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Scenario-Based Land Management Options for the Highlands of Ethiopia: A Decision Support Tool to Implement Rural Land Use Plans

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The implementation of locally acceptable land management practices is crucial to improving the livelihoods of local communities and reducing the degradation of

ecosystem services. This is particularly important in mountain regions, where steep slopes, fragile soils, high erosion risk, and climate variability intensify land degradation and livelihood shocks, while also influencing downstream water regulation and sediment delivery. This study was conducted in Tara Gedam watershed, northwestern Ethiopia, to evaluate 4 ecosystem-service-based scenarios—business as usual (BAU), transition agriculture (TAG), intensified agriculture (INA), and optimized ecosystem services (OPE)—as land management options using the analytic hierarchy process method. A stakeholder workshop and group discussions with farmers, agricultural experts, and

local decision-makers were conducted to set criteria for selecting the best management option. Livelihood benefits and environmental improvements were rated highest and are therefore the most influential factors in selecting land management options. These 2 criteria were responsible for the best performance of OPE and INA. INA and/or TAG were the options preferred by farmers because they provide livelihood benefits within a shorter time than OPE. Smallholder farmers should therefore be provided with financial and technical support to implement OPE. The results of this study will contribute to the knowledge base of agricultural experts to support future implementation of rural land use plans in the highlands and mountain regions of Ethiopia.

Keywords: analytic hierarchy process; business as usual; ecosystem services; Ethiopia; land management; optimized ecosystem services.

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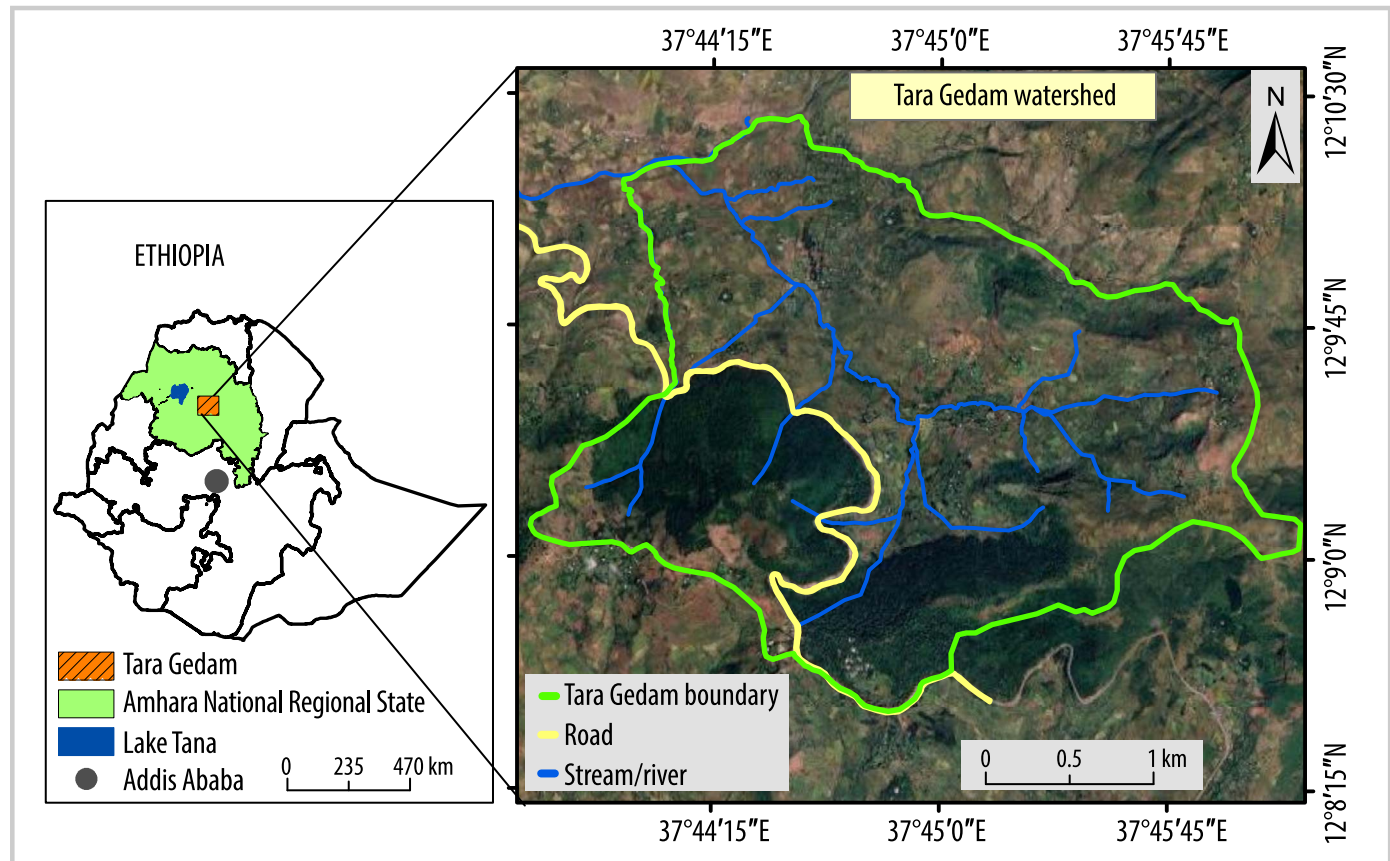
Introduction

Land resources in the highlands of Ethiopia are experiencing intense pressure from human activities, and this has led to severe land degradation (Chirwa 2014; Gebreselassie et al 2016; Mekuria et al 2017). Major causes of land degradation include deforestation, agricultural land expansion, overgrazing, and the absence of land use plans (Nyssen et al 2004; Kirui and Mirzabaev 2014). Land degradation in the highlands of Ethiopia has resulted in a persistent decline in the diversity of forests, agriculture, and ecosystem services (Aerts et al 2016; Amare et al 2017). These ecosystem services are tangible or intangible deliverables from ecosystems in the form of direct or indirect benefits that sustain, govern, and/or support human livelihoods (MEA 2005). In response to the problem of land degradation, the Ethiopian government, in collaboration with donors and local communities, has made a number of land restoration interventions in the last 30 to 40 years (Egoh et al 2008; Amare et al 2017; Mekuria et al 2018; Kassa et al 2022; UNCCD n.d.). The biggest challenge in this endeavor is ensuring that such interventions are sustainable and meet the livelihood goals of local communities (Mekuria et al 2017).

In line with this, Ethiopian land use policy states that land use plans and management should be prepared by respective experts based on an ecosystem approach, which involves the integrated management of natural resources in a sustainable and equitable way (Amare et al 2019). However, this policy has not been implemented because of knowledge gaps, such as lack of implementation guidelines and decision support tools (Amare et al 2019). Thus, the development of decision support tools that incorporate an ecosystem approach and farmers' knowledge is needed for the implementation of the country's land use policy and context-based development plan to achieve both environmental and livelihood needs.

Studies (eg Linkov et al 2006; Fontana et al 2013) have demonstrated that multicriteria decision analysis (MCDA) provides reasonable and objective results in studies with different (in terms of interests and backgrounds) stakeholders. Several studies have used the MCDA concept to aid decision-making, for example, for farm management (Tiwari et al 1999; Rozman et al 2006; Pazek et al 2010), environmental management (Munda et al 1994; Kiker et al 2005; Linkov et al 2006; Steele et al 2009), forest management (Ananda and Herath 2009; Jactel et al 2012;

FIGURE 1 Location of the study area. (Map by Menale Wondie; satellite image taken from Google Earth 2025).



Acosta and Corral 2015), choice of bioenergy system (Buchholz et al 2009), river rehabilitation (Langhans and Lienert 2016), and integrated land management for ecosystem services (Yatsalo et al 2010; Schwenk et al 2012). Studies (eg Mendoza and Prabhu 2003; Mendoza-González et al 2012; Khalili and Duecker 2013) have also indicated that MCDA is well suited to addressing interdisciplinary and complex environmental problems.

However, the most appropriate natural resource management interventions for improving livelihood and ecosystem services vary regionally, depending on both environmental and socioeconomic settings (Fontana et al 2013). Accordingly, the results of the above-cited studies cannot be applied to northwestern Ethiopia, as it differs in terms of socioeconomic conditions, land use practices, rainfall amount and distribution, key soil properties, and natural resource management practices. Land fragmentation in the highland and mountainous areas of Amhara Region is also a factor (Wondie 2015). Despite this, Amhara Region has developed land use policy based on general conditions, rather than those specific to the region. Against this background, the present study was conducted in northwestern Ethiopia to (1) evaluate, select, and recommend land management options that can improve the livelihoods of local communities while maintaining or improving the environment and (2) draw lessons for future land use planning in this mountain region from the smallholders' perspective. The novelty of this study lies in its contribution to the implementation of Ethiopian rural land use policy in general, and site-specific development initiatives in particular, by enabling local land use practitioners to make informed decisions in the mountainous areas of

Amhara Region. The study focuses on livelihood benefits and environmental improvements as the top drivers in ranking scenarios, supporting balanced decision-making in fragile mountain regions. The framework is designed to be adapted and transferable to other mountain regions facing similar erosion, land degradation, and watershed challenges.

Research methodology

Study area

This study was conducted in the Tara Gedam watershed located in northwestern Ethiopia (Figure 1). It is characterized by rugged topography and highlands with elevation ranging from 2000 to 2600 masl. The study watershed covers an area of 8.9 km². It is drained by the Aguat Mefesasha stream, which is a tributary of the Arno River. The soils are of volcanic origin, dominated by Nitisols, followed by Cambisols, Leptosols, and Luvisols (Abiyu 2012; Feyisa 2012). The mean monthly temperature ranges from 18 to 34°C. The average annual rainfall is 1175 mm. Mixed farming, which integrates crop with livestock production, is the major livelihood activity in the watershed. Crops are grown both for household consumption and to generate income. The land cover is dominated by cropland (49.6%) and forestland (24.8%), with shrublands constituting the rest. An increase in human and livestock populations accompanied by low use of agricultural technology and poor cultivation has resulted in shortages of agricultural products. Smallholder farmers are food insecure and have low incomes. Seasonal migration is common in these areas as a means of generating additional income by selling labor.

TABLE 1 Description of the 4 ecosystem-service-based land management scenarios (Adapted from (Wondie 2015)).

Scenarios	Description
Business as usual (BAU)^{a)}	This scenario refers to the current land use and land management systems. It assumes an annual population growth of 3.1%, a negative impact of farming practices on ecosystem services, and that the community is characterized by a lack of self-sufficiency and low income.
Transition agriculture (TAG)^{b)}	This scenario assumes that priority is given to food security, while less attention is given to conservation and environmental protection. Other assumptions include an annual population growth of 2.7%, average annual agricultural production increase of 1% in the whole watershed using wheat equivalent, and an average wheat demand of 407 kg y ⁻¹ (207 kg for food and 200 kg for other household expenses).
Intensive agriculture (INA)^{c)}	This scenario assumes that the selected land management options target agricultural production for both consumption and market, with an annual population growth of 2.4% (CSA 2013, for Ethiopia) and an annual average agricultural production growth of 6.6%. It also assumes that food security can be achieved in the short term and emphasizes a farm-level (not watershed-based) approach.
Optimized ecosystem services (OPE)^{d)}	This scenario assumes a well-designed land use plan focusing on improving food production and restoring degraded lands, with an annual population growth of 1.8% (CSA 2013, for Amhara Region) and overall annual production increases of 7% for the first 10 years and then 10%. This scenario is based on the assumption that improved land management using a watershed-based approach will increase agricultural productivity while maintaining or improving the environment: a win-win situation for conservation and development.

^{a)} The assumption regarding the annual population growth is based on field survey results.

^{b)} The assumption regarding the annual population growth is based on expert judgment.

^{c)} The land management options included in this scenario comprise agroforestry practices, water harvesting technologies, small-scale irrigation, watershed management, and use of agricultural inputs that increase agricultural productivity (enhancing food, forage, and cash crop production). It emphasizes farm parcel level productivity.

^{d)} Similar to INA but gives equal emphasis to improving the environment and natural resource management activities (soil fertility maintenance, enhancement of water resources, and flood management).

Modeling land management scenarios

Scenario modeling was employed (Wondie 2015; Berg et al 2016; Deng et al 2016; Zhang et al 2018) to investigate land management options that could enhance agricultural productivity while maintaining or improving ecosystem services. For this study, we proposed 4 scenarios: (1) business as usual (BAU), (2) transition agriculture (TAG), (3) intensive agriculture (INA), and (4) optimized ecosystem services (OPE) (Table 1).

These scenarios were designed in collaboration with farmers, agricultural experts, and local decision-makers.

Selecting the best land management option or scenario

We used MCDA to select the best management option from 4 scenarios (Table 1) for the watershed studied. An analytic hierarchy process (AHP) was adopted to decompose the complex MCDA into simplified, objective-based analytical processes. AHP is an MCDA method that is used to facilitate the decision-making process and involves transforming subjective judgment and change into objective decisions using mathematical models (Saaty 1990). It has been widely used to make environmental management decisions under complex social and environmental conditions (Linkov et al 2006; Convertino et al 2013; Kasperczyk and Knickel 2022). AHP uses weighting and hierarchical decision-making in a participatory and interdisciplinary manner (Macharis et al 2004) and relies on the judgments of experts (Kasperczyk and Knickel 2022). It involves quantifying, scoring, and weighting a range of quantitative and qualitative criteria to rank land management option scenarios (Fontana et al 2013; Favretto et al 2016).

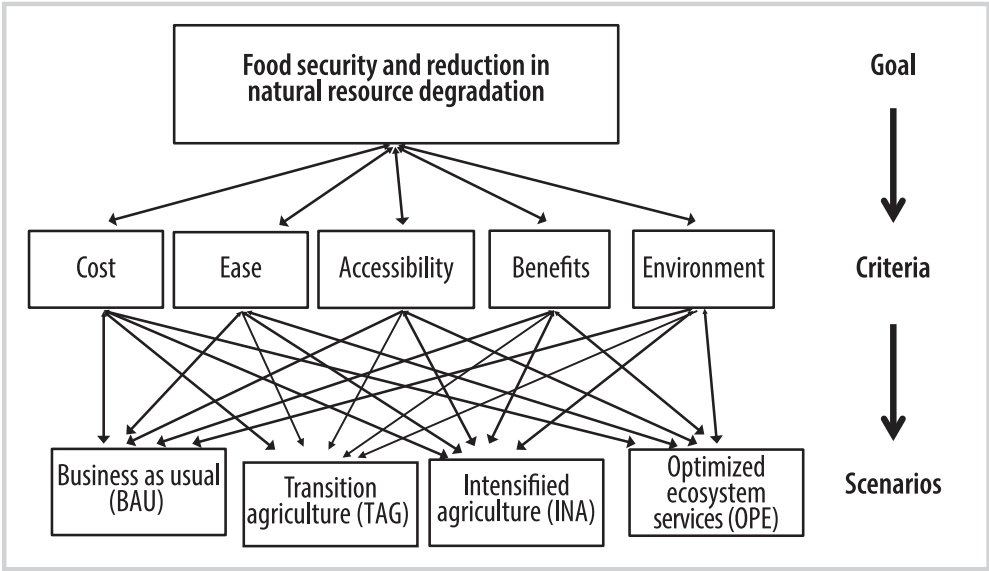
AHP has 3 levels for ranking the scenarios (Figure 2). The first level is the goal (ie food security and reduced natural resource degradation), the second level represents the criteria used to conduct comparisons among proposed scenarios, and the third level represents the proposed land management options.

This study followed 5 steps to reach a decision on the scenario best suited for the development of Tara Gedam watershed using the AHP approach (Belton and Goodwin 1996; Sun et al 2013). The steps within the levels were (1) identifying the problem and setting the objectives, (2) selecting criteria, (3) comparing and weighting the criteria chosen to evaluate the land management options, (4) ranking the alternatives, and (5) conducting MCDA evaluation.

Different approaches (both quantitative and qualitative) were employed to gather data to identify problems, set criteria, compare and weight the criteria, and rank alternatives (land management options). The approaches used included field observation, a household survey, a workshop, land cover change analyses, and estimation of crop production and productivity. Three focus group discussions, each with 6–8 farmers, were held (Figure 3). In addition, a stakeholder validation workshop was conducted with agricultural experts over 3 consecutive days. The group included experts in natural resource management, crop production, livestock production, soil management, forestry, economics, and social science. Prior to gathering data at the stakeholder validation workshop, the proposed scenarios (Table 1) and criteria (Figure 2) were briefly described to the stakeholders (farmers and experts).

The participants of the stakeholder validation workshop were then divided into 2 groups, each comprising 7 individuals. Both groups were asked to set criteria for selecting the best alternative from the proposed options. This was done to reduce bias and errors in setting criteria. Each group had a facilitator and a rapporteur elected by the participants. The facilitator presented ideas and discussion points based on predetermined alternatives (development options). The participants discussed the suggested criteria and chose among the alternatives. The workshop and group discussions were designed in such a way that every participant contributed ideas and suggestions on the

FIGURE 2 Hierarchy model: defining the goal, criteria, and alternatives (scenarios).



proposed criteria. Once each group had summarized their own set of criteria, the 2 groups met and found consensus on a common set of criteria to evaluate the proposed land management options. These were cost, ease, accessibility, benefits, and environmental improvement (Table 2).

After setting the criteria (Table 2), the participants of the stakeholder workshop defined a weight for each decision criterion. These weights were values that indicated the relative importance of the different criteria in comparing the proposed land management options. Then the participants were asked to perform pairwise comparison to reflect the relative importance of each choice (Favretto et al 2016) and choose the best alternative among the 4 proposed options. The matrix for pairwise comparison of alternatives $A_i = [a_{ij}]$, determined using Equation 1, represents the preference between individual pairs of alternatives (scenarios). The participants compared pairs of alternatives and criteria using the scale of importance developed by Saaty (1990):

$$W = [w_i/w_j] = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{pmatrix}$$

$$\Rightarrow W = [a_{ij}] = \begin{pmatrix} 1 & a_{12} & a_{13} & a_{14} \\ \frac{1}{a_{12}} & 1 & a_{23} & a_{24} \\ \frac{1}{a_{13}} & \frac{1}{a_{23}} & 1 & a_{34} \\ \frac{1}{a_{14}} & \frac{1}{a_{24}} & \frac{1}{a_{34}} & 1 \end{pmatrix} \quad (1)$$

TABLE 2 Criteria used to evaluate the proposed scenarios.

Criteria	Description
Cost	Initial investment cost incurred to plan, implement, and monitor each proposed scenario; affordability of initial investment cost from the farmers' perspective; timing of receipt of benefits; and subsidies (eg construction of road and electricity)
Ease	Compatibility of the proposed land management options with the existing farming system, culture, and values of the local communities
Accessibility	Physical accessibility of improved land management practices, availability of options, and availability of inputs to implement the alternatives
Benefits	Economic benefits obtained following the implementation of improved land management practices
Environment	Contribution of proposed land management option to minimizing land degradation, rehabilitating degraded lands, reducing soil erosion, improving soil fertility, conserving biodiversity, and improving microclimate

FIGURE 3 Focus group discussion in Tara Gedam watershed in 2013. (Photo by Menale Wondie).



TABLE 3 Values of *RI* for the given number of criteria and alternatives (Saaty 1990).

No. of criteria and alternatives	<i>RI</i>
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

where *W* is the unknown true overall weight of alternative *i* compared to *j*, *w* is the unknown true weight for each alternative *i* compared to *j*, *a* is the observed weight for each alternative *i* compared to *j*, and *a_{ij}* gives the relative importance of the criteria/alternatives *i* and *j*.

Pairwise comparisons were made among land management options (alternatives) with respect to each criterion. Following pairwise comparisons, the rank was obtained from the normalized score table using matrix analysis. The matrix was developed to evaluate the alternatives in accordance with the criteria selected. It enabled the alternatives to be ranked by identifying their relative importance, strengths, and weaknesses. The scoring of each alternative was based on the rating of its relative importance (Table 3).

The consistency of the judgment was evaluated and checked using the consistency ratio (*CR*) and consistency index (*CI*) (Saaty 1990). The *CR* is calculated as

$$CR = \frac{CI}{RI}, \quad CI = \frac{\lambda_{\max} - n}{n - 1} \quad (2)$$

where $\lambda_{\max}$ is the eigenvalue, and *RI* is the random index using the Saaty (1990) scale (see Table 3). The *CR* is acceptable if, and only if, *CR* < 10%. The AHP analysis (ie *CR*, *CI*, and weighting) was calculated using Microsoft Excel 2010 (Microsoft, Redmond, WA, USA).

Results and discussion

Importance of criteria for evaluating land management scenarios

The results indicated that local communities preferred land management scenarios that provide livelihood benefits within a short period (Table 4). This selection can be attributed to the local communities' poverty and their need for immediate support to sustain their life (Grieg-Gran et al 2005; Kansanga et al 2021), and the difficulty of quantifying all environmental benefits (eg the values of aesthetic benefits, ecotourism, and carbon sequestration) of management options. Probstl-Haider et al (2016) demonstrated that farmers prefer land management options that maximize economic benefits (improving land productivity through land management, reduction of flood and erosion, and enhancement of water resources), which will ultimately impact ecosystem services, tourism opportunities, and biodiversity.

Land management scenarios that support the environment and enhance ecosystem services ranked second. A study by Favretto et al (2016) indicated that the value of a land use is linked not only to the availability of an ecosystem service, but also to its relative importance to society. Cost also contributed 11% of the weighting value to the choice of the given land management scenario, suggesting that the initial investment costs of the proposed land management options were not considered a major problem. Ease had the smallest weighting value (3%) because the proposed scenarios were chosen by stakeholders familiar with the study watershed. Accessibility had a 6% weighting value, referring to the physical accessibility of technologies, presence of choices, and availability of inputs to implement the alternatives.

Evaluation of land management scenarios

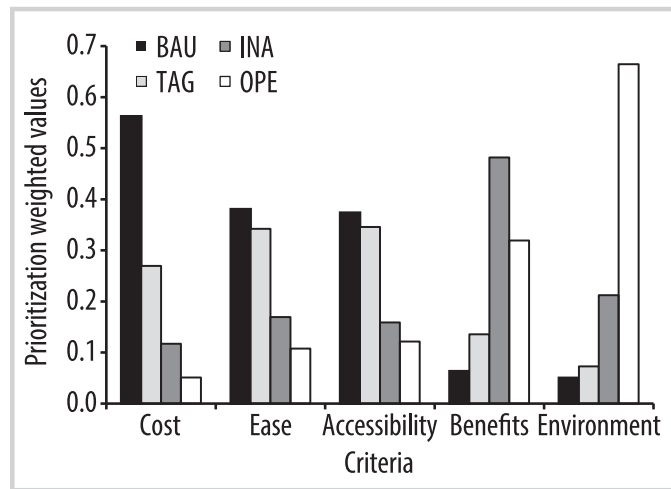
The selection of a land management scenario depends on the demand(s) or objective(s) of the stakeholders and the criteria used to evaluate the scenarios (Figure 4). For example, BAU would be preferred if cost were the most important evaluation criterion, whereas OPE would be selected if environmental improvement were given the highest weight (Figure 4). However, according to the ultimate scores in the decision matrix, OPE provided the greatest overall benefits (Figure 5) compared to other options. It achieved the highest weighted score (39%). INA was chosen as a second development option. The high scores assigned to OPE were influenced by the type and amount of ecosystem services and their contribution to sustainability through environmental improvement.

TABLE 4 Criteria weighting based on the rating technique with inputs from stakeholders.

Criteria	Cost	Ease	Accessibility	Benefits	Environment	Weight	Lambda ($\lambda_{\max}$)
Cost	1.0	6.0	2.0	0.1	0.2	0.11	5.2
Ease	0.2	1.0	0.4	0.1	0.1	0.03	5.1
Accessibility	0.5	2.5	1.0	0.1	0.1	0.06	5.2
Benefits	7.1	8.0	8.0	1.0	2.0	0.46	5.7
Environment	5.0	8.0	10.0	0.5	1.0	0.34	5.7

Note: Italics indicate the reciprocal (inverse) values that correspond to the primary judgments, bold script indicates the primary pairwise comparison judgments in the table (ie the directly assigned comparison scores).

FIGURE 4 Weighted values of the different land management scenarios with respect to each of the 5 criteria.



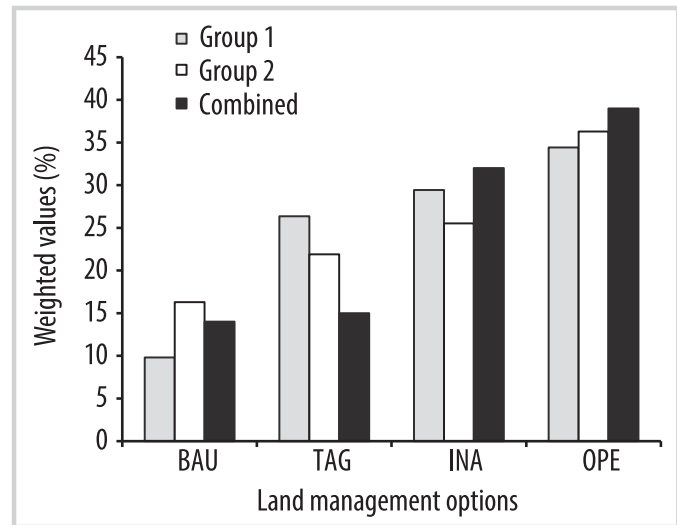
Environmental deterioration, food insecurity, and soil erosion were widespread in the highland and mountainous areas of Amhara Region. Hence, the choice of the OPE and INA management options by the stakeholders reflected the environmental situation rather than mere benefit-oriented goals. A previous study conducted in the highlands of Ethiopia (Wondie 2015) also recommended OPE and INA as the 2 best land management scenarios.

In this study, however, the 2 groups gave different weighting values for each land management scenario due to variation in group composition and knowledge-based differences in describing the land management scenarios (Figure 5). The ranking was also different when groups were brought together. The variation among groups (both separately and in aggregation) was attributed to differences in the skills and experience of the facilitators and participants. The result of this study is consistent with the findings of other studies in that assigning weight to each criterion can be influenced by the knowledge, experience, and preferences of participating decision-makers (eg Kumar et al 2017; Pamucar et al 2018).

The ranking of the proposed options was most influenced by livelihood benefits and environmental improvement and related objectives. These 2 criteria contributed positively to the best performance of OPE and INA. Both options provided higher provisioning (eg food, feed, and wood) and regulating (eg water regulation, biodiversity conservation, protection of the environment) ecosystem services than the other proposed options. However, INA and TAG were the options preferred most by farmers. This was attributed to the delivery of livelihood benefits within a shorter period compared to OPE. In contrast, BAU had the lowest values and was not selected. This was attributed to its negative effects on the environment and associated ecosystem services, which in turn could contribute to worsening food insecurity, land degradation, and poverty.

The evaluation results corresponded to the local decision-makers' expectations and were in line with the findings of a previous study (Wondie 2015). The highest value was obtained for OPE because it enables the achievement of food security and sustainable land management in the long run (Wondie 2015). The potential delivery of diverse ecosystem

FIGURE 5 Rankings by groups 1 and 2 separately and both groups combined.



services and additional nonmarketable products further contributed to the selection of this alternative. The result can be additionally explained by the estimated high value of marketable products. This judgment was related to the assumption that products were organic, which confers high market value.

Implications for future interventions

The increases in human and livestock populations have heightened demand for food, feed, and energy. This demand cannot be met under current land management (ie the BAU scenario). BAU has low investment costs, but it offers less diverse ecosystem services and relies on simple production procedures. Improved land management scenarios are required. However, to implement improved scenarios, such as OPE, farmers need financial and technical support. In the long run, OPE would be more beneficial than INA; however, local communities prefer INA, as it generates livelihood benefits in the short run. Therefore, INA can be used as an entry point to improve resource use in the watershed, and through time there could be a shift from INA to OPE, provided that local communities were incentivized to adopt long-term land management options.

Conclusion

The results of our study demonstrate that livelihood benefits and environmental improvement were the most influential criteria for decisions on land management options. We observed that farmers preferred INA as a development option over the other proposed land management options. However, the aggregated result that included the preferences of experts indicated that OPE was the most preferred scenario. The findings of this study give rise to the following recommendations.

As demonstrated by the differences in ranking between groups, identifying key stakeholders and facilitators is fundamental to properly evaluating different land management scenarios and developing sustainable watershed management strategies. Farmers preferred the INA land management scenario, which is crucial to achieving

food security and reducing natural resource degradation. Integrating farmers' preferences supports the sustainability of interventions, as it harmonizes livelihood activities with environmental benefits. The ranking of land management options presented here builds on context-based and location-specific recommendations made by farmers, agricultural experts, and local decision-makers. As such, the scenario-based AHP decision support tool will help to improve food security and reduce natural resource degradation in the mountainous areas of Amhara Region.

Overall, the scenario-based AHP decision support approach provides a transferable planning framework that can guide rural land use plans in Ethiopian highland and mountain regions. It can also be implemented in mountain regions worldwide where communities need to balance immediate livelihood demands with long-term watershed protection, erosion control, and ecosystem sustainability.

Further studies are required to fully quantify the environmental benefits of the land management options investigated. In particular, quantifying and estimating the economic benefits of changes in soil fertility, microclimate, and carbon sequestration following the implementation of the different management options is crucial to making informed decisions. In addition, further research is also required on technical challenges (data availability, technical capacity, and continuous updates), scalability of the best-ranking scenario (OPE), and how to adapt the tool for use in other mountainous regions of Ethiopia.

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