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EDITED BY
Augustine Ovie Edegbene,
Federal University of Health Sciences Otukpo, Nigeria

REVIEWED BY
Sahil Raj,
Punjabi University, India
Abebe Getahun,
Addis Ababa University, Ethiopia

*CORRESPONDENCE
Mesfin Gebrehiwot
gebrehiwotmesfin@yahoo.com

†These authors have contributed equally to this work and share first authorship

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Participatory management of weed infestation in Lake Tana - setting a better future in the front mirror

Birhanu Sewunet[1†], Haileyesus Girma[2,3†], Sisay Abebe Debela[4], Amana Ogeto Luke[5] and Mesfin Gebrehiwot[1*†]

[1]Department of Environmental Health, Wollo University, Dessie, Ethiopia, [2]Department of Environmental Health Science, Haramaya University, Harar, Ethiopia, [3]Department of Economics, Ghent University, Ghent, Belgium, [4]Department of Public Health, Salale University, Fitche, Ethiopia, [5]Department of Public Health, Rift Valley University, Addis Ababa, Ethiopia

Lake Tana is one of the biosphere reserves in Ethiopia registered by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Water hyacinth is expanding in the lake owing to increased nutrient load from the watershed. As efforts from the government alone could not bring the anticipated change, local peoples' engagement and contribution are believed to sustainably and effectively manage the watershed and prevent the weed's spreading. This study, therefore, aims to estimate households' contribution (willingness to pay–WTP–and willingness to contribute labor–WTCL–) to prevent and control water hyacinth and hence improve lake ecosystem services through a hypothetical watershed management in Lake Tana. This study applied quantitative and qualitative methods. It was conducted among 560 randomly selected households of the Libo-kemkem district using a contingent valuation method from March to April/2021. Eleven key informant interviews were also conducted. Bivariable and multivariable interval regression models were used to identify the determinants of households' potential contribution. Thematic analysis was used to analyze the qualitative data. As the weed is believed negatively impact the ecosystem services provided by the lake, 72% of the respondents showed willingness to contribute to the proposed management program. About 32 and 39% of the respondents were willing to pay in cash and to contribute labor, respectively, to prevent weed infestation. On the other hand, 28% of them were neither willing to contribute in cash nor in labor to the hypothetical market. The findings showed respondents' mean annual WTP and WTCL were 632.8 Ethiopian birr and 30.1 man-days per household, respectively. The place of residence, educational status, farm plot area, household income, family size, and conference participation significantly influenced WTP and/or WTCL. In this hypothetical improvement scenario, an estimated annual WTP and WTCL of nearly 12 million Ethiopian birr and 700 man-days per year, respectively, are reported considering the total households in the study area. Therefore, collaborative efforts by different stakeholders are the next steps to realize the hypothetical contributions.

KEYWORDS

improved ecosystem services, Lake Tana, willingness to pay and contribute labor, water hyacinth infestation, Ethiopia

Introduction

The largest lake in Ethiopia (Lake Tana) was registered by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as a biosphere reserve in 2015. It is established as a global biodiversity hotspot area (Worku, 2017). The lake provides important ecosystem services to the local people and contributes to the country's economy at large. These services include fish production (e.g., annual fish production of US$ 1.1 million), tourism, recreation, transport, habitat for fauna and flora, and nutrient retention (Wondie, 2018; Bires and Raj, 2020).

Unfortunately, increasing anthropogenic activity near the lake watershed leads to high irrigation runoff, improper waste management, and overexploitation of the aquatic/wetland resources, which increases the nutrient levels in the Lake (Asmare et al., 2016). These situations benefited the expansion of an exotic plant, water hyacinth (*Eichhornia crassipes*). Currently, Lake Tana is highly infested with water hyacinth (Anteneh et al., 2015). Water hyacinth is characterized by its rapid reproduction rate and ability to consume a large amount of water, which could result in a gradual lake water level reduction. It has deleterious impacts on water balance, biotic structure, and all-rounded ecosystem services provided by aquatic ecosystems (Chapungu et al., 2018; Ongore et al., 2018).

Although several strategies (i.e., mechanical, chemical, and biological control) are being implemented to remove water hyacinth, each has its limitations (Shiferaw et al., 2018; Dersseh et al., 2019) and fails to succeed. The weed is rather expanding, particularly on the northeastern side of Lake Tana (Dersseh et al., 2019; Kebedew et al., 2020). Therefore, integrated watershed management practices are recommended as sustainable solutions (Dersseh et al., 2019; Sewunet et al., 2022). If properly implemented, integrated watershed management could substantially reduce adverse impacts, such as pollution loads and nutrient enrichment (Wang et al., 2016). As efforts from the government alone could not bring the anticipated change (Bires and Raj, 2019; Gebrehiwot, 2020), local peoples' engagement and contribution are believed to manage the watershed effectively and hence prevent the spreading of water hyacinth (Wang et al., 2016; Xu et al., 2018).

Local peoples' voluntary contribution to improving lake ecosystem service can be assessed by employing non-market valuation methods (Xu et al., 2018). The most frequently used economic valuation technique is the Contingent Valuation Method (CVM). The CVM is a stated preference economic valuation approach that utilizes a questionnaire to value goods/services not in the market (Venkatachalam, 2004; Dong, 2012).

Different authors used CVM to elicit the contribution of local people to the improvement of freshwater ecosystem services. For instance, Makwinja et al. (2022) estimated the public's WTP for ecosystem restoration of a shallow lake in Malawi. They reported that more than half of the respondents were willing to pay an average amount of US$28.4 per year to restore Lake Malombe. CVM was also used to determine farmers' willingness to contribute to the restoration of Lake Ziway (Ethiopia) (Girma et al., 2021). Similarly, Van Oijstaeijen et al. (2020) employed CVM to determine the preferences of farmers' for water hyacinth control in Lake Tana. However, these studies did not emphasize preventive approaches and mainly focused on farmers. The contribution of other community members is unknown. Thus, to apprehend the total economic benefit of the lake, it is necessary to include both direct and indirect users. Although a recent study by Sewunet et al. (2022) assessed factors affecting the contribution of local people to the management of the weed in Lake Tana, the study considered a status-quo scenario assuming that "*the prevention of water hyacinth infestation of Lake Tana through a watershed management program would work to keep the infestation levels constant at current levels and thus maintain ecosystem services gained from the lake at the current levels*." However, for the sustainable management of the lake, a better future aiming at reducing and avoiding infestation (improvement of the ecosystem) should be suggested. This study, therefore, estimates households' willingness to pay–WTP–and willingness to contribute labor–WTCL–for improving Lake Tana ecosystem services (improvement scenario) through watershed management.

Materials and methods

Study area

The study was conducted in Lake Tana, north-western Ethiopia, from March to April/2021. The lake's surface area and average depths are about 3,200 square kilometers and 8 meters, respectively. The lake's catchment contains 347 Kebeles (*kebele- the lowest administrative unit in Ethiopia*) and 21 districts, and covers an area of 16,500 square kilometers (IFAD, 2007). Libo-kemkem (kemekeme) district (Figure 1), where this study focuses, is one of the districts in the Lake Tana watershed with an area of 1,081.57 square kilometers (Figure 1).

The lake was relatively meagerly infested with water hyacinth in 2015 and before (Anteneh et al., 2015). However, recently, weed infestation is increasingly intensifying, particularly towards the northern part of the lake where Libo-kemkem district is situated (Dersseh et al., 2019). This is mainly because of flooding and the resultant high concentration of dissolved phosphorus in the sediment (Kebedew et al., 2020).

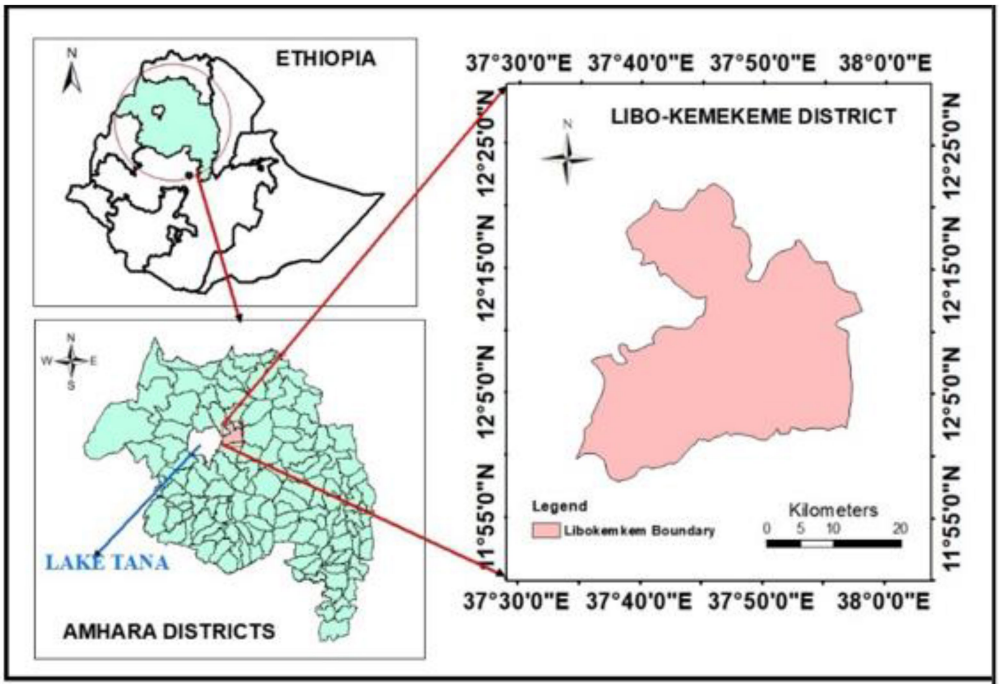

FIGURE 1
Location of Libo-kemkem district, North-Western Ethiopia.

Contingent valuation method

To elicit respondents' WTP and WTCL, CVM was used under a hypothetical improvement scenario. In this study, the scenario describes the proposed change (improvement of Lake Tana ecosystem services) in a simple and understandable way. The program would work to prevent and decrease water hyacinth infestation of the lake, and thus ecosystem services gained from the lake would improve accordingly.

Sample size determination

The sample size (n) was determined following a single population proportion formula with a 95% confidence level and a 5% margin of error. The sample proportion (p) was 63% (Girma et al., 2021).

$$n = \frac{(Z\alpha/2)^2 p(1-p)}{d^2}$$

where $Z_{\alpha/2}$ is the critical value of the normal distribution at $\alpha/2$ (e.g., for a confidence level of 95%, α is 0.05, and the critical value is 1.96), p is the sample proportion, and d is the margin of error. Then, a 1.5 design effect and a 5% non-response rate were used. Accordingly, the final sample size was 564 households.

Sampling technique and procedure

From the 37 kebeles (32 rural and 5 urban) of the Libo-kemkem district, eight rural and two urban kebeles were selected randomly. Then, a proportional allocation was made to each Kebele (see formula below). A systematic random sampling technique was then applied to select the study households.

$$n_j = (n'/N) * N_j$$

where nj is the sample size in each kebele, Nj is the total households in the Kebele, $n'$is the calculated sample size, and N is the total households in all 10 study kebeles.

Data collection methods and tools

A face-to-face interview was used to collect data. As depicted in Supplementary Annex I, the CVM questionnaire consisted of (1) socio-demography and economy, (2) ecosystem services, level of awareness, and impact of water hyacinth, and (3) the hypothetical market (see below)–WTP and/or WTCL.

Respondents who chose monetary contribution in the initial valuation question were presented with the following question:

'*What would be the household's maximum annual payment in Ethiopian Birr (ETB) to prevent and decrease water hyacinth infestation permanently and improve the services you get from the Lake accordingly?*'

(A) 1 – 200 (B) 201 – 400 (C) 401 – 600
(D) 601 – 800 (E) 801 – 1000 (F) > 1000

On the other hand, respondents were presented with the following question if they chose labor contribution: '*What would be the household's maximum annual labor contribution in man-days to prevent and decrease water hyacinth infestation permanently and improve the services you get from the Lake accordingly?*'

(A) < 20 (B) 20 – 30 (C) 31 – 40 (D) 41 – 50 (E) 51 – 60 (F) > 60

Quality assurance

Initially, the questionnaire was prepared in English and translated into the local language (Amharic). The data collectors attended two days of training about the mode of communication with respondents, the questionnaire, and ethical issues. A pre-test was also conducted among 25 households in Birra Abo Kebele.

Key informant interview

In order to supplement our valuation approach, 11 key informant (KI) interviews were performed using open-ended questions (Supplementary Annex II). The KIs were from the Lake Tana and other water bodies protection and development agency ($n = 1$), from wereda (district) level environmental protection office ($n = 1$), from wereda level natural resource management office ($n = 1$), from kebele level natural resource management offices in four kebeles ($n = 4$), and from community representatives in selected four (4) kebeles (Kab, Tezamba, Tibaga, and Addis ZemenK4 – *refer the list of kebeles from* Supplementary Annex III). The interviews were audio-recorded in the local language (Amharic), transcribed, and translated into English.

Data processing and analysis

The data was entered into Epidata manager 4.6 and then exported to STATA version 14.0 for management, cleaning, and further analysis. As the dependent variables were coarse-interval-censored, interval regression models were used (Cameron and Huppert, 1989). Correlation among the independent variables was checked using Variance Inflation Factor (VIF) with a threshold of 10. Fourteen regressors (Supplementary Annex III) were used to determine variables influencing WTP/WTCL. Due to dominant responses (above 90%), 'gender' and 'marital status' were excluded (Sewunet et al., 2022). From the bivariable interval regression model (model 1), variables with a value of p less than 0.25 were taken into the multivariable interval regression model (model 2). From model 2, regressors without statistical significance (value of $p \geq 0.25$) were dropped from further analysis. From the final model (model 3), variables with a significance level of $p < 0.05$ were taken as significantly associated. The detailed descriptions of variables used in this analysis are presented in Supplementary Annex III.

In order to discover common themes/patterns, the qualitative data were analyzed by thematic analysis using OpenCode 4.03. In addition, a narrative was assigned to the diverse data to gain and convey a sound understanding of the respondents' ideas and experiences (Braun and Clarke, 2006; Crawford et al., 2008). In this study, the themes were the impacts of water hyacinth infestation on Lake Tana ecosystem services, existing water hyacinth management strategies, and willingness to contribute to water hyacinth management.

Results

Socioeconomic and demographic characteristics

A total of 560 household heads completed the questionnaire, giving a response rate of 99.3%. About three-fourths of the respondents live in rural areas (411, 73.4%). Farming was the main source of income, supporting 70.8% of the households. Among those who had private farmland ($n = 465$), most (70.3%) owned less than 1.5 ha, and the farm plots for 369 (79.3%) households were located at least 1 km far from Lake Tana. Other socioeconomic and demographic characteristics of the respondents are summarized in Supplementary Annex IV.

Willingness to pay

From the total of 560 respondents, 183 (32%) were willing to contribute in cash money; of which 34.3, 28.4, and 18% were willing to pay in the ranges of 401–600, 601–800, and 801–1000 ETB per year, respectively (Figure 2).

The interval regression estimation model results indicated a mean yearly WTP of 632.8 ETB (95% confidence interval [600.4, 665.2]) and a robust standard error of 16.5. Willingness of residents in the urban area was higher (+88.2 ETB, $p = 0.032$) than those in rural areas. Similarly, respondents who attended formal education and participated in water

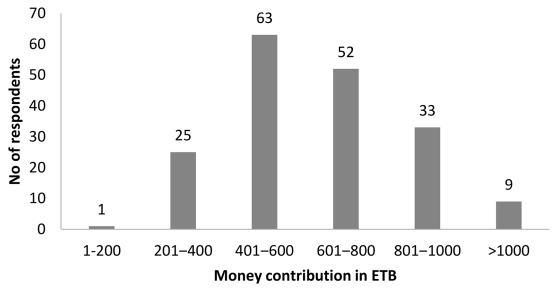

FIGURE 2
Respondents' annual maximum willingness to pay for improving Lake Tana ecosystem services (One US$=43.5 Ethiopian Birr (ETB) on June 19, 2021 (Source: https://www.Combanketh.et/en/exchange-rate/).

hyacinth-related conferences were willing to pay an extra 169.5 ($p < 0.001$) and 157.9 ($p = 0.01$) ETB than those who cannot read and write and who did not participate in training, respectively (Table 1). Households who owned the widest farm plot area had a higher willingness to pay (at least an additional 105.3 ETB, $p < 0.0001$) than those with the narrower farm plot area. Household heads with annual income INC >150,000 and INC 100,000–150,000 were willing to pay 139.8 ETB ($p = 0.002$) and 76.8 ETB ($p = 0.042$) more than those with lower annual income (INC ≤ 50,000), respectively. On the other hand, farm plot distance to Lake Tana (DISTANA > 1 km) was found to negatively influence WTP (i.e., −101.9 ETB contributions, $p = 0.028$) (Table 1).

Willingness to contribute labor

A total of 217 (39%) respondents were willing to contribute labor. For this improvement scenario, 72 (33%) respondents were willing to contribute 21–30 man-days annually (Figure 3).

The regression model results indicated a mean yearly WTCL of 30.1 man-days (95% confidence interval [28.2, 32.0]) and a robust standard error of 1.0. WTCL of households was positively associated with location, educational level, and family size. On the other hand, living in urban kebeles at $p = 0.001$ negatively influenced WTCL. The detailed findings on WTCL considering improvement scenario are described in Table 2.

In this study, 28% of the respondents were neither willing to contribute in cash nor in labor to the hypothetical market. Explanations for non-willingness were associated mainly with the distance of households' from the Lake and considering that only direct users are responsible to pay. Other justifications for non-willingness include lack of financial capability, believing that they do not encounter a problem due to water hyacinth infestation of the Lake, lack of trust in the people who will collect and handle the money, and assuming that water hyacinth management is the responsibility of the government alone.

Impacts of water hyacinth infestation on Lake Tana ecosystem services

The qualitative assessment results indicated that the infestation of the lake is negatively impacting its ecosystem services. According to the key informants (KIs), water hyacinth has social and economic impacts on the community, mainly by reducing the fish stock and impairing lake water quality and quantity. The effect of water hyacinth was stated by the key informants as follows.

"*…water hyacinth increases water evapotranspiration up to three times, prevents the entrance of sunlight and oxygen (causes fish species destruction), has high ion absorption capacity (leads to body mass reduction, diarrhea, reduction of meat and milk taste in livestock), harbors snakes, causes itching on human, and affects biodiversity including grass and other native macrophyte species*" (Regional office, KI-1). In addition, "*the weed causes water pollution due to decomposition*" (Wereda office, KI-2), "*leads to destruction of wetland areas, changes in the taste, odor and color of the water*" (Wereda office, KI-3), "*increases temperature*" (Community representative, KI-8) and "*causes reduction in entrepreneurship in fishing and transportation*" (Community representative, KI-10).

Cultural and religious activities, one of the important ecosystem services in Lake Tana, are also impacted by the infestation. The weed covers an enormous area that limits small and large size boats transportation to the islands. Lake Tana is said to have more than 37 islands and more than 30 monasteries on these islands. One of the key informants from the Kebele offices mentioned this problem: "*Lake Tana monasteries and churches are being surrounded by water hyacinth, and this prevents the transportation of people, including tourists*" (Kebele office, KI-5).

Existing water hyacinth management strategies

The key informant from the regional office said that, "*…in the last ten years, free service of labor-based water hyacinth management system was being implemented in Lake Tana with an estimated annual average man-day of 250,000–300,000.*

In 2019, Lake Tana and other water bodies protection and development agency was established, and a five-year strategic plan was proposed. An incentive payment of 150 ETB per man-day with an annual budget of 95 million ETB was started in 2020. We have implemented 85% water hyacinth collection without burning until March 2020. But the labor-based removal system was not as effective due to vicious-circle growth of the uncollected water hyacinth, high growth and multiplication capacity of water hyacinth (doubling within two weeks), and entrance of high amount of nutrients from upstream areas."

Key informants stated their views regarding the relevance of sustainable management of water hyacinths. The key informant from the wereda natural resource management office said that "*watershed management is one of the sustainable water*

TABLE 1 Bivariable (Model 1) and multivariable (Models 2 and 3) interval regression results of WTP for improving Lake Tana ecosystem services (*n*=183).

Variables		Model 1	Model 2	Model 3
Residence	URBAN	73.2 (32.5)**	130.1 (55.1)**	88.2 (29.2)**
Location (kebeles)	LOCTEHR&ADSZEMK4	154.4 (47.7)***	41.9 (53.2)	
	LOCBURA&ANGOT	34.9 (48.9)	9.6 (48.2)	
	LOCTIBG&YIFG	139.1 (43.6)***	62.1 (63.4)	
	LOCKAB&TEZMB	297.6 (47.9)***	73.3 (97.1)	
Educational level	EDUNOFORMAL	87.3 (41.0)**	56.8 (36.7)	59.5 (35.9)*
	EDUGRADE	139.6 (39.9)***	162.7 (45.5)***	169.5 (46.1)***
Age	AGE	0.73 (1.7)		
Household family size	FAMSIZE	16.1 (9.6)*	4.3 (9.0)	
Occupation	OCCFARM	43.2 (38.2)		
Work experience	Exp 11–20	60.6 (47.4)		
	Exp 21–30	45.2 (45.3)		
	Exp > 30	55.8 (61.8)		
Farm plot area	FARMAREA	100.0 (45.0)**	113.9 (30.9)	105.3 (30.0)***
Farm plot distance to Lake Tana	DISTANA>1Km	−211.6 (41.3)***	−33.8 (81.54)	−101.9 (46.4)**
Farm plot distance to Rib River	DISTRIB>1Km	36.6 (40.1)		
Main agricultural activity	AGRIMIXED	−83.4 (39.4)**	−60.8 (36.5)**	−42.2 (37.0)
Annual household income	INC 50,000–100,000	71.0 (40.4)*	3.3 (36.5)	9.5 (35.5)
	INC 100,000-150,000	199.9 (47.4)***	67.3 (47.5)*	76.8 (29.6)**
	INC > 150,000	299.6 (47.2)***	124.3 (51.3)**	139.7 (44.6)***
Water hyacinth related conference participation	YES	231.3 (36.0)***	132.8 (49.8)***	157.8 (48.6)***
Level of awareness	GOODAWAR	95.4 (34.8)***	25.5 (34.9)	
Constants	CONSTANTS		309.7 (115.8)***	391.6 (64.2)***

Significance levels *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

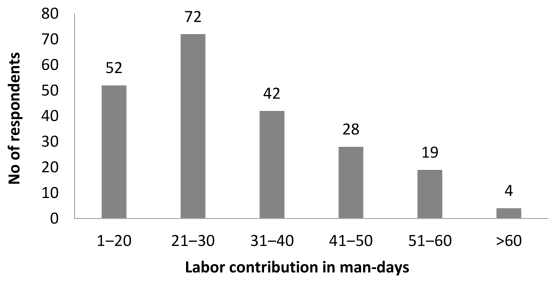

FIGURE 3
Annual maximum willingness to contribute labor (in man-days) for improving Lake Tana ecosystem services.

hyacinth management options by implementing afforestation, terracing, reducing overgrazing, reducing chemical usage in the upstream, and buffer zone delineation thus could reduce the nutrient loading into the Lake." In addition, the key informant from the regional office said "*watershed management program is the best solution for the sustainability of Lake Tana and water hyacinth management if it is properly implemented. Watershed management is one of the components of our five-year strategic plan. However, it requires a long time with high resource allocation and consciousness development.*"

Willingness to contribute to water hyacinth management

Community members, mainly those directly benefiting from Lake Tana ecosystem service, have been ready to participate in controlling the invasive weed since its emergence in 2011. However, the choice of contribution is different and depends on the individual's interest and ability. The community representatives (Kebele administrator, KI-9) said that, "*…the community has a strong commitment to participate and support the water hyacinth management either in cash and/or labor based on their preferences.*"

On the other hand, the key informants pointed out that some factors trigger the community not to contribute to watershed management voluntarily. Some of the reasons were "*low socioeconomic status*" (KI-4) and "*lack of awareness by the upstream community regarding the consequence of weed invasion*" (KI-6). It is also stated that "*some individuals believe that protecting the lake is the responsibility of the government, and thus they require benefit and reward for what they are doing against the weed*" (KI-7). In addition, "*inconsistent and reduced attention and effort by the government, including budget shifting to other activities, reduces the credibility of initiatives*" (KI-11). Moreover, some people perceive that "*water hyacinth infestation of Lake Tana would be a source of income for the local community; manual collection and removal of the weed is helping local people earn money*" (KI-4).

TABLE 2 Interval regression results of WTCL for improving Lake Tana ecosystem services (n=217).

Variables		Model 1	Model 2	Model 3
Residence	URBAN	−15.3 (1.9)***	−10.4 (3.7)**	−8.2 (2.5)***
Location (kebeles)	LOCTEHR&ADSZEMK4	1.2 (1.9)	6.5 (1.8)***	6.2 (1.9)***
	LOCBURA&ANGOT	2.6 (2.1)	3.9 (2.0)**	4.0 (1.9)*
	LOCTIBG&YIFG	1.5 (2.0)	8.8 (2.1)***	8.7 (1.8)***
	LOCKAB&TEZMB	24.2 (1.7)***	41.2 (8.5)***	43.2 (7.4)***
Educational level	EDUNOFORMAL	4.5 (3.2)*	4.1 (2.1)**	4.2 (2.1)**
	EDUGRADE	2.7 (3.3)	11.0 (2.2)***	11.4 (2.1)***
Age	AGE	0.02 (0.1)		
Household family size	FAMSIZE	0.9 (0.6)	1.0 (0.4)**	1.1 (0.4)**
Occupation	OCCFARM	7.6 (2.8)***	2.0 (5.2)	
Work experience	Exp 11–20	−2.1 (2.6)		
	Exp 21–30	3.1 (2.5)		
	Exp > 30	3.5 (4.5)		
Farm plot area	FARMAREA	0.7 (2.3)		
Farm plot distance to Lake Tana	DISTANA>1Km	−21.0 (1.6)***	−10.3 (7.6)*	−12.3 (6.6)*
Farm plot distance to Rib River	DISTRIB>1Km	1.7 (1.9)		
Main agricultural activity	AGRIMIXED	−3.1 (2.3)	0.1 (1.7)	
Annual household income	INC 50,000–100,000	−8.4 (2.9)***	−2.0 (1.7)	
	INC 100,000-150,000	−5.9 (2.8)**	0.4 (1.8)	
	INC > 150,000	−1.7 (2.8)	0.9 (1.8)	
Water hyacinth related conference participation	YES	21.1 (1.6)***	6.0 (3.6)*	6.0 (3.5)*
Level of awareness	GOODAWAR	10.8 (1.8)***	−0.6 (1.2)	
Constants	CONSTANTS		2.4 (2.3)*	2.8 (7.9)*

Significance levels *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$.

Discussion

The qualitative study findings indicated that infestation of the lake with water hyacinth has social, economic, and cultural impacts on the surrounding community. For instance, the key informants mentioned that it affected crop production by reducing the water quantity required for irrigation, fishing, water transportation, and other economic activities. The weed also disturbs the lake's ecological integrity by preventing the entrance of sunlight and oxygen, impacting aquatic species (e.g., fisheries and native macrophytes), decomposition, and resultant eutrophication. Our findings are consistent with the study reports by Enyew et al. (2020) and Damtie and Mengistu (2022). In line with a study by Enyew et al. (2020), the key informants confirmed that the infestation negatively affected their livelihood as many people depend on the natural resources and ecosystem services from the Lake.

Regarding its management, different measures have been taken to control water hyacinth infestation and reduce its multitude of threats (Shiferaw et al., 2018). Although physical (i.e., labor-based) and mechanical removal methods have been implemented in the last decade, neither of them brought the intended changes. The local community emphasized that for the sustainable management of water hyacinth, an integrated watershed management program is a superlative solution if it is properly implemented.

The quantitative study findings indicated that 32 and 39% of the respondents were willing to pay in cash and labor contributions, respectively, to prevent weed infestation. Our finding on cash contribution was slightly higher compared with the study report for the Lake Tana protection program (24%) (Van Oijstaeijen et al., 2020) and Lake Ziway restoration program (29.4%) (Girma et al., 2021). On the other hand, in the present study, the contribution by labor was lower than the previous similar study findings by Van Oijstaeijen et al. (2020) and Girma et al. (2021), which reported 56 and 63% contribution, respectively. During the key informant interview, the community representatives reflected that since Lake Tana is a life-sustaining resource for the surrounding community, they are positive about managing the infestation. However, the choice in terms of cash and/or man-days could be different depending on their economic status, living standard, location of the household relative to the lake, and awareness about the consequence of the water hyacinth. The quantitative results also indicated the same with residence, education, water hyacinth related conference participation, income, farm plot area and distance to Lake Tana being the significant factors influencing contributions in cash and labor.

The cash and labor contributions survey indicated that their willingness varies reasonably. For instance, a higher WTP was reported among households with a higher level of education, larger farm plot area, higher annual income, and good participation in water hyacinth-related conferences. The labor

survey also showed higher WTCL when a household is located near the lake and has more family size. Similar findings were also reported for a status-quo scenario in the same study system (Sewunet et al., 2022). Our findings are in agreement with other CVM studies (Van Oijstaeijen et al., 2020; Girma et al., 2021).

Considering the total number of households in the study area (58,856 households) (Libo-kemkem district administration, 2021), and 32% WTP and 39% WTCL, the cumulative contributions (WTP/WTCL) will be 11,917,916.24 ETB and 690,910 man-days per year, respectively. Compared with the previous findings based on the status-quo scenario, there is a 3,718,318 ETB and 176,056 man-days increase for the WTP and WTCL, respectively, for the proposed improvement scenario. The yearly aggregate WTP was 13.5% of the Ethiopian biodiversity institute budget (i.e., a recurrent budget of 74.5 million and a capital budget of 15 million ETB), which is aimed at managing the alien invasive weeds in the country (EBI, 2019). Therefore, if the hypothetical market and the watershed management program are realized, it could substantially support the activities being undertaken to remove the weed from the lake.

This study has limitations. Due to closed-ended property, the maximum WTP/WTCL of respondents' in the polychotomous questions were possibly influenced by the initial dichotomous bid questions. In addition, this study did not use follow-up questions for respondents who were against the hypothetical management program.

Conclusion

In this improvement scenario, an estimated yearly WTP and WTCL of 632.8 ETB and 30.1 man-days per household, respectively, were reported. This is equivalent to nearly 12 million Ethiopian birr and 700 man-days per year in the study area. The place of residence, educational status, farm plot area, household income, family size, and conference participation significantly influenced WTP and/or WTCL. Therefore, government officials in collaboration with local stakeholders, non-governmental organizations, and private sectors should design and implement powerful policies on watershed management activities, such as waste treatment, buffer zone delineations, pollution-reducing agricultural system, and multidisciplinary and scientific management options.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was approved by the institutional review board of the Wollo University, College of Medicine and Health Sciences. Written informed consent for participation was not required for this study in accordance with national legislation and institutional requirements.

Author contributions

BS, MG, and HG contributed to the study conception, tool preparation, and design. BS, MG, and SD performed the data collection and analysis. BS and HG wrote the first draft of the manuscript. SD, MG, and AL critically revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.1029170/full#supplementary-material

References

Anteneh, W., Tewabe, D., Assefa, A., Zeleke, A., Tenaw, B., and Wassie, Y. (2015). Water hyacinth coverage survey report on Lake Tana biosphere reserve. *Tech. Rep. Ser.* 2

Asmare, E., Demissie, S., Tewabe, D., and Endalew, M. (2016). Impact of climate change and anthropogenic activities on livelihood of fishing community around Lake Tana, Ethiopia. *E.C. Agric.* 3, 548–557.

Bires, Z., and Raj, S. (2019). Determinants of environmental conservation in Lake Tana biosphere reserve, Ethiopia. *Heliyon* 5:e01997. doi: 10.1016/j.heliyon.2019.e01997

Bires, Z., and Raj, S. (2020). Tourism as a pathway to livelihood diversification: evidence from biosphere reserves, Ethiopia. *Tour. Manag.* 81:104159. doi: 10.1016/j.tourman.2020.104159

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Cameron, T. A., and Huppert, D. D. (1989). OLS versus ML estimation of non-market resource values with payment card interval data. *J. Environ. Econ. Manag.* 17, 230–246. doi: 10.1016/0095-0696(89)90018-1

Chapungu, L., Mudyazhezha, O., and Mudzengi, B. (2018). Socio-ecological impacts of water hyacinth (Eichhornia Crassipes) under dry climatic conditions: the case of Shagashe River in Masvingo, Zimbabwe. *J. Environ. Public Health* 02, 36–52. doi: 10.26502/jesph.96120027

Crawford, P., Brown, B., and Majomi, P. (2008). Professional identity in community mental health nursing: a thematic analysis. *Int. J. Nurs. Stud.* 45, 1055–1063. doi: 10.1016/j.ijnurstu.2007.05.005

Damtie, Y. A., and Mengistu, D. A. (2022). Water hyacinth (Eichhornia crassipes (Mart.) Solms) impacts on land-use land-cover change across northeastern Lake Tana. *J. Indian Soc. Remote Sens.* 50, 975–986. doi: 10.1007/s12524-022-01504-z

Dersseh, M. G., Melesse, A. M., Tilahun, S. A., Abate, M., and Dagnew, D. C. (2019). "Water hyacinth: review of its impacts on hydrology and ecosystem services—lessons for management of Lake Tana," in *Extreme Hydrology Climate Variability*, 237–251. doi: 10.1016/B978-0-12-815998-9.00019-1

Dong, Y. *Contingent Valuation of Yangtze Finless Porpoises in Poyang Lake*. China: Springer Science and Business Media. (2012). doi:10.1007/978-94-007-2765-6.

EBI (2019). *Performance Audit Report of the Auditor General on the Ethiopian Biodiversity Institute's (Ebi) Action on the Management of Invasive Alien Weed Known as Water Hyacinth (Eichhornia Crassipses)*. Addis Ababa, Ethiopia.

Enyew, B. G., Assefa, W. W., and Gezie, A. (2020). Socioeconomic effects of water hyacinth (Echhornia crassipes) in Lake Tana, North Western Ethiopia. *PLoS One* 15:e0237668. doi: 10.1371/journal.pone.0237668

Gebrehiwot, M. (2020). Local ecological knowledge and wetland management in the Ethiopian Rift Valley. *GeoJournal* 87, 215–229. doi: 10.1007/s10708-020-10250-z

Girma, H., Hugé, J., Gebrehiwot, M., and Van Passel, S. (2021). Farmers' willingness to contribute to the restoration of an Ethiopian Rift Valley lake: a contingent valuation study. *Environ. Dev. Sustain.* 23, 10646–10665. doi: 10.1007/s10668-020-01076-3

IFAD (2007). *Community-Based Integrated natural resources Management Project in Lake Tana Watershed-Ethiopia. Ifad Project Document, Government of the Federal Republic of Ethiopia*. Addis Ababa.

Kebedew, M. G., Tilahun, S. A., Zimale, F. A., and Steenhuis, T. S. (2020). Bottom sediment characteristics of a tropical Lake: lake Tana, Ethiopia. *Hydrology* 7:18. doi: 10.3390/hydrology7010018

Makwinja, R., Mengistou, S., Kaunda, E., and Alamirew, T. (2022). Willingness to pay for the ecological restoration of an inland freshwater shallow Lake: case of lake Malombe, Malawi. *Heliyon* 8:e08676. doi: 10.1016/j.heliyon.2021.e08676

Ongore, C. O., Aura, C. M., Ogari, Z., Njiru, J. M., and Nyamweya, C. S. (2018). Spatial-temporal dynamics of water hyacinth, Eichhornia crassipes (Mart.) and other macrophytes and their impact on fisheries in Lake Victoria, Kenya. *J. Great Lakes Res.* 44, 1273–1280. doi: 10.1016/j.jglr.2018.10.001

Sewunet, B., Gizeyatu, A., Lingerew, M., Girma, H., Keleb, A., Malede, A., et al. (2022). On the use of contingent valuation method to assess factors affecting the contribution of local people for the management of water hyacinth in Lake Tana, northwestern Ethiopia. *Environ. Sci. Pollut. Res.* 13, 1–4. doi: 10.1007/s11356-022-21846-y

Shiferaw, W., Demissew, S., and Bekele, T. (2018). Invasive alien plant species in Ethiopia: ecological impacts on biodiversity a review paper. *Int. J. Mol. Biol.* 3, 171–178. doi: 10.15406/ijmboa.2018.03.00072

Van Oijstaeijen, W., Van Passel, S., Cools, J., de Bisthoven, L. J., Hugé, J., Berihun, D., et al. (2020). Farmers' preferences towards water hyacinth control: a contingent valuation study. *J. Great Lakes Res.* 46, 1459–1468. doi: 10.1016/j.jglr.2020.06.009

Venkatachalam, L. (2004). The contingent valuation method: a review. *Environ. Impact Assess. Rev.* 24, 89–124. doi: 10.1016/S0195-9255(03)00138-0

Wang, G., Mang, S., Cai, H., Liu, S., Zhang, Z., Wang, L., et al. (2016). Integrated watershed management: evolution, development and emerging trends. *J. For. Res.* 27, 967–994. doi: 10.1007/s11676-016-0293-3

Wondie, A. (2018). Ecological conditions and ecosystem services of wetlands in the Lake Tana area, Ethiopia. *Ecohydrol. Hydrobiol.* 18, 231–244. doi: 10.1016/j.ecohyd.2018.02.002

Worku, M. (2017). Lake Tana as biosphere reserve: review. *J. Tour. Hosp.* 6, 1–2. doi: 10.4172/2167-0269.1000310

Xu, X., Jiang, B., Tan, Y., Costanza, R., and Yang, G. (2018). Lake-wetland ecosystem services modeling and valuation: Progress, gaps and future directions. *Ecosystems* 33, 19–28. doi: 10.1016/j.ecoser.2018.08.001