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Yalemzewd Nigussie[a,b], Edwin van der Werf[*,a,c], Xueqin Zhu[a], Belay Simane[b], Ekko C. van Ierland[a]

[a] Environmental Economics and Natural Resources Group, Wageningen University & Research, The Netherlands

[b] College of Development Studies, Addis Ababa University, Ethiopia

[c] CESifo, Munich, Germany

Abstract: Climate change is expected to have severe negative impacts on the livelihoods of smallholder farmers in developing countries. However, smallholder farmers and governments in these regions tend to be ill-prepared for the impacts of climate change. We present the results of a stakeholder-based multi-criteria analysis of climate change adaptation options for agriculture, natural resource management and water management in the upper Blue-Nile basin in Ethiopia. We use the PROMETHEE II outranking method to analyse data from a survey in which farmers and experts were asked to evaluate adaptation options based on potentially conflicting criteria. Adaptation options for soil and land management, such as crop rotation and composting, score high based on two sets of criteria for assessing adaptation options for agriculture. River diversion, preventing leaching and erosion, and drip irrigation are ranked highest as adaptation options for water management. Regarding natural resource management, the highest ranked adaptation options are afforestation, water retention and maximizing crop yield. Rankings by farmers and by experts are weakly correlated for agriculture and water management, and negatively correlated for natural resource management, which shows the importance of extension services and of involving farmers in the decision-making process to ensure the feasibility of adaptation options.

Keywords: Adaptation, Agriculture, Stakeholders, Climate Change, Multi-Criteria Analysis, Ethiopia

[*] Corresponding author. Environmental Economics and Natural Resources Group, Wageningen University & Research, P.O. Box 8130, 6700EW, Wageningen, The Netherlands. Email: edwin.vanderwerf@wur.nl.

1. Introduction

Since the risks associated with climate change are real but uncertain, societies need to develop adaptation strategies, especially for those who are highly vulnerable (Adger et al. 2003). The consequences of climate change for developing countries are more severe than for developed countries due to low adaptive capacity and high vulnerability in developing countries. For example, Ethiopia is heavily dependent on rain-fed agriculture, and its geographical location and topography in combination with low adaptive capacity imply a high vulnerability to adverse impacts of climate change. Historically, land degradation in the form of soil erosion has negatively affected agricultural production and economic development in Ethiopia (Balana et al. 2010). Rainfall variability and recurrent droughts result in a fluctuating run-off to the Nile tributaries (World Bank 2010; 2015).

Several studies have proposed strategies, both at the micro and the macro level, to tackle problems related to the effects of climate change and natural resource degradation in Ethiopia (e.g. Deressa et al. 2008; Tesso et al. 2012; Tesfaye and Brouwer 2012; Simane et al. 2012, 2013). Since policy interventions for climate change adaptation require participation of and dialogue with stakeholders, stakeholder analysis has become a tool for prioritizing adaptation options in various countries (e.g. Champalle et al. 2015; Dilling and Berggren 2014). Since long-term impacts of climate change in Ethiopia are expected to be severe (Conway and Schipper 2011; World Bank 2010), adaptation options identified through empirical research and government policies and programs need to be evaluated and prioritized by stakeholders from different groups. However, there is a lack of stakeholder-level evaluation and stakeholder dialogue to identify adaptation options on the basis of well-defined evaluation criteria in the process of adaptation to climate change at different hotspots, such as the upper Blue-Nile basin in Ethiopia.[1] Previous studies about adaptation in the upper Blue-Nile basin have failed to evaluate adaptation options based on (possibly conflicting) criteria. Due to a lack of resources and skills, adaptation interventions in Ethiopia are designed without considering the specific characteristics of the agro-ecosystem (Simane et al. 2012). This gap can be filled through an approach that enables stakeholders' engagement in the different stages of the assessment of relevant adaptation options.

In this paper, we rank and evaluate possible adaptation options for smallholder farmers in the upper Blue-Nile basin using a set of conflicting criteria, using information from both local farmers and experts. We used a stakeholder workshop and a survey of farmers and experts to identify alternative adaptation options, select evaluation criteria and collect data. We subsequently analysed these data using the PROMETHEE II preference outranking method for Multi-Criteria Analysis (MCA). MCA is a decision-support tool applicable to choice problems in different contexts under a number of different

[1] An exception is the Ethiopian National Adaptation Plan of Action (NAPA 2007), which is a stakeholder level project evaluation framework developed on the basis of cost benefit analysis.

alternatives and possibly conflicting criteria (Hajkowicz et al. 2000). It is an evaluation method used to rank or score the performance of alternative (policy) options against multiple criteria (Hajkowicz 2007).

We find that adaptation options for soil and land management – such as crop rotation, composting and changes of fertilizer use methods – score high based on two sets of criteria for assessing adaptation options for agriculture. River diversion, preventing leaching and erosion, and drip irrigation are ranked highest as adaptation options for water management. Regarding adaptation options for natural resource management, the highest ranked options are afforestation, maximizing water retention and maximizing crop yield. When analysing the data from experts separately, we find that the ranking by farmers and the ranking by experts are only weakly correlated for agriculture and water management, and even negatively correlated for natural resource management. This shows the importance of extension services and of involving farmers in the decision-making process to ensure the applicability and socio-economic feasibility of the chosen adaptation options.

The paper is organized as follows. Section 2 presents the materials and methods including the identifcation and evaluation process of adaptation options by MCA. Section 3 presents the rankings based on uni-criterion analysis and MCA. We provide concluding remarks in Section 4.

2. Materials and methods

2.1. Multi-Criteria Analysis

There are different methods to assess and prioritize alternative policy options for climate change adaptation (Zhu et al. 2016). In Cost Benefit Analysis (CBA), the benefits and costs of adaptation are expressed in monetary terms, and the net benefits are calculated. Applicability of CBA is limited for many adaptation options since benefits of climate change adaptation do not always have a clear monetary value (see e.g. Palma et al. 2007, De Bruin et al. 2009). Similarly, Cost Effectiveness Analysis (CEA) also requires monetization of costs which is not always feasible in the context of the study. In addition, the costs of an adaptation option may differ between farmers. Because of these drawbacks of CBA and CEA we have chosen Multi-Criteria Analysis (MCA) as method to rank the adaptation options that combines qualitative and quantitative approaches (e.g. Palma et al. 2007, De Bruin et al. 2009; Pearce et al. 2012; Hayashi et al. 2014). MCA is a systematic method for assessing and scoring options against a range of decision criteria. In contrast to other qualitative and participatory approaches (e.g., Analytic Hierarchy Process), the main strength is that MCA provides a systematic method for assessing and scoring options, some of which are expressed in physical or monetary units, and some which are qualitative. The various criteria can then be weighted to provide an overall ranking of options. These steps are undertaken using stakeholder consultation and/or expert input. MCA has been widely applied in the environmental domain and has also been used as a tool for adaption analysis (e.g. De Bruin et al., 2009).

There are three approaches to MCA. The first is rooted in multi-attribute utility theory, which requires the identification of utility functions and weights for each attribute that can then be assembled in a unique synthesizing criterion (Keeney and Raiffa 1993). The second approach in MCA refers to interactive methods. These require preference information from the decision-maker throughout the selection process and require progressive articulation of preferences (see for example Geoffrion et al. 1972). The third MCA approach is the outranking method. It focuses on building a relation called 'outranking relation', which represents the decision-maker's preferences. Ranking of the alternatives is done on the basis of pair-wise comparisons of alternatives (choices). Examples of well-known outranking methods are PROMETHEE (Brans and Vincke 1985), ELECTRE (Roy 1973), and MACBETH (Bana e Costa and Vansnick 1997). Cinelli et al. (2014) provide an overview of MCA methods for sustainability assessment.

In this paper, we use MCA to evaluate adaptation options. In the implementation of MCA, we need to make pair-wise comparisons of alternatives to establish the ranking of the alternatives. Particularly for ranking the alternatives, we choose the Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), which can make pair-wise comparisons of all alternatives and therefore allows for the ranking of alternatives based on a set of evaluation criteria, where each criterion has an assigned weight (Brans and Vincke, 1985). PROMETHEE methods are widely used in the evaluation and ranking of environmental options (e.g, Palma et al. 2007, Jactel et al. 2012). PROMETHEE is transparant, and enables the absolute ranking of the options and showing the relative position of the various options that are considered. It also allows for sensitivity analysis of the weights used, and for establishing a weight stability interval (see Section 3.2.2 below). PROMETHEE has advantages over other methods (e.g. ELECTRE and MACBETH) in terms of data management and specifically its representation, supporting comparisons of scenarios, visualization of the influence of different weights, criteria, and preference functions (Geldermann and Zhang 2001; Brans and Mareschal, 2005; Mareschal 2014).

Examples of applications of PROMETHEE are Palma et al. (2007), who evaluated the integrated performance of silvoarable agroforestry on hypothetical farms, and Jactel et al. (2012) who analysed the ranking of forest management alternatives in the context of forest damage risk due to climate change. We follow Palma et al. (2007) and use the PROMETHEE II method (Brans and Vincke, 1985) as it enables the ranking of alternatives in a convenient and transparent manner.

2.2. Outranking procedure of adaptation options

MCA outranking methods start from a decision matrix describing the performance of the alternatives to be evaluated with respect to identified criteria and focus on pair-wise comparisons of alternatives (Belton and Stewart 2002). We denote the set of alternatives to be evaluated with $A = \{A_1, \dots, A_i, \dots A_m\}$ and the set of criteria with $C = \{C_1, \dots, C_k, \dots C_q\}$. Alternatives and criteria can then be expressed in an

$m \times q$ evaluation matrix, in which each row describes an alternative and each column describes the performance of the alternatives for a specific criterion. On the basis of the evaluation matrix, the alternatives are compared in pairs in order to determine how one option is to be ranked relative to any other. A general characteristic of PROMETHEE is that all m alternatives are compared in a pair-wise manner, separately for each criterion. Let $f_k(A_i)$ be the score of climate adaptation option A_i under criterion k. Then, the preference score of two alternatives A_i and A_j is calculated using the preference function $P_k(A_i, A_j),\ i \neq j$:

$$P_k(A_i, A_j) = \begin{cases} 0 \text{ if } f_k(A_i) - f_k(A_j) \leq 0 \\ 1 \text{ if } f_k(A_i) - f_k(A_j) > 0. \end{cases} \tag{1}$$

The uni-criterion net flow Φ_k indicates the performance of alternative A_i against all other alternatives for criterion k and is calculated as follows:

$$\Phi_k = \frac{1}{m-1}\left(\sum_j P_k(A_i, A_j) - \sum_j P_k(A_j, A_i)\right),\ i \neq j. \tag{2}$$

An ideal option has $\Phi_k = 1$.

The multi-criteria preference degree for alternative A_i against alternative A_j is calculated as the weighted sum of the pairwise preferences over the two alternatives for all criteria:

$$\pi(A_i, A_j) = \sum_{k=1}^{q} w_k P_k(A_i,\ A_j),\ i \neq j \tag{3}$$

where w_k represents the weight of criterion k, with $w_k \geq 0$ and $\sum_{k=1}^{q} w_k = 1$. In the presence of m adaptation options, the PROMETHEE II outranking method provides two preference flows. The first, $\Phi^+(A_i)$, reflects how strongly an alternative A_i dominates all other alternatives and the second, $\Phi^-(A_i)$, reflects how strongly A_i is dominated by all other alternatives:

$$\Phi^+(A_i) = \frac{1}{m-1}\sum_j \pi(A_i,\ A_j)\ \ i \neq j, \tag{4}$$

$$\Phi^-(A_i) = \frac{1}{m-1}\sum_j \pi(A_j,\ A_i),\ i \neq j. \tag{5}$$

The net preference flow $\Phi(A_i)$ is calculated as follows:

$$\Phi(A_i) = \Phi^+(A_i) - \Phi^-(A_i). \tag{6}$$

An ideal option has $\Phi(A_i) = 1$.

Finally, alternatives can be ranked by their net preference flow $\Phi(A_i)$. We use the Visual PROMETHEE software for our analysis.

2.3 Identification of adaptation options

The study area is the Choke (Choqa) mountain ecosystem in Ethiopia, the largest stretched watershed in the upper Blue-Nile basin. The landscape is dominated by low-input mixed crop-livestock subsistence agriculture, with cultivation extending from the Blue Nile gorge (800 meters above sea level) up to 3800 meters above sea level. Climate change has already been perceived in extreme rainfall events and an upward trend of regional temperatures over the past 20 years (Simane et al. 2012). At the national level, both the frequency and intensity of droughts have increased and inflicted severe damages on the livelihoods of millions of people (Simane and Zaitchik 2014). We identified possible adaptation options for agriculture, water management and natural resource management in the study area through a literature review and a stakeholders' workshop.

The agricultural sector in Ethiopia has frequently been affected by climate variability and change (Tesso et al. 2012; World Bank 2010). In the highlands, soil degradation is very pervasive and many farmers perceive erosion to be a problem (Teshome et al. 2014). Seasons have been fluctuating over the past decades and are expected to continue to do so in the next 25 years (Conway and Schipper 2011; World Bank 2010; Ethiopian EPA 2011). As a response to this, farmers in the Upper Blue-Nile basin have started to use agricultural adaptation options including change in crop calendar (Simane and Zaitchik 2014), conservation tillage (Temesgen et al. 2012), and improved varieties (Simane et al. 2012).

Second, in addition to its impact on agriculture, climate change affects water resources upon which agricultural systems in developing countries depend, for example through changes in the patterns of temperature, precipitation and river flow (FAO 2011). Despite the fact that there are large uncertainties concerning the impact of climate change on precipitation, models predict that there will be more variability in rainfall patterns, with increased occurrence of extreme events like intense precipitation or longer periods of low or zero rainfall (Bates et al. 2008; FAO 2011). Practices that retain the surface runoff in the uplands and lowlands, improved water-holding capacity of the soil, and practices that increase groundwater recharge and protect the top soil have been suggested as water-related adaptation options (e.g. FAO 2014).

Third, climate change may also have impacts on the provision of natural resources. Natural resource management is important in improving adaptive capacity of smallholder farmers and has both ecological and economic implications (Teshome et al. 2014). Ecological benefits of adaptive natural resource management include improved soil fertility, temperature regulation, improved water retention and afforestation (Power 2010; FAO 2011), while economic benefits include improved crop yield and fodder production and agroforestry benefits, and less conflict over resources (Teshome et al. 2014).

For the stakeholders' workshop, 20 individuals were carefully selected and invited for a one-day workshop.[2] Participants included five farmers from five different villages (who are the direct bearers of climate change impacts), three local government representatives (decision makers), one representative of Debre Markos University (the regional university), six experts from the zonal agricultural department (who are directly involved in the design and execution of programs and projects), and five representatives from five non-governmental organizations (particularly those who are concerned with

[2] Bedru et al. (2010) and Mendoza and Prabhu (2000a, b) indicate that a team of 12 persons is sufficient to generate criteria and indicators when carrying out an MCA evaluation such as ranking and pair-wise comparisons.

environmental conservation). More details can be found in Appendix A in the Supplementary Material. The workshop was organized in the city of Debre Markos in East Gojjam, the heart of the upper Blue-Nile basin, in May 2015. During the workshop, a list of adaptation options for the Choke mountain ecosystem was created based on stakeholders' views and perspectives. The final list of adaptation options is presented in Table 1.

Table 1. List of adaptation options identified both from literature and stakeholders' workshop

Agriculture	Water resources	Natural resources
Budding (L)	Cash crops using irrigation (L,F)	Agro forestry (L,F)
Changing fertilizer use methods (L)	Drip irrigation (L,F)	Afforestation (L,F)
Composting (L, F)	Hand dig pumping (L)	Enhancing soil fertility (L)
Crop rotation (L,F)	Planting trees with high water storage capacity (L,F)	Maximizing water retention (L)
DAP and urea application (L)	Preventing leaching and erosion (L,F)	Measures to improve crop yield (L)
Farming implements (L)	River diversion (L,F)	Measures to improve fodder production (L)
Improved varieties (L,F)	Use of surface and ground water (L,F)	Minimizing conflicts over resources (L)
Integrated farming (L,F)	Using water evicting technologies (F)	Minimizing risk of pest harboring (L)
Introducing new harvest periods (L,F)	Water allocation rules (L)	Minimizing soil losses (L,F)
Modification of crop calendar (L,F)	Water efficient technologies (L,F)	Temperature regulation by shading (L)
Reducing tillage (L)	Water harvesting (L,F)	
Storing technology (L,F)		
Terracing (L,F)		
Use of pesticides (L,F)		
Watershed management (L,F)		

Note: (L) = coming from the literature; (F) = coming from focus group; (L,F) = coming from literature and focus group.

2.4. Selection of criteria and weights

To determine criteria to evaluate climate change adaptation options, we first identified criteria in the literature and then discussed these in the stakeholder workshop.

De Bruin et al. (2009) studied options for adapting to climate change for The Netherlands. Using insights from Smith and Lenhart (1996) and Füssel (2007) and a stakeholder workshop, they selected two groups of criteria. The first group consists of importance (expected gross benefits), urgency (need to act soon), no-regret characteristics (extent to which the option would be good to implement even in the absence of climate change), co-benefits to other sectors, the effect on climate change mitigation.

The second group consists of feasibility criteria: technical, social and institutional complexity. Dolan et al. (2001) identified effectiveness, economic efficiency, flexibility, institutional compatibility, farmer implementability and independent benefits as criteria for ranking adaptation options for farmers in Canada. Selected criteria should be relevant for the decision context (Füssel, 2007). Accordingly we adjusted the criteria used in studies for Canada and the Netherlands for the local context and discussed the resulting list with stakeholders in the focus group discussion. This resulted in further adjustments. For instance, as a departure from studies in Netherlands, we rank adaptation options related to agriculture also based on agro-ecosystem relevance, applicability, and affordability. For water related adaptation options we followed the stakeholders in the focus group discussion and adjusted the criteria to include agro-ecosystem feasibility, technical feasibility, institutional feasibility and socioeconomic feasibility. The workshop then resulted in the final list of criteria as presented in Table 2, which largely covers the composite set of evaluation criteria identified in Bhave et al. (2014).

Table 2. Criteria and weights used

Agriculture		Water resources		Natural resources	
Criterion	Weight (%)	Criterion	Weight (%)	Criterion	Weight (%)
Importance	40	Agro-ecosystem feasibility	40	Importance	20
Urgency	30	Technical feasibility	30	Urgency	20
No regret	10	Institutional feasibility	20	No regret	20
Co-benefits	10	Socioeconomic feasibility	10	Co-benefits	20
Mitigation	10			Mitigation	20
Applicability	50				
Affordability	25				
Agro-ecosystem relevance	25				

Stakeholders can have different objectives depending on their personal values and on their socio-economic circumstances. We use insights from the stakeholder workshop to assign a weight to each criterion. Table 2 presents actual weights used in the evaluation. In section 3.2.2 we discuss the sensitivity of the results regarding the weight attached to each criterion.

3. Results of identified adaptation options and their ranking based on MCA

In this section we present the results of our multi-criteria analysis. The data to rank and compare different adaptation options were generated from a survey of farmers and experts in the Choke mountain area. A total of 175 individuals (145 farmers and 30 experts) participated in the survey, which was conducted in June and July 2015. Farmers were selected from four villages found in two agroecosystems (AES 4 and AES 5). AES 4 covers midland slopping lands, and AES 5 covers hilly and mountainous highlands of the Choke mountain ecosystem (see Simane et al. 2012). The survey was conducted by trained enumerators who are fluent in local languages.

3.1. Uni-criterion analysis

In this section, we present the performance of each adaptation option under each individual criterion using the calculation method in equations (1) and (2). Table 3 presents the uni-criterion performance of agricultural adaptation options regarding the criteria importance, urgency, no-regret, co-benefits and mitigation. In Tables 3-6, an ideal option has a value of 1 for the uni-criterion net flow. A positive net flow value for option i under criterion k indicates that the option is preferred over more than half of the alternative options for this criterion. Terracing has long been practiced in the study area and scores highest for the criteria urgency and no regret, while crop rotation scores highest for importance it scores lowest for co-benefits. Options that score high on importance tend to score high on urgency as well but low on co-benefits. Options that score high on no regret tend to score high on co-benefits as well.

Table 3. Uni-criterion net flow Φ_k of agricultural adaptation options for the criteria importance, urgency, no regret, co-benefits and mitigation

	Criteria				
Options	Importance	Urgency	No regret	Co-benefits	Mitigation
Budding	-0.4286	-0.2857	0.2857	0.5714	0.3571
Changing fertilizer use methods	0.2857	0.1429	0.4286	0.2857	-0.8571
Composting	0.5714	0.0000	-0.7143	-0.8571	0.6429
Crop rotation	1.000	0.4286	-0.1429	-1.000	0.3571
DAP and urea application	-0.2857	0.8571	-0.4286	-0.5714	-0.5714
Farming implements	0.7143	0.7143	-0.8571	0.0000	0.0714
Improved varieties	-0.6429	-0.8571	-1.000	-0.1429	-0.7143
Integrated farming	0.8571	0.2857	-0.2857	-0.4286	-0.1429
Introducing new harvest periods	0.1429	-0.1429	0.8571	0.1429	-0.4286
Modification of crop calendar	-0.1429	-1.000	0.7143	0.9286	-0.2857
Reducing tillage	-0.9286	-0.5714	0.5714	0.7143	0.8571
Storing technology	-0.9286	-0.7143	1.000	0.4286	1.000
Terracing	0.4286	1.000	1.000	0.0000	-0.7143
Use of pesticides	-0.6429	-0.4286	0.1429	0.9286	0.0714
Watershed management	0.0000	0.5714	-0.5714	-0.2857	0.6429

Table 4 shows the uni-criterion scores for the agricultural adaptation options for the feasibility criteria. While some options score well (improved varieties) or poor (budding, storing technology) on all criteria, again most options do not show a consistent pattern in terms of ranking. Options that score high on applicability tend to score high on affordability as well.

In Table 5 we present the uni-criterion performance of adaptation options related to water resource management. Again we see trade-offs between the criteria as many options that score well on one criterion perform poorly on others. Drip irrigation performs highest on agro-ecosystem and institutional feasibility but rather poorly on the other criteria. Drip irrigation, river diversion, and planting trees with high water storage capacity perform highest on the criterion agro-ecosystem feasibility. The presence of abundant rivers, and underground and surface water bodies in the Upper Blue-Nile basin makes these three options feasible in terms of agro-ecosystem relevance.

Table 6 shows the uni-criterion performance of adaptation options for natural resource management. Scores on importance are positively correlated with scores on urgency but negatively correlated with scores on the mitigation criterion. Options that score high on no regret tend to score high on mitigation as well.

Table 4. Uni-criterion net flow Φ_k of agricultural adaptation options for the feasibility criteria (applicability, affordability and agro-ecosystem relevance)

	Feasibility criteria		
Options	Applicability	Affordability	Agro-ecosystem relevance
Budding	-0.7143	-0.8571	-1.000
Changing fertilizer use methods	0.7143	0.4286	-0.4286
Composting	0.8571	0.8571	-0.2857
Crop rotation	1.000	0.7143	-0.1429
DAP and urea application	0.1429	-0.2857	-0.5714
Farming implements	-0.3571	0.5714	0.8571
Improved varieties	0.5000	1.000	1.000
Integrated farming	-0.1429	-0.4286	0.5714
Introducing new harvest periods	0.0000	0.1429	0.1429
Modification of crop calendar	-0.9286	0.0714	0.7143
Reducing tillage	-0.9286	-1.000	0.2857
Storing technology	-0.3571	-0.7143	-0.7143
Terracing	-0.5714	-0.5714	0.4286
Use of pesticides	0.2857	0.2857	-0.8571
Watershed management	0.5000	-0.0714	0.0000

Table 5. Uni-criterion net flow Φ_k of adaptation options for water management

Options	Criteria			
	Technical feasibility	Agro ecosystem feasibility	Institutional feasibility	Socio-economic feasibility
Cash crops using irrigation	-1.0	-1.0	-1.0	1.0
Drip irrigation	-0.4	1.0	1.0	-0.8
Hand dig pumping	0.4	0.4	0.0	0.0
Planting trees with high water storage capacity	-0.6	0.6	-0.8	-1.0
Preventing leaching and erosion	0.6	0.4	0.4	0.6
River diversion	0.9	0.8	-0.6	0.6
Use of surface and ground water	-0.8	-0.8	0.7	-0.6
Using water evicting technologies	0.9	-0.6	0.7	-0.4
Water allocation rules	0.2	0.0	0.2	0.6
Water efficient technologies	0.0	-0.2	-0.3	0.2
Water harvesting	-0.2	0.2	-0.3	-0.2

Table 6. Uni-criterion net flow Φ_k of adaptation options for natural resource management

	Criteria				
Options	Importance	Urgency	No regret	Co-benefits	Mitigation
Agro forestry	-0.7778	-0.5556	0.7778	0.5556	0.7778
Afforestation	1.000	0.7778	1.000	-1.000	0.3333
Enhancing soil fertility	0.1111	0.1111	-0.7778	-0.3333	-0.5556
Maximizing water retention	-0.5556	1.000	0.1111	-0.1111	0.5556
Maximizing crop yield	-1.000	-0.7778	0.5556	0.7778	1.000
Maximizing fodder production	0.5556	0.3333	-0.5556	-0.7778	-0.2222
Minimizing conflicts over resources	0.3333	-0.1111	-0.1111	0.1111	-1.000
Minimizing risk of pest harboring	-0.1111	-0.3333	0.3333	0.3333	0.1111
Minimizing soil losses	-0.3333	0.5556	-1.000	-0.5556	-0.2222
Temperature regulation	0.7778	1.000	-0.3333	1.000	-0.7778

3.2. Ranking of adaptation options using multi-criteria analysis

3.2.1. Outranking results of adaptation options by farmers and experts jointly

In this section, we present the complete outranking results of adaptation options using the net preference flow in Equation (6), based on the surveys of both farmers and experts. In Tables 7 and 8, the higher the value for the net preference flow for adaptation option i, the better the performance of that adaptation option, taken over all criteria. An ideal option has $\Phi(A_i) = 1$.

In Table 7, we present the outranking results of agricultural adaptation options, ranked by their performance on feasibility. Options that score well on the feasibility criteria tend to score well on the second group of criteria (Importance, Urgency, No regret, Co-benefits and Mitigation) as well, with the notable exception of improved varieties. Indeed, this option scores highest on feasibility and lowest on the second group of criteria. Still, there are six options that score well on both groups of criteria: crop rotation, composting, changing fertilizer use methods, watershed management, farming implements and introducing new harvest periods. Crop rotation scores well on both accounts since there is severe land degradation and poor soil fertility in the upper Blue-Nile basin. Terracing is ranked fourth for the second group of criteria but twelfth for the feasibility criteria.

Generally, adaptation options for soil and land management score well in both groups of criteria for the Choke mountain area. Indeed, Temesgen et al. (2012) indicate that modern farm implements like conservation tillage improve crop production, while Teshome et al. (2014) recommend soil conservation practices (such as composting and crop rotation) for the highlands of Ethiopia.

Table 7. Outranking results of agricultural adaptation options

	Criteria			
	Feasibility(Applicability, Affordability and Agro-ecosystem relevance)		Importance, Urgency, No regret, Co-benefits and Mitigation	
Options	Rank	$\Phi(A_i)$	Rank	$\Phi(A_i)$
Improved varieties	1	0.7500	15	-0.7000
Crop rotation	2	0.6429	1	0.4500
Composting	3	0.5714	7	0.1357
Changing fertilizer use methods	4	0.3571	6	0.1429
Watershed management	5	0.2321	5	0.1500
Farming implements	6	0.1786	2	0.4214
Introducing new harvest periods	7	0.0714	8	0.3429
Use of pesticides	8	0.0000	12	-0.2714
Integrated farming	9	-0.0357	3	0.3429
DAP and urea application	10	-0.1429	9	-0.0143
Modification of crop calendar	11	-0.3036	11	-0.2214
Terracing	12	-0.3214	4	0.3000
Storing technology	13	-0.5357	14	-0.3429
Reducing tillage	14	-0.6429	13	-0.3286
Budding	15	-0.8214	10	-0.1357

In the left part of Table 8 we present the outranking results for water management adaptation options for the Choke mountain area. River diversion, preventing leaching and erosion, and drip irrigation have the highest net preference flow. FAO (2014) indicates that climate smart agriculture can sustainably increase productivity and system resilience while reducing greenhouse gas emissions. River diversion performed well in the uni-criterion analysis on technical, agro-ecosystem and socio-economic feasibility but rather poor on institutional feasibility, which suggests that improved institutional arrangements are required for optimal adaptation in the area. Indeed, we observed that, in the study area, sound water allocation rules are non-existent and there is frequent conflict over water user rights. Under sound institutional arrangements and considering the relevance of the technology to the specific agro-ecosystem, it is possible to enhance the uptake of drip irrigation technologies (FAO 2014).

In the right part of Table 8, we present the outranking results of adaptation options for natural resource management. Afforestation (ecological benefit), maximizing water retention (ecological benefit), and maximizing crop yield (economic benefit) were ranked highest, with afforestation clearly having the highest net preference flow. Simane et al. (2012, 2013) and Simane and Zaitchik (2014) indicate that ecological disturbances in the upper Blue-Nile basin are increasing and suggest a strategy to focus on rehabilitation of the ecology.

Table 8. Outranking results for adaptation options for water resources and natural resource management

Water management adaptation options	Rank	$\Phi(A_i)$	Natural resource management adaptation options	Rank	$\Phi(A_i)$
River diversion	1	0.5300	Afforestation	1	0.6667
Prevent leaching and erosion	2	0.4800	Maximizing water retention	2	0.2000
Drip irrigation	3	0.4000	Maximizing crop yield	3	0.0556
Water allocation rules	4	0.1600	Temperature regulation	4	-0.0222
Using water evicting technologies	5	0.1300	Minimizing conflict over resources	5	-0.0444
Hand dig pumping	6	-0.0400	Minimizing risk of pest harboring	6	-0.1111
Water efficient technologies	7	-0.0600	Enhancing soil fertility	7	-0.1111
Water harvesting	8	-0.1200	Minimizing soil losses	8	-0.1778
Planting trees with high water store capacity	9	-0.2000	Agro forestry	9	-0.2111
Use of surface and ground water	10	-0.4800	Maximizing fodder production	10	-0.2444
Cash crops using irrigation	11	-0.8000			

3.2.2 Sensitivity analysis

In this section, we discuss the sensitivity of the results to the choice of weights in the outranking procedure. Table 9 presents actual weights used in the evaluation, and the weight stability interval for the top three ranked alternatives; i.e., the range in which the weight of a criterion can be changed without altering the ranking of the top three adaptation options. For adaptation options for agriculture, if within the first group of criteria the weights were neutral (i.e. each has a weight of 1/3), the ranking of the top three results would not change. For the second group of criteria for adaptation options the neutral weight is 1/5. The top three results would change if the weight for importance were halved from 0.4 to 0.2 or the weight of the co-benefits criterion were doubled. The results for water resources adaptation options appear to be rather sensitive to the weights that resulted from our stakeholder workshop. Except for technical feasibility, changing the weight to 1/4 would affect the top three results.

3.3. Outranking results of adaptation options by experts only

In a smallholder economy, policies and programs are often designed in a top-down approach, and without consultation of farmers. Hence it is interesting to analyse how the outranking results for farmers and experts presented above differ from those for just the experts. Comparing the rankings resulting from the surveys of both farmers and experts (section 3.2.1) with those for experts only, we observe that there are large differences in rankings.

Table 9. Summary of criteria and weight stability interval for top three ranked alternatives

Options related to	Criteria	Actual weights used (%)	Weight stability interval (%)	
			Max	Min
Agriculture	Applicability	50	58.28	26.09
	Affordability	25	50.00	0.00
	Agro-ecosystem relevance	25	44.19	17.24
	Importance	40	61.29	33.33
	Urgency	30	33.96	14.29
	No regret	10	20.88	6.25
	Co-benefits	10	12.50	0.00
	Mitigation	10	27.74	5.26
Water management	Agro-ecosystem feasibility	40	47.06	31.43
	Technical feasibility	30	42.04	23.91
	Institutional feasibility	20	23.81	0.00
	Socioeconomic feasibility	10	23.17	4.55
Natural Resource Management	Importance	20	29.41	6.67
	Urgency	20	39.62	17.65
	No regret	20	25.00	0.00
	Co-benefits	20	25.00	0.00
	Mitigation	20	33.33	7.69

In Table 10 we present the outranking results for the experts' evaluation for adaptation options for agriculture. Regarding the feasibility of agricultural adaptation options, there is only a weak correlation between the results for experts, and for experts and farmers combined (as reported in Table 6). While both groups rank crop rotations high (first and second, respectively), the only other option with a positive net preference flow for both groups is farming implements (ranked fourth and sixth, respectively). Improved varieties (which was ranked highest for the pooled survey results) ranks only sixth with a negative net preference flow under experts. For the criteria importance, urgency, no regret, co-benefits and mitigation, we find only a weak correlation between the rankings of the two groups of stakeholders as well. Experts rank improved varieties first whereas farmers rank this option last. Crop rotation was ranked highest by the experts and farmers combined, while experts rank it fourth. Farming implements were ranked second and fifth by the two respective groups; integrated farming third and seventh.

Table 11 shows the ranking by experts for adaptation options for water resources and for natural resource management. The ranking of adaptation options for water management by experts and by the two groups of respondents combined (reported in Table 7) is weakly correlated. River diversion and preventing leaching and erosion were ranked first and second by the two groups of respondents combined, and third and first, respectively, by the experts. Experts rank water harvesting second whereas it was ranked eighth by the combined group.

Table 10. Outranking results of experts' evaluation of agricultural adaptation options

	Criteria			
	Feasibility (Applicability, Affordability and Agro-ecosystem relevance)		Importance, Urgency, No regret, Co-benefits and Mitigation	
Options	Rank	$\Phi(A_i)$	Rank	$\Phi(A_i)$
Crop rotation	1	0.3750	4	0.1714
Storing technology	2	0.3750	12	-0.2857
Use of pesticides	3	0.3750	3	0.3429
Farming implements	4	0.1786	5	0.1429
Modification of crop calendar	5	0.1786	10	0.0571
Improved varieties	6	-0.0893	1	0.5857
Watershed management	7	-0.0893	2	0.3429
Composting	8	-0.0893	6	0.1429
DAP and urea application	9	-0.0893	15	-0.5643
Budding	10	-0.0893	11	-0.2857
Integrated farming	11	-0.0893	7	0.1429
Introducing new harvest periods	12	-0.0893	13	-0.4857
Changing fertilizer use methods	13	-0.0893	8	0.1429
Reducing tillage	14	-0.2679	14	-0.5071
Terracing	15	-0.5000	9	0.0571

Table 11. Outranking results for experts' evaluation of adaptation options for water resources and natural resource management

Water management adaptation options	Rank	$\Phi(A_i)$	Natural resource management adaptation options	Rank	$\Phi(A_i)$
Prevent leaching and erosion	1	0.4600	Maximizing fodder production	1	0.7556
Water harvesting	2	0.2400	Agro forestry	2	0.2111
River diversion	3	0.1600	Minimizing soil losses	3	0.1111
Cash crops using irrigation	4	0.1600	Enhancing soil fertility	4	-0.0444
Hand dig pumping	5	0.1600	Maximizing crop yield	5	-0.0778
Water allocation rules	6	0.1600	Maximizing water retention	6	-0.1000
Drip irrigation	7	0.0400	Afforestation	7	-0.1222
Water efficient technologies	8	-0.2800	Minimizing risk of pest harboring	8	-0.1222
Planting trees with high water storage capacity	9	-0.3600	Minimizing conflict over resources	9	-0.2556
Use of surface and ground water	10	-0.3700	Temperature regulation	10	-0.3556
Using water evicting technologies	11	-0.3700			

For adaptation options for natural resources, the correlation coefficient for the ranking by the two groups of respondents is negative (so is the correlation coefficient for the net preference flows). The top five adaptation options of the two groups are completely different (see Table 7). While farmers rank afforestation first, experts rank it seventh, and while experts rank maximizing fodder production first, it is ranked last by farmers.

These results show the importance of involving various stakeholders in the development of policies for climate change adaptation, and the importance of extension services. While experts may know more than farmers about the adaptation potential of alternative technologies and farming practices, farmers bring the local applicability and socio-economic feasibility to the table. Farmers and experts have different preferences due to different interests in reality. For instance, farmers may have a higher rate of time preference than experts (Herman et al. 2015; Yesuf and Bluffstone 2008), hence experts may be less concerned about economic feasibility and cost (investment) considerations, while giving a higher weight to future benefits than farmers do. Furthermore, attitudes to new technologies differ by education level (Allahyari et al., 2016).

4. Discussion

From the outranking results of the MCA analysis (Tables 7 and 8), we can identify four adaptation options that score highest: improved varieties and crop rotation for the agricultural adaptation options; river diversion for the water management adaptation options; and afforestation for the natural resource management adaptation options. In this section, we discuss the suitability and policy implications of these findings.

Using improved varieties is ranked as the first option among agricultural adaptation options. This is because climate change has a significant impact on crop yields, particularly in Ethiopia, while an increasing population in Ethiopia demands higher crop yields to ensure food security. Improved varieties, including heat- and drought-resistant crops, can improve yields greatly (Wale 2012). Furthermore, Ethiopia has also established many trial and demonstration sites all over the country for using improved varieties (EIAR 2017). As found in previous literature (e.g. Zhu et al., 2016) this adaptation option offers a great opportunity for farmers to adapt to climate change. It is also consistent with the general government policy for improving adaptive capacity and agricultural productivity and disseminating high-yield varieties in Ethiopia.

Crop rotation is ranked in the top 2 of agricultural adaptation options for both sets of criteria. Crop rotation can enhance soil fertility and water use efficiency. Although adoption of this practice by smallholder farmers is still not popular, it can be relatively easily introduced to farmers through extension workers.

River diversion is ranked first for water resource management. Compared to other options such as building dams, diverting rivers is cheaper and requires low capital inputs and skills. For implementing this option, government can help farmers in building the infrastructure to bring water to the crop fields by providing advice on irrigation and growing crops. This is in line with Simane et al. (2012) and the recommendation made by FAO (2013) on climate smart agriculture and water allocation rules.

Finally, afforestation is ranked first amongst the natural resource management adaptation options. This option can be implemented in Ethiopia, because the Ethiopian government has recently developed a climate resilient green economy policy (Government of the Federal Democratic Republic of Ethiopia 2011). In this policy, afforestation, among other efforts, is one of the crucial interventions.

Although these adaptation options have been ranked high by the stakeholders, various barriers to actual adoption of these options exist. The 5th Assessment Report of the International Panel on Climate Change (IPCC, 2014) provides a comprehensive literature survey, identifying transaction costs, externalities, and behavioural obstacles as the main barriers to adoption. From an economic point of view, the financial means of smallholder farmers to implement adaptation measures such as improved varieties could be a barrier. Next, implementing adaptation options often involves both public and private actors. For example, river diversion would need government and farmers to work together, yet information asymmetries and lack of trust may be barriers to cooperation.

5. Concluding remarks

Policy interventions for climate change adaptation require dialogue with and participation of stakeholders. While long-term impacts of climate change in Ethiopia are expected to be severe, there is a lack of stakeholder-level evaluation and stakeholder dialogue in the process of adaptation to climate change. We have presented the results of a multi-criteria analysis for adaptation options for smallholder farmers in the upper Blue-Nile basin, based on information from a stakeholder workshop and a survey among farmers and experts.

First, adaptation options for soil and land management, such as crop rotation, composting and changing fertilizer use methods, score high on two sets of criteria for assessing adaptation options for agriculture. However, while the option of improved varieties was ranked first under the set of feasibility criteria, it was ranked last under the second set of criteria. This shows that evaluation criteria for adaptation options can be conflicting, and stakeholders and decision-makers need to make the importance of each criterion clear in the decision-making process.

Second, we looked at adaptation options for water management, where river diversion, preventing leaching and erosion, and drip irrigation have the highest net preference flows. This finding is in line with the findings of Teshome et al. (2014).

Third, we analysed adaptation options for natural resource management. Here, afforestation, maximizing water retention and maximizing crop yield were ranked highest. According to Simane et al. (2012), there is frequent ecological disturbance in the upper Blue-Nile basin due to high population pressure accompanied by deforestation and land degradation.

Taking into account the perspectives of different stakeholders, our analysis provides some useful insights on how vulnerable smallholder farmers in the upper Blue-Nile basin can improve their climate change adaptation strategies. The method we use to arrive at our conclusions can be adapted to other developing countries.

We also performed the same analysis using survey results from experts only. Since policies and programs in developing countries are often designed without consultation of smallholder farmers, it is interesting to see to what extent the priorities for the two groups differ. Generally, there is only a weak correlation between the rankings by the two groups of stakeholders. For adaptation options for natural resource management, the rankings are actually negatively correlated, which shows that the priorities of farmers and experts may differ strongly. These results show the importance of extension services (showing farmers the opportunities of alternative adaptation options), but also the importance of involving farmers in the decision-making process to ensure local applicability and socio-economic feasibility.

A society consists of various stakeholders with diverse interests. The difference in outranking results for the stakeholder groups confirms the diverse views of experts and farmers. Therefore it is challenging for policy makers to balance the interests of different stakeholders among the various goals such as economic, social and environmental objectives. Hence, an inclusive dialogue and stakeholder level engagement is required in order to have a sustainable climate change adaptation interventions. This requires good governance in order to implement good programs and policies on climate change adaptations.

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Supplementary Material

Appendix A: Details about stakeholder workshop/focus group meeting

Workshop participants included the following groups, with one representative from each organisation:

- Farmers representatives, each from a different village
- Nongovernmental organizations (NGOs) representing conservationists, notably:
    - AMELD: Amhara rehabilitation and development enterprise. It mostly takes part in seed distribution, fertilizer, and extension works
    - MIGBARE SENAY: a local NGO working on children, women, nutrition and natural resources management
    - Organization for Rehabilitation and Development in Amhara (ORDA): works in Amhara region on rehabilitation, natural resource development, water resource development, and food security and agriculture programs
    - Ethiopia Orthodox Church Development and InterChurch Aid Commission (EOC-DICAC): working on rehabilitation, water resources and natural resource management
    - Agri-service: An NGO which engages in value chain development, water supply, climate change adaptation and mitigation and in the agriculture sector
- Local government:
    - Bibugn woreda (district) administration
    - Gozamin woreda (district) administration
    - Sinan woreda (district) administration
- University (Debre Markos University)
- Experts:
    - Environment office of the Zonal agricultural department
    - Forestry division of the Zonal agricultural department
    - Soil division of the Zonal agricultural department
    - Water and irrigation division of the Zonal agricultural department
    - Plant breeding division of the Zonal agricultural department
    - Animal breeding division of the Zonal agricultural department

At the focus group meeting, stakeholders identified the following list of options:

- Agriculture:

    - Honey bee and related breeding works as it generates cash
    - Chicken breeding
    - High yield and genetically modified sheep and goats breeding
    - Using fish harvest as an alternative livelihood using ponds and artificial water stores
    - Crop rotation
    - Using low water consuming crops
    - Using advanced post-harvest technologies as they reduce waste and loss
    - Using traditional composts
    - Pesticide resistant crops
    - Introducing agro-ecosystem-friendly crops and animals
    - Introducing new varieties
    - Integrated farming
    - Introducing agro-ecosystem-based water and soil conservation works
    - Introducing new harvest periods
    - Changing fertilizer use methods.
- Water resources:
    - Stream upgrading
    - Water harvesting and restriction from contact both animals and people
    - Using water saving technologies like drip irrigation
    - Using underground water resources efficiently
    - Constructing water evicting structures
    - Preventing water loss and leaching
    - Focusing on trees that enhance water storage
- Natural resources management:
    - Integrated rehabilitation of highly degraded landscapes using plants that have dual benefit
    - Exerting effort on activities which enhance soil moisture
    - Afforestation
    - Agro-forestry on lands that are highly degraded
    - Terracing on steep slopes
    - Rehabilitating gullies and protection

Appendix B: Descriptions of adaptation options

Agriculture	**Description**
Budding	Propagating drought resistant new varieties with local varieties to improve productivity under climate change
Changing fertilizer use methods	Improve efficiency of fertilizer use to increase soil productivity in a changing climate
Composting	Use local materials to prepare compost so that adaptive capacity to climate change will be improved
Crop rotation	Rotating different crops on the same plot over time to adjust to changing rainfall and temperature patterns
Di-ammonium phosphate (DAP) and urea application	Improved fertilizer use to increase crop production in response to changing rainfall and temperature patterns
Farming implements	Use modern farm implements to improve water infiltration, leaching and acidity
Improved varieties	Change to crop and livestock varieties that give high yields under climate change
Integrated farming	Apply integrated farm management system which aims to deliver more sustainable agriculture
Introducing new harvest periods	Introduce new harvest seasons to adjust to changing rainfall and temperatures
Modification of crop calendar	Adjusting harvest and planting season to changing rainfall and temperatures
Reducing tillage	Minimize soil disturbance and allowing crop residue or stubble to remain on the ground instead of being thrown away or incorporated into the soil under climate change
Storing technology	Apply modern storage facilities suitable for rainfall variability and recurring droughts
Terracing	Use terraces to reduce erosion in drying areas
Use of pesticides	Use of pesticides to reduce crop damage from changing weather patterns
Watershed management	Improve water and land use practices to adapt to changing rainfall patterns

Water resources	Description
Cash crops using irrigation	Divert rivers and streams to improve income from cash crops under changing temperatures and rainfall patterns
Drip irrigation	Use micro-irrigation to save water and nutrients by allowing water to drip slowly to the roots of plants to improve water use efficiency
Hand dig pumping	Use hand dug wells as water source to adapt to increased rainfall variation and droughts
Planting trees with high water storage capacity	Introduce trees that have high water storage capacity to cope with increased rainfall variability and droughts
Preventing leaching and erosion	Reduce leaching and erosion to improve water availability and soil quality to cope with increased rainfall variability and droughts
River diversion	Divert rivers and streams to cope with increased rainfall variability and droughts
Use of surface and ground water	Improve use of surface and ground water resources to enable farmers to produce all year round despite increased rainfall variability and droughts
Using water evicting technologies	Use of ditches and canals to evict water and avoid water logging in periods of heavy rainfall
Water allocation rules	Develop and apply water allocation rules to reduce conflict over water resources and enable equitable allocation in response to increased rainfall variability and droughts
Water efficient technologies	Technologies to improve water efficiency in response to increased rainfall variability and droughts
Water harvesting	Use rain water harvesting to improve cash crop harvesting to cope with increased rainfall variability and droughts

Natural resources	Description
Agro forestry	Combine crops with shrubs or trees to diversify production, retain moisture and provide shading in response to increased rainfall variability and drought occurrence

Afforestation	Establish forest cover in an upland open area to retain moisture, provide shade and reduce erosion
Enhancing soil fertility	Enhance soil fertility in response to changing climatic conditions
Maximizing water retention	Maximize soil water retention in response to increased rainfall variability and drought occurrence
Maximizing crop yield	Adjust resource management to maximize crop yield in response to increased rainfall variability and drought occurrence
Maximizing fodder production	Enhance and maximize fodder production under climate change
Minimizing conflicts over resources	Develop and apply rules to minimize conflicts over natural resources, which are expected to increase due to climate change
Minimizing risk of pest harboring	Adjust resource management to minimize risk of pest harboring, which is expected to increase due to climate change
Minimizing soil losses	Adjust resource management to minimize soil loss in response to increased rainfall variability and drought occurrence
Temperature regulation	Improve temperature management in response to changing climatic conditions (e.g. through shading)