small apple orchard. Precis. Agric. 11 (5), 538–556.

Agidew, A.W., 2015. Land suitability evaluation for sorghum and barley crops in South Wollo Zone of Ethiopia. J. Econ. Sustain. Dev. 6 (1), 14–26.

Anderson, P.R., 2015. Low-chill Apple Cultivars for North Floridaand North Central Florida.

Arabinda, L., 2003. Integrating GIS and Multi-Criteria Decision-Making Techniques for Land Resource Planning. M.S. Thesis. International Institute for Geo-Information Science and Earth Observation. Enschede, The Netherlands.

Asher, D., Deckers, T., Nynsen, J., Bihon, W., Tsegay, A., Tekie, H., Poensen, J., Haile, M., Wondumagegnehu, F., Raes, D., 2010. Growing apple (Malus domestica) under tropical mountain climate conditions in Northern Ethiopia. Exp. Agric. 46, 53–65.

Atalay, I., 2006. The effects of mountainous areas on biodiversity: a case study from the northern Anatolian mountains and the Taurus Mountains. Grazer Schriften der Geographie und Raumforschung 41, 17–26.

Behalai, A., Kebede, J., 2018. A study on the causes of apple (Malus domestica) fruit loss at Chencha woreda of gofa gofa zone, southern Ethiopia: J. Stored Prod. Postharvest Res. 9 (7), 72–77.

Beyene, Getachew, Dechassa, Nigussie, Regasa, Alemayehu, Wogi, Lemma, 2022. Land suitability assessment for apple (Malus domestica) production in Sentele watershed in hadyia zone, southern Ethiopia. Hindawi Appl. Environ. Soil Sci.

Bezabih, A., 2009. Growing apple (Malus domestica) under tropical mountain climate conditions in Northern Ethiopia. Exp. Agric. 46, 53–65.

Bossag, A., Tayas, F., Gray, A.S., 2016. AHP and GIS-based land suitability analysis for Cihanbeyli County. Environ. Earth Sci. 75, 813.

Bundela, D.S., 2007. Water Management in Northeast India - Some Case Studies. CSSRI, Karnal, pp. 40-46.

Calderon-Zavala, G., Lakso, A.N., Piccioni, R.M., 2004. Temperature effects on fruit and shoot growth in the apple (Malus Domestica) early in the season. Acta Hortic. 678.

Cengiz, T., Akbulak, C., 2009. Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: a case study of damire village (çanakkale, Turkey). Int J SustDev World Ecol 16 (4), 286–294.

Chada, K.L., 2009. Handbook of Horticulture. Indian Council of Agriculture Research (ICAR), New Delhi, India.

Chattopadhyay, T.K., 2009. A Textbook on Poonamte (Temperate Fruits). Kalyani Publishers, Chennai, India.

Devkota, L.N., 1999. Deciduous fruit production in Nepal. In: Papademetriou, M.K., Herath, E.M. (Eds.), Deciduous Fruit Production in Asia and the Pacific. RAP Publication: 1999/10. Food and Agriculture Organization of the United Nations: Regional Office for Asia and the Pacific, Bangkok, pp. 63–78.

Do, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Devkota, L.N., 1999. Deciduous fruit production in Nepal. In: Papademetriou, M.K., Herath, E.M. (Eds.), Deciduous Fruit Production in Asia and the Pacific. RAP Publication: 1999/10. Food and Agriculture Organization of the United Nations: Regional Office for Asia and the Pacific, Bangkok, pp. 63–78.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.

Dor, V.H., La, N., Mulia, R., Bergkvist, G., Dahlin, A.S., Nguyen, V.T., Pham, H.T., Òbom, I., 2020. Fruit tree-based agroforestry systems for smallholder farmers in northwest Vietnam—a quantitative and qualitative assessment. Land 9 (11), 451.
