Impact of water hyacinth on rural livelihoods: the case of Lake Tana, Amhara region, Ethiopia

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ABSTRACT

Water hyacinth covers a significant portion of Lake Tana affecting the livelihoods of thousands of rural households. The general objective of the study was to assess the impact of water hyacinth on the livelihoods of rural households living around Lake Tana. Quasi-experimental research design was applied to achieve the specified objectives of the study. Data was collected from 413 survey households, thirteen key informants, six focus group discussions and field observation. Descriptive statistics and propensity score matching (PSM) using STATA 15.0 were used for data analysis. Results of the study revealed that crop, livestock, and fishery production are the most important livelihood strategies of the study area accounting for 99.3, 95.2 and 9% of the sample households, respectively. The average annual crop production of the households was 2629.1 kg of rice equivalent. However, the weed affected the crop production of 34.1% of the sample households through covering the agricultural land and making the land preparation difficult. In addition, the weed affected 36.6% of the households’ livestock production. The impact was revealed in covering the grazing land, causing disease and/or death of the livestock and elevating the livestock production cost. Furthermore, water hyacinth was found as a reason for the reduction of fish population, blockage of fishing entry sites and disruption of the transport system. A statistically significant reduction of fish production, 45.7% in wet season and 49.9% in dry season, was generated because of water hyacinth. The PSM result showed that the water hyacinth significantly decreased the crop production (278.7–475.4 kg of rice equivalent) and livestock production (0.083–0.114 TLU) of the affected households. The study recommended management of water hyacinth to control the impacts on rural livelihoods and further studies towards medication of water hyacinth caused livestock diseases and the possible ways of the weeds consumption as a feed.

1. Introduction

Capital assets are invested by the people to employ diverse livelihood strategies with an interest in achieving their targeted livelihood outcome (Baumann and Sinha, 2001). According to Nicol (2000) water creates part of the required natural asset to run livelihoods by households. Though the extent varies from high to low, almost all livelihoods use water as an input (WB, 2006). The rural livelihood strategies could fail or impaired due to the existence of vulnerability contexts in water bodies. Because of high dependence on agriculture and animal husbandry, failure of crop and animal production will be devastating to the rural households (Wiseman et al., 2010). Water hyacinth among the aquatic invasive weeds delivers a significant threat to water resources that have an active economic engagement (Arp et al., 2017).

Water hyacinth, Eichhornia crassipes (Mart.) Solms, is an aquatic weed native to the Amazon in tropical South America (Labrada et al., 1995; Coetzee et al., 2017). It is a perennial aquatic herb belonging to a family Pontederiaceae (Herfjord et al., 1994; Practical Action, 2006; Patel, 2012; Jana, 2015). Water hyacinth is the worst aquatic plant on the earth with fast productivity capacity (Tham, 2012; Saleh, 2016). The weed is a fast grower which doubles its population within two weeks (Jana, 2015). Presently, it has conquered all tropical and subtropical countries of the world (Tham, 2012). The weed is becoming a critical challenge for a number of countries in the African continent including Ethiopia (Labrada, 1996). Water hyacinth is one of the 35 invasive weed species...
identified in Ethiopia (Shiferaw et al., 2018). The weed's appearance on Lake Tana, the largest Lake of the country, was declared in 2011 (Ejigu and Ayele, 2018; Kibret and Worqlul, 2018). Plentiful of negative impacts are posed by water hyacinth on aquatic ecosystems and local livelihoods with varied levels of influence (Patel, 2012; Rakotoarisoa et al., 2015).

Strategies are the ways in which households utilize and combine their assets to obtain food, income and other goods and services, in the context in which they live (WFP, 2009). The influence of the vulnerability condition ranges to the livelihood strategies that in turn hamper outcomes. The water hyacinth plays a similar role towards affecting households’ livelihood strategies. The water hyacinth weed negatively affects the activities of the people with direct and indirect dependence on the infested water bodies ecosystem (Ayalw et al., 2020). The hazards impact differs across livelihoods context and effective hazard impact assessment must be in consideration of livelihoods analysis (Lawrence et al., 2007). Therefore, local livelihood change analysis is vital to capture the impact of hazards on affected households (Lawrence et al., 2007; Vaitla et al., 2012).

Scholars from different disciplines attempt to capture the impact of water hyacinth on rural livelihoods. The works of Adan and Onywere (2010), Tewabae et al. (2017), Bufebo and Elias (2018), Hiruy (2019) and Alemu (2018) are examples on the issue. However, most of the available literatures on the impact of water hyacinth on livelihoods are qualitative. How far the hyacinth weed influenced the livelihoods is not well captured. In addition, these studies are conducted to observe the impact of the weed across some specific types of livelihood strategies. Specially, most of these studies were focused on fishery whereas crop and livestock production were left undiscovered. Meanwhile, fragmented studies on water hyacinth analysis have failed to display the full picture of the weed's impact on rural livelihood strategies.

Buwebo and Elias (2018) noted the importance of studying the livelihood impacts of invasive alien species including water hyacinth should be studied across the country, Ethiopia. Hence, further studies are required to maintain the water hyacinth to an unproblematic extent and sustain water bodies (Mengist and Mogens, 2019). In recognition of the gap points, it is vital to identify and estimate the rural livelihoods impact of water hyacinth across its infestation of water bodies along the plan and implementation of its management strategies. Research projects on water hyacinth impacts are critical to broaden the existing knowledge on invasive species (Villamagna and Murphy, 2010). For that reason, the purpose of this study was designed to analyze the impacts of water hyacinth on rural livelihoods with evidence of its abundance in Lake Tana water body of Amhara national regional state in Ethiopia.

2. Study area description

The study area, Lake Tana, is a tropical lake situated in the north-western part of Ethiopian highlands (Vijverberg et al., 2009). Lake Tana is about 563km far from Addis Ababa which is the capital city of Ethiopia (UNESCO, 2015). Administratively, the lake is found in the Amhara National Regional State (ANRS) of Ethiopia. The absolute location of the lake extends from 11°25'07"-12°29'18" north and 36°54'01" - 37°47'20" east (UNESCO, 2015). Lake Tana is the largest lake in the country and it is found at an altitude of 1830m above sea level (Vijverberg et al., 2009; Mundt, 2011). The average temperature of the Lake Tana basin is 20 °C (Abebe et al., 2017) while the rainfall of the basin extends from 816 up to 2344mm (ADSWE, 2015). Lake Tana basin is a home for numerous biodiversity resources. The basin delivers a comfortable place for various flora and fauna. Cultural heritages and waterfalls in the Blue Nile basin are well acknowledged and are good sources of the region’s economy (Mundt, 2011). Lake Tana basin holds an endemic fish species that are unique across the world. Among 27 fish species in the Lake Basin, 20 of them are endemic to the area (Tewabe, 2015).

Like the rest of the country, 88.6% of the population in Amhara National Regional State reside in rural areas and their economy is dependent on subsistence agriculture (ANRS, 2011). As a natural resource, Lake Tana supports the settlement and livelihoods of many people. About 2 million people live near Lake Tana and its catchment including the town of Bahir Dar (Vijverberg et al., 2009). In other information, Ejigu and Ayele (2018) pointed out that Lake Tana and its watershed provides livelihood security for 5 million people. More specifically, Lake Tana and neighboring wetlands deliver a livelihood for more than 500,000 people both directly and indirectly (Vijverberg et al., 2009). The Lake supports various livelihoods though agriculture is the dominant one (Goshu and Aynalem, 2017). Among the different livelihood strategies, fishing is the major livelihood of the surrounding people. However, because of different natural and human made calamities these resources are in danger not only the fish resource but also the entire lake as well.

Livelihoods are influenced by locations and resources available in the area that determine opportunities available to the people (Ajala, 2008). Patterns of livelihoods are usually shown in livelihood zone maps and it is the first step for livelihood based analysis (PEG, 2006). Livelihood zone is a geographical area at which people engage in the same pattern of livelihoods and access to market (Holzmann, 2008). According to a report generated by USAID (2018) areas around Lake Tana fall under two livelihood zones: Tana Zuria Livelihood Zone (TZA) and Tana Zuria Rice Livelihood Zone (TZR) (see Figure 1). The two livelihood zones used to be one primarily and letter on split into two in recognition of the rice production which is a distinctive characteristic for TZR (USAID, 2017).

3. Methodology

Quasi-experimental research design was applied to achieve the objective of the study. Combinations of different methods of research, what Murray (2001) called mixed methods research are effective in conducting livelihood research. Hence, both qualitative and quantitative research methods were applied for the livelihoods analysis. The study was conducted in Lake Tana because of two reasons. Primarily, high proliferation of water hyacinth is available on Lake Tana (Ejigu and Ayele, 2018; Kibret and Worqlul, 2018). Secondly, the study fills the multidisciplinary and quantitative data needed on Lake Tana towards the weed and its impacts (Asmare, 2017; Shiferaw et al., 2018). The study used multi-stage sampling techniques to select the sample households. Firstly, two districts (Fogera and Gondar Zuria) among the nine districts affected by water hyacinth were selected randomly. Secondly, from the thirty rural kebele administrations (RKAs) six RKAs that are adjacent to the lake were randomly selected. Finally, the systematic random sampling technique was used to select the sample households proportionally to the total population. The sample size determination formula forwarded by Cochran (1963) when target population is unknown was used to set the sample size. Based on the equation the minimum sample size was found as 384. Key informants and focus group discussants were selected purposively from offices and RKAs that are related to the issue of water hyacinth.

Primary data were collected from household survey, key informants interview, focus group discussion and observation. To assess the impact of water hyacinth on rural livelihoods, a survey on 413 randomly selected households was practiced. The survey involved 220 water hyacinth infested and 193 non-infested households. Beside six focus group discussions, one per sample RKA, were employed with community representatives. In addition, thirteen interviews were conducted with experts and officials working on the issue of water hyacinth and rural livelihoods. Furthermore, direct observations were conducted to cross check the data obtained from the other data collection sources. The observations were made on water hyacinth infested areas to visualize the weeds characteristics and its impact on the rural livelihoods. Data of the study was collected from May 20-30, 2021. In addition, document review was conducted to collect data from articles, reports and other documents from government offices written on the issue of water hyacinth and rural livelihoods to capture secondary data and complement the primary.
sources. The reviewed articles were selected based on being published in reputable journals and not being old. Reports and government documents were taken from credible sources.

The best picture of livelihoods can be witnessed at individual and household level. Individuals can engage in various activities, however, the real impacts of these activities are shown at household level (Messer and Townsley, 2003). Thus, the level of analysis in this study was household. Holzmann (2008) noted that the effects of water hyacinth as a shock are specific to different livelihoods. Varieties of livelihood strategies are available and it is the responsibility of the investigators to choose the most appropriate one to the context of the study. Considering the different livelihood strategies, this study analyzed the impact of the weed on crop, livestock and fishery production in the area.

There is no simple algorithm for the measurement of livelihoods (Scoones, 1998). In consideration of a difficulty in measuring the livelihoods, the study selected appropriate analysis methods. Quantitative data analysis pertaining the effect of water hyacinth on rural livelihood was analyzed by using descriptive statistics such as percentage, frequencies and tables. The crop production of the households was measured by rice equivalent while tropical livestock unit (TLU) and kilogram respectively measured the livestock and fishery productions. Propensity score matching model (PSM) was applied to show the impact of water hyacinth on rural livelihoods. The PSM analysis was conducted the by psmatch2 analysis program using STATA 15.0 analysis software. However, the impact of the weed on fishing was not analyzed by PSM because the weed affects all of the fish producer households and it was not possible to have a control group. Therefore, paired sample t-test was applied to compare the fish production difference before and after water hyacinth introduction. In addition, an independent sample t-test was used to assess the significance of crop and livestock production difference on the water hyacinth affected and non-affected households. Thematic analysis was used in order to triangulate the quantitative data collected from the survey. It was used for elaboration of analysis that numbers do not give complete description of the phenomena at data analysis and interpretation stage.

### 3.1. Livelihood production estimation methods

The crop production of the households was expressed in terms of rice equivalent in kg. Summation of different crop types with a difference in price and nutrient value is meaningless. Therefore, we need to project the crop production into a common product. For this study, the crops of diverse types were transferred into rice equivalent due to two main reasons. Primarily rice is an international crop and secondly it is a widely cultivated crop in the study area with the majority of the households. The calorie values of the crop types taken from EHNRI (1998) and WFP (2000) were vested to estimate the rice equivalent of the crops. The following equation was used to estimate the rice equivalent of each crop

\[
\text{Rice equivalent of crop in kg} = \frac{\text{Quantity of crop in kg} \times \text{Calorie of crop}}{\text{Calorie of rice}}
\]

The livestock production of the rural households was measured in terms of Tropical Livestock Unit (TLU). A livestock conversion factor given by Storck et al. (1991) was used to construct the TLU. In addition, the fishery production of the households was estimated in kilograms of fish catch per annum.

### 3.2. Propensity score matching (PSM) model

The PSM model was used to show the difference in livelihoods outcome among water hyacinth affected and non-affected households residing around Lake Tana. This model was selected because there is no baseline data to compare the impact of water hyacinth in the study area and to reduce participant’s selection bias. The PSM analysis was conducted in consideration of the five steps of PSM recommended by Caliendo and Kopeinig (2005) that are stated below.
Estimating the Propensity Score: Propensity score estimation is the primary step in the implementation of PSM (Heinrich et al., 2010a). Two basic decisions must be done in the propensity score estimation. The first decision is towards the selection of the model for the score estimation while the second is determination of variables to be included in the model (Caliendo and Kopeinig, 2008). For dummy treatment variables (1 water hyacinth affected and 0 non-affected) logit and probit models are frequently used for propensity score estimation and show no strong difference is available between the two models (Heinrich et al., 2010a). For this study, a probit model was selected to estimate the propensity score after checking the fitness of both probit and logit models on the data of the study. The multicollinearity problem was detected by variance inflation factor (VIF) for continuous variables and contingency coefficient (CC) for the categorical variables. Furthermore, the fitness of the model was checked by a goodness-of-fit test to assess whether the model fit to this type of data or not.

Impact evaluation analysis through PSM requires three types of variables: treatment, outcome and covariates. Based on the investigators knowledge on previous empirical studies and institutional situations, the variables were selected for the model. As shown in Table 1, the study identified the treatment, outcome, and covariate variables with their appropriate level of measurement.

Matching Algorithms Choice: Next to propensity score estimation, the researchers have to choose the matching algorithm. Matching of water hyacinth affected and non-affected group households can be conducted based on propensity scores using various matching algorithms: nearest neighbor, caliper matching, radius matching and kernel matching (Heinrich et al., 2010a). In this study, the choice of matching algorithm was built on the performance criteria such as number of insignificant variables after matching, low pseudo R² after match, high number of matched sample size and lower standard bias.

Check Overlap/Common Support: The common support condition was determined after the treatment and control groups property scores are plotted. Sample households in regions without overlap were excluded from the coming analysis (Jalan and Ravallion, 2003). The overall region of the control and treatment groups can be observed using the mirror histogram and density distribution plots of the two group propensity scores (Heinrich et al., 2010a; Staffa and Zurawkowski, 2018). Households beyond the region of common support were removed from the analysis. This study managed identification of common support region among treatment and control groups by using maximum and minimum values.

Matching Quality Evaluation and Effect Estimation: Balancing tests were conducted to check the balanced distribution of the covariates across the water hyacinth affected and non-affected groups. The purpose of the tests is to check the balance of the propensity scores distribution across the two groups. The common tests to check the matching quality of the PSM model are standardized bias, t-test, stratification test, joint significance and Pseudo-R².

The percentage of covariates bias reduction was calculated as 100 (1-Bias after matching/Bias before matching). After matching of the covariates, bias reductions beyond 20% are taken as large (Rosenbaum and Rubin, 1985). A two-sample t-test was used to check if there are significant differences between the means of the covariates of both the treated and control groups. Although some level of statistically significant difference can be found before matching, it is not expected after matching since the covariates balance the treatment and control groups. The t-test aims to measure the statistical significance of the two groups (Caliendo and Kopeinig, 2005).

The sensitivity test categorize the propensity scores of the treatment and control group households in to blocks of equal score range and checks for the existence of the statistically significant difference across the mean score of the two groups blocks using t-test (Dehejia and Wahba, 2002; Caliendo and Kopeinig, 2005). Finally, the joint significance and pseudo-R² were checked. The pseudo-R² result indicates the extent of being water hyacinth affected explained by covariate regressor variables. Low pseudo-R² and insignificant joint effect is expected after matching of the propensity scores (Caliendo and Kopeinig, 2005).

The result of impact estimation cannot be interpreted without the standard errors that deliver the level of errors in the estimates generated. However, analysis of treatment significance and the level of standard errors is not an easy task. This is due to the fact that estimation of treatment effect variance requires estimation of variance from propensity score generation, common support region selection and the order of the treated individuals matching (Caliendo and Kopeinig, 2005; Heinrich et al., 2010b). Usually the bootstrapping method is applied to obtain the standard errors in PSM analysis. In general, the bootstrap relies on sampling from the analysis sample with replacement, replicating the analysis multiple times. The standard error is the standard deviation of the estimated-impact estimate across replications (Heinrich et al., 2010a). In this study, standard error was estimated by bootstrapping with 100 replications.

Sensitivity Analysis: Some variables will be affected by water hyacinth treatment (outcome) while others will not be affected at all (covariate). Difference among water hyacinth affected and non-affected households before the treatment is an overt bias and shall be measured where failure to capture the pretreatment difference will result in hidden bias. The PSM analysis shall successfully identify and measure covariate and outcome variables. The extent of the hidden bias influence on the impact estimation generated is tested by sensitivity analysis (McFadden, 2015). The bounding approach (bounds) was used to analyze the influence of the hidden bias on the matching conducted. The analysis was computed only for significant outcome variables.

4. Results and discussion

Water hyacinth impact analysis was conducted in three rural livelihood strategies: crop production, livestock production and fishery that
have direct link with water hyacinth. The analysis was managed by using the descriptive statistics and propensity score matching (PSM) econometric model.

4.1. Agricultural production in Lake Tana

The study area is under Tana Zuria Rice (TZR) and Tana Zuria (TZA) livelihood zones. The two livelihood zones used to be under the same livelihood zone and they share similar characteristics. The demarcation was done in recognition of rice production which is typical in Tana Zuria Rice livelihood zone (USAID, 2017). Crop production is the backbone of the rural households economy in the study area and 99.3% of the households were found engaged in the strategy. The characteristic of production is mostly traditional using animal power and small equipment despite some use of fertilizer, pesticide and herbicides. The study sample households possessed a mean agricultural land of 0.91ha and 0.34ha of irrigated land.

The rich water resources in Lake Tana and the surrounding areas enable the households to practice irrigation and flood recession agriculture beside the rain-fed one. The Lake Tana by itself and its tributaries of Reb and Gumara help 59% of the households to practice small-scale irrigation. In addition, about 20% of the households were found engaged in recession agriculture. The common productions in the study were onion, rice, maize, teff, chickpea and garlic in descending order of production quantity. The production of all the crops was converted into rice equivalent and the crop production of the households was estimated as 19819.3 ETB per annum. A study conducted by Hiruy (2019) has also reported a reduction in productivity and quantity of crop production due to water hyacinth invasion on agricultural lands.

Livestock is the second most important livelihood in Lake Tana surrounding areas and 95.2% of the respondents practice this strategy. The study area is familiar with the well-known cattle variety, Fogera breed.

Table 2. Crop production among water hyacinth infested and non-infested households.

| Type of crop | Water hyacinth Mean production (n = 409) |
|--------------|------------------------------------------|
|              | Non-affected (n = 273) | Affected (n = 136) |
| Rice         | 983.4 | 613.3 | 860.4 |
| Maize        | 362.4 | 257.0 | 327.4 |
| Sorghum      | 172.4 | 49.0  | 131.4 |
| Finger millet| 87.6  | 44.2  | 73.2  |
| Teff         | 291.2 | 391.7 | 324.6 |
| Wheat        | 4.5   | 5.9   | 4.9   |
| Oats         | 6.3   | 0     | 4.2   |
| Horse bean   | 70.4  | 23.0  | 54.6  |
| Sunflower    | 12.4  | 1.7   | 8.8   |
| Lentil       | 4.6   | 0.7   | 3.3   |
| Chickpea     | 359.6 | 128.2 | 282.7 |
| Vetch        | 81.8  | 27.1  | 63.7  |
| Potato       | 60.5  | 27.6  | 49.6  |
| Pepper       | 10.8  | 3.2   | 8.3   |
| Coffee       | 0.9   | 2.3   | 1.4   |
| Tomato       | 290.2 | 10    | 197.0 |
| Garlic       | 285.9 | 257.5 | 276.5 |
| Onion        | 1004.3| 1018.1| 1008.9|
| Rice equivalent | 3043.1| 1798.1| 2629.1|
| t-test       | 1.878* |

* Significant at less than 10% probability level.

Table 3. Livestock production of water hyacinth infested and non-infested households.

| Type of livestock | Water hyacinth Mean production (n = 393) |
|-------------------|------------------------------------------|
|                   | Non-affected (n = 246) | Affected (n = 147) |
| Cow               | 1.24 | 1.12 | 1.20 |
| Ox                | 1.43 | 1.25 | 1.36 |
| Heifer and Bull   | 0.71 | 0.73 | 0.72 |
| Weined calf       | 0.46 | 0.39 | 0.44 |
| Calf              | 0.56 | 0.51 | 0.54 |
| Horse/Mule        | 0.01 | 0.02 | 0.02 |
| Donkey (Adult)    | 0.49 | 0.46 | 0.48 |
| Donkey (Young)    | 0.20 | 0.24 | 0.21 |
| Sheep and Goat (adult) | 0.89 | 0.54 | 0.76 |
| Sheep and Goat (young) | 0.56 | 0.27 | 0.45 |
| Beehives          | 0.21 | 0.17 | 0.19 |
| Chicken           | 9.78 | 3.14 | 7.30 |
| TLU               | 4.19 | 3.74 | 4.02 |
| t-test            | t = 1.6779* |

* Significant at less than 10% probability level.
fragile. The results of this study towards crop production are similar to what has been reported by Tewabe et al. (2017). In line with this finding, Alemu (2018) has reported that water hyacinth makes agricultural land preparation difficult and demands an extra labor force.

As of the crop production, the impacts of the weed were shown on livelihood production too. Among the households engaged in livestock production, 36.6 % have reported the influence of the weed in this strategy. The impact of the weed on the livestock sector was manifested in different forms. Since 84.5% of the households practice free grazing based livestock production, the existence of private and communal grazing land is necessary. However, 29.3% of the respondents reported that the weed covers and destroys their grazing land that lead them to interrelated complex problems: purchasing of supplementary feed, consumption of the weed as a feed, sickness and death of livestock. The coverage of grassland by the weed enforces the rural households to purchase supplementary feed to complement the grassland gap. The households invested a mean of 1546.6 ETB to purchase the supplementary feed that replaces the lost grassland due to the weed coverage. The weed also clogs the watering points of our livestock and it forces us to travel further to find water for the livestock.

On the other hand, 33.7% of the households let their livestock feed the weed despite already knowing that the weed is not suitable for the livestock (see Figure 3). In this regard, one focus group discussant aged 30 years from Wagetera rural kebele administration stated the problems in the following ways.

I allow my livestock to feed Enboch [water hyacinth] though the weed is not suitable for their health. I did it deliberately because I do not have any choice to survive my livestock. This is due to the fact that my grazing land is totally covered by this dangerous weed. Unless the community including me fights against the weed, I may not have livestock for the future. However, my livelihood is totally dependent in one way or the other on the livestock and livestock products (Focus group participant, 2021).

Tewabe (2015) differently presented that the livestock shall not directly feed the water hyacinth weed, since it has a high amount of tannin content despite 95% of the weed is water. The intercellular space of water hyacinth that is filled with air is also believed to be the cause of livestock disease manifested in the gut bloating and continuous diarrhea. In order to remove similar impacts cutting of the weed into pieces that help to remove the air contained in the weed stake is recommended. The weed is also blamed for creating a suitable environment and increasing the breeding of the internal parasites in the lake and surrounding wetlands that are responsible for weight loss and death of the livestock (Ayalew et al., 2020).

The non-suitability of the water hyacinth weed was understood as a cause of sickness and death for many of the livestock. The 30% of sample households reported that they have visited veterinary service for weed caused diseases and cost an average of 317.6 ETB for the medication of their livestock. Furthermore, 18.2% of households witnessed a death of livestock because of water hyacinth and the mean estimated cost of the loss was 19026.6 ETB. In addition, the weed was found responsible for the reduction of livestock productivity. Hiruy (2019) in his study at Lake Tana showed that feeding of water hyacinth weed was resulted in sickness of livestock, thinning of excrement and tastelessness of milk. A key informant aged 40 from Nabega rural kebele administration noted the situation as follows.

Many households visit our animal health center in need of water hyacinth caused by livestock medication. Unfortunately, the types of diseases occurring to the livestock due to the weed are not well understood.
The survey results revealed that the fish production is usually implemented by canoe and gill net while some people used motor boats, cast net (menae), fyke net (keffo), fishing hock (mekaten) and others for the purpose. Even though there are many fish varieties in the lake, the common types of fish caught are Tilapia, Catfish and Labeobarbus. Most of the fishers engaged in fishing as a part-time job besides crop and livestock activities. According to Kibret (2017), the current fish production in Lake Tana is about 1000 tons despite having a potential of 13,000 tons of production. These days, the reduction of fish production is strongly supported by the existence of water hyacinth in the lake environment.

Among the total respondents, 9% were found engaged in fishing. In contrast, 24% of the respondents used to be fishers ahead of water hyacinth introduction in Lake Tana. The result revealed the decrease in the number of fishers in Lake Tana surrounding households and water hyacinth appear as a major reason to halt fishing in the study area. Despite lack of interest in fishing, reduced fish stock, increased fishing cost and personal problems were also contributing factors for the decreased number of fishers; water hyacinth took the lion share pointed out by 61.4% of the ex-fisherman respondents. The households abandoned the fishery livelihood because of a number of serious problems triggered by the water hyacinth weed.

The current fisheries have an ample experience in fishing ranging from one up to thirty years with an average experience of 9.3 years. The key informants’ interview and the survey result showed that there is a reduction in the quantity of fish catch and income gained from the strategy. The extent of mean fish production decline was 37.3kg in wet season and 35.9kg in dry season per each catch day. The reduction covers 45.7% and 49.9% of the total production both in wet and dry seasons, respectively. The paired sample t-test result revealed that the amount of fish production during the study period, 2021, has shown a statistically significant reduction as compared to before water hyacinth production both in wet and dry season (Table 4). The extent of fish production decline in this study is higher than a reduction of 13kg per catch day reported by Ayalew et al. (2020) in Lake Tana though the proportion of fish catch reduction (46.4%) was almost similar. The possible reason for the high disparity could be the type of fish producers included in the study. In this study, most of the fishers with small equipment and canoe were out of business and the one included in the study are fishers with the better capacity including boats. On the other hand, the households who have stopped fishing due to water hyacinth have reported an estimated annual income loss of 1,000 to 50,000 ETB per annum (mean = 16, 089ETB) from fishing.

One possible reason for the decline of fish catch in the study is the reduction of fish population in the area. The proliferation of the weed on the lakeshore, the tributary river mouths and wetlands are responsible for the fish population and fish catch reduction in the area. Despite a variety of fish species available in the lake, Oreochromis niloticus and Labeobarbus were the most seriously affected species (Ayalew et al., 2020). The lakeshore is a suitable area for the reproduction of fish because of its warm temperature, low wave disturbance and better existence of nutrients that are the feed of the fish. However, the water hyacinth weed is also located in the lakeshore with high amounts and affects the fish reproduction. The dense mates of water hyacinth around the lakeshore makes the fish entangle and destruct the migration of fish to their spawning habitat. In addition, the fast growth of the weed occurs with the consumption of nutrients which are also a fish feed (Alemu, 2018; Ayalew et al., 2020). Therefore, the reproduction of the fish becomes difficult in water hyacinth infested areas of the lake and even the fish become dead or small in size because of the weeds tick biomass and long roots (Alemu, 2018).

The other major challenge faced by water hyacinth is the blocking of the fishing ground access points. The huge mates of the weed laid on the lakeshore cover the entry points to the lake. Around 8.5% of the

| Season               | Before water hyacinth | After water hyacinth | Difference | Paired t-test |
|----------------------|-----------------------|----------------------|------------|---------------|
| Wet (rainy) (May–October) | 81.7                  | 44.4                 | 37.3       | 2.6670**      |
| Dry (November–April)  | 71.9                  | 35.9                 | 35.9       | 3.6549*       |

**P < 0.05, *P < 0.1.

4.3. Impact of water hyacinth on fishery production

The survey results revealed that the fish production is usually implemented by canoe and gill net while some people used motor boats, cast net (menae), fyke net (keffo), fishing hock (mekaten) and others for the purpose. Even though there are many fish varieties in the lake, the common types of fish caught are Tilapia, Catfish and Labeobarbus. Most of the fishers engaged in fishing as a part-time job besides crop and livestock activities. According to Kibret (2017), the current fish production in Lake Tana is about 1000 tons despite having a potential of 13,000 tons of production. These days, the reduction of fish production is strongly supported by the existence of water hyacinth in the lake environment.

Among the total respondents, 9% were found engaged in fishing. In contrast, 24% of the respondents used to be fishers ahead of water hyacinth introduction in Lake Tana. The result revealed the decrease in the number of fishers in Lake Tana surrounding households and water hyacinth appear as a major reason to halt fishing in the study area. Despite lack of interest in fishing, reduced fish stock, increased fishing cost and personal problems were also contributing factors for the decreased number of fishers; water hyacinth took the lion share pointed out by 61.4% of the ex-fisherman respondents. The households abandoned the fishery livelihood because of a number of serious problems triggered by the water hyacinth weed.

The current fisheries have an ample experience in fishing ranging from one up to thirty years with an average experience of 9.3 years. The key informants’ interview and the survey result showed that there is a reduction in the quantity of fish catch and income gained from the strategy. The extent of mean fish production decline was 37.3kg in wet season and 35.9kg in dry season per each catch day. The reduction covers 45.7% and 49.9% of the total production both in wet and dry seasons, respectively. The paired sample t-test result revealed that the amount of fish production during the study period, 2021, has shown a statistically significant reduction as compared to before water hyacinth production both in wet and dry season (Table 4). The extent of fish production decline in this study is higher than a reduction of 13kg per catch day reported by Ayalew et al. (2020) in Lake Tana though the proportion of fish catch reduction (46.4%) was almost similar. The possible reason for the high disparity could be the type of fish producers included in the study. In this study, most of the fishers with small equipment and canoe were out of business and the one included in the study are fishers with the better capacity including boats. On the other hand, the households who have stopped fishing due to water hyacinth have reported an estimated annual income loss of 1,000 to 50,000 ETB per annum (mean = 16, 089ETB) from fishing.

One possible reason for the decline of fish catch in the study is the reduction of fish population in the area. The proliferation of the weed on the lakeshore, the tributary river mouths and wetlands are responsible for the fish population and fish catch reduction in the area. Despite a variety of fish species available in the lake, Oreochromis niloticus and Labeobarbus were the most seriously affected species (Ayalew et al., 2020). The lakeshore is a suitable area for the reproduction of fish because of its warm temperature, low wave disturbance and better existence of nutrients that are the feed of the fish. However, the water hyacinth weed is also located in the lakeshore with high amounts and affects the fish reproduction. The dense mates of water hyacinth around the lakeshore makes the fish entangle and destruct the migration of fish to their spawning habitat. In addition, the fast growth of the weed occurs with the consumption of nutrients which are also a fish feed (Alemu, 2018; Ayalew et al., 2020). Therefore, the reproduction of the fish becomes difficult in water hyacinth infested areas of the lake and even the fish become dead or small in size because of the weeds tick biomass and long roots (Alemu, 2018).

The other major challenge faced by water hyacinth is the blocking of the fishing ground access points. The huge mates of the weed laid on the lakeshore cover the entry points to the lake. Around 8.5% of the

Figure 4. Fishing boat stacked in thick water hyacinth mat. Source: Image taken during field observation, 2021.
### Table 5. Probit regression model results of water hyacinth on crop and livestock production.

| Covariate Variables | Crop production (N = 409) | Livestock production (N = 393) |
|---------------------|---------------------------|-------------------------------|
|                     | Coef. Std. Err.           | Coef. Std. Err.               |
| Sex of HH           | -0.525 0.356             | 0.009*** 0.004                |
| Age of HH           | 0.011** 0.006             | 0.009 0.012                   |
| Education of HH     | -0.074 0.086              | -0.078 0.086                  |
| Family size         | 0.003 0.035               | -0.012*** 0.002               |
| DLake Tana          | -0.012*** 0.002           | -0.011*** 0.003               |
| DAnimal health      | -0.001 0.003              | -0.001 0.003                  |
| DSchool             | -0.006 0.004              | 0.009*** 0.004                |
| DWater              | -0.006 0.008              | -0.006 0.007                  |
| DMarket             | 0.002 0.002               | 0.002 0.002                   |
| DRoads              | 0.000 0.001               | 0.000 0.001                   |
| DLivelihood zone    | -1.228*** 0.197           | -0.530*** 0.190              |
| cons                | 0.228 0.553               | 0.292 0.197                   |

**P < 0.05, ***P < 0.01, D-Distance, HH-Household Head.

### 4.4. Econometric model results

The impact of water hyacinth on crop and livestock production was estimated using a propensity score matching (PSM) model. The weed impact on the crop and livestock production of the households was found different. In this regard, two separate PSM analyses were conducted to reveal the impacts of water hyacinth on the two rural livelihoods.

#### 4.4.1. Estimation of propensity scores

The probit regression models were employed to estimate the propensity scores using 12 covariate variables. The matching of the water hyacinth affected and non-affected group households were managed using the propensity scores generated. Before running the regression analysis, the correlation problem among variables was checked by variance inflation factor (VIF) and contingency coefficient (CC) multi-collinearity tests. The tests showed that there was no strong correlation among explanatory covariate variables. Classification tables, the Hosmer and Lemeshow test, pseudo R² and Pearson chi-square test were used to observe the fitness of the model. The Pseudo R² values of the two outcome variables (crop production and livestock production) explained 22.9% and 18.4% of the total variations of the models, respectively. In addition, the likelihood ratio of the results of the two outcome variables was P < 0.01 significance level indicating that the models are fitted to run the regression analysis.

The probit model showed the pseudo R² value for the crop and livestock productions were 0.2292 and 0.1839, respectively. This implies that the covariate variables in the two probit models represent 22.92% and 18.39% of the total variance of being impacted by water hyacinth. In addition, the likelihood ratio of the results was significant at less than one percent probability level for both crop and livestock production models which indicates the significance of the models to run the regression analysis.

The probit regression model (see Table 5) showed that the impact of water hyacinth on the crop production was determined by distance to Lake Tana and being in Tana Zuria (TZA) livelihood zone negatively while age of the household age and distance to animal health center affect it positively. On the other hand, livestock production impact of the weed was significantly influenced by only two variables negatively: distance to Lake Tana and being in Tana Zuria (TZA) livelihood zone.

#### 4.4.2. Common support identification

The PSM analysis is based on an assumption of enough regions of common support among the affected and non affected households. The region of common support for the affected and non-affected households was identified by looking for the maximum-minimum values. Those households beyond the region were excluded from the analysis. As Table 6 shows the mean propensity scores for the crop and livestock PSM analysis were 0.335 and 0.374 in order of their appearance. The region of common support was 0.058–0.973 for crop impacts analysis and 0.068 to 0.935 for the livestock production impacts analysis. Among the total sample, 24 treated households in the crop impact analysis and 6 from livestock impact analysis were found off-support and excluded from the analysis.

### Table 6. Propensity scores distribution.

| Rural livelihood | Group | Number of HHs | Observations | Matched | Off support | Propensity score | Mean | Std. Dev |
|------------------|-------|---------------|--------------|---------|-------------|-----------------|------|----------|
| Crop production  | Total | 409           | 385          | 24      | 0.335       | 0.245           |
|                  | Treatment | 136 | 112          | 24      | 0.515       | 0.251           |
|                  | Control | 273 | 273          | 0       | 0.246       | 0.185           |
| Livestock production | Total | 393 | 387          | 6       | 0.374       | 0.229           |
|                  | Treatment | 147 | 141          | 6       | 0.512       | 0.215           |
|                  | Control | 246 | 246          | 0       | 0.292       | 0.197           |
Table 7. The joint significant test result.

| Rural livelihood | Sample | Pseudo R² | LR chi² | P > chi² | Mean Bias | Med Bias |
|------------------|--------|-----------|---------|----------|-----------|----------|
| Crop production  | Unmatched | 0.229 | 119.24 | 0.000 | 30.6 | 25.7 |
|                  | Matched | 0.010 | 3.070 | 0.995 | 5.8 | 4.1 |
| Livestock production | Unmatched | 0.184 | 95.54 | 0.000 | 33.9 | 17.9 |
|                  | Matched | 0.012 | 4.78 | 0.965 | 3.9 | 3.2 |

Table 8. Impact of water hyacinth on rural livelihoods.

| Outcome variable | Matching algorithm | Water hyacinth | Difference (ATT) | Std Error¹ | t-test |
|------------------|-------------------|---------------|------------------|------------|--------|
|                  |                   | Affected      | Non-affected     |            |        |
| Crop production  | NNM               | 1379.6        | 1855.0           | -475.4     | 263.3  | -1.99* |
|                  | RM                | 1379.6        | 1658.3           | -278.7     | 263.3  | -1.56* |
|                  | KM                | 1379.6        | 1658.3           | -278.7     | 263.3  | -1.56* |
| Livestock production | NNM | 3.74 | 3.84 | -0.101 | 0.355 | -0.27* |
|                  | RM                | 3.74 | 3.85 | -0.114 | 0.355 | -0.40* |
|                  | KM                | 3.74 | 3.82 | -0.083 | 0.355 | -0.27* |

¹P < 0.1.
Source: computed from survey data (2021).
ⁱ The S.E. is estimated with bootstrapping of 100 replications.

4.4.3. Matching quality test

The quality of the matching is the guarantee to run the impact estimation across the water hyacinth affected and non-affected households. The balancing test aimed to assess the premise: the distribution of the covariates after the matching shall be the same after the matching of the propensity scores. Different testing procedures ensured that the estimations’ balancing powers were maintained. The mean standardized bias between matched and mismatched households is reduced, and equality of means is tested using the t-test and the chi-square test for joint significance of the variables used (see Table 7).

The standardized bias results for the models were within the acceptable limit of less than 20%. The crop production impact PSM model showed a standardized bias of 25.7 and 4.1% before and after matching. Similarly, the standardized bias for the livestock impact PSM model was 17.9% before the matching and 3.2% after matching of the covariates. As a result of the matching process, the treatment and control samples have a high degree of covariate balance that is ready to utilize in the estimated procedure. On the other hand, the t-test used to assess the quality of the matching and no variable is expected to have a p-value of less than 0.05 after the matching is conducted. The result showed that no covariate variable had a statistically significant difference after matching on the two models while seven variables for the crop and five for livestock impact analysis used to be significant ahead of propensity scores matching.

Moreover, the stratification test assesses the balance of covariates across the blocks of equal size. The result showed that the balancing property is satisfied and there is no significant difference across the five blocks of water hyacinth affected and non-affected households in the two models. Finally, the joint significance and pseudo R² scores of the two models were checked. If the pseudo R² decreases and approaches 0, it indicates that a successful balance has been reached. However, there is no standard for determining how much of a reduction in pseudo R² is reasonable (Staffa and Zurakowski, 2018). The pseudo-R² value for crop impacts analysis has been reduced to 1% and to 1.2% for the livestock production impacts analysis. On both of the PSM models, the likelihood ratio (LR) results after matching were insignificant indicating the covariates are not determining the water hyacinth impact on crop and livestock production of the households.

4.4.4. Treatment effect on the treated (ATT)

The average treatment effect of water hyacinth on rural livelihoods of the households was estimated by using the three different estimation algorithms: kernel-based matching (KBM), nearest neighbor (NNM), and radius or caliper (RM) methods. The standard error of the impact estimation was calculated using bootstrapping method with 100 replications. The pre-treatment differences between the treated and untreated groups were controlled using PSM. The differences in the crop production and livestock production were regarded as the impacts of the water hyacinth on rural livelihoods of the households.

The result presented in Table 8 divulged that water hyacinth has negatively affected the rural livelihoods of the households in the study area. Being water hyacinth infested was found with a reduction of 475.4, 287.6 and 278.7 kg of rice equivalent crop production by NNM, RM and KM, respectively. The percentage of reduction represents 25.6, 17.3 and 16.8% of the total crop production in the three matching algorithms. Also, the livestock production reduced by 3.84, 3.85 and 3.82% covering 2.96 up to 2.17% in the three matching algorithms employed. Both the crop and livestock production difference among the water hyacinth affected and non-affected households was found statistically insignificant at less than 10% significance level.

4.4.5. Sensitivity analysis

The final step of the PSM model was sensitivity analysis that checks whether the impact estimated from the model is influenced by hidden bias because of unmeasured variables or not. Unmeasured pre-treatment difference across the treatment and control groups is hidden bias (McFadden, 2015). According to Mulatu et al. (2017) propensity scores estimation operates with an assumption that all appropriate covariates are included in the estimation model and there is insignificant influence of the hidden bias/unmeasured variables.

As Rosenbaum (2002) points out, sensitivity analysis for insignificant impacts on the outcome variable is not a useful tool for testing. As a result, the significant and lower bound outcome variables are evaluated using sensitivity analysis. That is, the p-critical values are significant for crop and livestock production outcome variables estimated at various levels of Gamma critical values, indicating that we have taken into account relevant covariates that influenced both participation and outcome variables. Even with the critical Gamma value set to 10, it was not possible to obtain the critical gamma value where the calculated ATT is questioned for both crop and livestock impacts analysis. Based on the sensitivity analysis results of the study, it is possible to conclude that the impacts of water hyacinth on crop and livestock rural livelihoods are not sensitive to hidden bias.

5. Conclusions and the way forward

The purpose of the study was designed to analyze the impact of water hyacinth on rural livelihoods of households around Lake Tana. The study identified crop, livestock and fishery production as the prominent livelihoods delivering food and income for the rural households. Water hyacinth was found responsible in disrupting the rural livelihoods delivering food and income for the rural households. Water hyacinth was found responsible in disrupting the rural livelihoods asset...
bases, their implementations and outcomes. The weed affected 34.1% and 36.6% of crop and livestock producer households in the study area. The average treatment effect of water hyacinth on crop and livestock production was 278.7 up to 475.4 kg of rice equivalent and 0.083 up to 0.114 TLU, respectively. The weed was able to produce a statistically significant difference among water hyacinth affected and non-affected households on agricultural production. Even though the Lake has a huge potential in fish production, only 9% of the households engage in the strategy and water hyacinth takes the largest share in the decline of fishers and fish production in the study area. The fish production was decreased by almost half due to the introduction of water hyacinth in Lake Tana. The study concludes that the weed affected the rural livelihoods of the households in the study area and water hyacinth control measures shall be designed and implemented by responsible stakeholders to protect the rural livelihoods. Moreover, researchers shall conduct further study on the health impacts of water hyacinth on livestock, the medication of water hyacinth caused livestock disease and the possible way of utilizing water hyacinth as a livestock feed.

Declarations

Author contribution statement

Yilebes A. Damtie; Arega B. Berlie; Gasawh M. Gessese: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

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