



(RESEARCH ARTICLE)



## Assessing the status of soil seed bank in *Parthenium hysterophorus* invaded land use types and its social aspects in Lower Hare Watershed, Southern Ethiopia

Tademe Minase <sup>1,\*</sup> and Wakshum Shiferaw <sup>2</sup>

<sup>1</sup> South Ethiopia Agricultural Research Institute, Arba Minch Agricultural Research Center, Soil and Water Conservation Research P. O. Box 1225 Arba Minch, Ethiopia.

<sup>2</sup> Arba Minch University College of Agricultural Sciences, Natural Resources Management, P. O. Box 21 Arba Minch, Ethiopia.

International Journal of Science and Research Archive, 2024, 13(01), 3335–3358

Publication history: Received on 19 September 2024; revised on 28 October 2024; accepted on 30 October 2024

Article DOI: <https://doi.org/10.30574/ijrsra.2024.13.1.2086>

### Abstract

In Ethiopia, *Parthenium hysterophorus* (*P. hysterophorus*) is an invasive alien plant affecting various ecosystems. *P. hysterophorus* displaced native plant species and caused a serious threat to biodiversity. This study aimed to assess soil seed bank of *P. hysterophorus* under major land use types and assess community perception towards the effects of *P. hysterophorus* on social aspects in lower Hare watershed. For this study, 210 soil samples were collected from fifteen transect lines in grassland, cropland, and forest land use types. Statistical analysis using three ways factorial ANOVA was used to analyze the difference in density of *P. hysterophorus* among various land uses soil depths, and sites ( $P < 0.05$ ). For the perception of local communities regarding the effects of *P. hysterophorus*, a total of 117 respondents were used and semi-structured and close-ended questionnaires for data collection. It found that all factors: land use, site, and soil depth significantly affected the soil seed bank density in the lower Hare watershed ( $P < 0.05$ ). Results indicated that mean density of seeds were the highest in croplands of other land use types. Meanwhile, the highest mean density of seeds was identified in 0-10 cm soil depth, but the lowest mean density of seeds was identified in 10-15 cm soil depth. The highest seeds were identified at Chano Cheliba, but the density of seeds the lowest in density at Kola Shera. 38.5% of households in Kola Shera, and 21.4% in Kola Cheliba, but 8.5% in Kola Doriga said that it had effects on ecosystem services such as crop yield and livestock production. There should be a need for increased awareness about the density of *P. hysterophorus* in various land uses and its impacts on native plant species. Seeking possible solutions such as biological and mechanical control methods are among the local people, researchers, and extension workers can use for the management of its invasion, and appropriate control measures can be designed to combat its further invasion and impacts on different land uses of the region.

**Keywords:** Weed density; Invasive plants; *Parthenium hysterophorus*; Social aspect; Soil seed bank

### 1. Introduction

Invasive alien species are recognized as the greatest threat to ecosystem services (Shiferaw et al., 2018). They are introduced to a region outside their natural range by various human activities (Masum et al., 2013). *Parthenium hysterophorus* is in the Asteraceae family and it is indigenous to tropical, subtropical America, Central, and South America (Masum et al., 2022). *P. hysterophorus* was accidentally introduced into Kenya and Ethiopia in the early 1970s (Ojong et al., 2021). *Parthenium hysterophorus* was accidentally introduced to Ethiopia possibly with contaminated wheat seeds from Australia (Tamado and Milberg, 2000; Seta et al., 2013; Pratt et al., 2017). Depending on the availability of moisture, *P. hysterophorus* flowers throughout the year and increases its dispersal pressure. *P. hysterophorus* was introduced to Ethiopia probably through army vehicles during the 1976 Ethio-Somalia war or along

\* Corresponding author: Tademe Minase

with contaminated grain for food aid (Tamado et al., 2000; Fessehaie and Walcott, 2005). It has spread to several parts of Ethiopia at alarming rates and coverage areas through vehicles, wind, water, and urban waste. During different times and spaces, it entered agricultural fields from non-agricultural areas (Seta et al., 2013). On grazing lands, it co-existed with other plants that affected native forage cover such as natural pasture and other forage legumes in the invaded areas (Ojija and Ngimba, 2021; Ojija, 2022; Ojija and Lutambi, 2022).

In Asia, Africa, and Australia, *P. hysterophorus* is considered as one of the most aggressive invasive plant species affecting various ecosystems (Rubaba et al., 2017; Shabani et al., 2020). But, soil seed bank researches in relation to *P. hysterophorus* in Africa, Asia, and Australia are scarcer than its effects crop yield, forage production, and plant species diversity and composition. For instance, study by Karim et al. (2017) show that soil seed bank was declined down the soil depth in Batang Kali, Selangor of Malaysia. Moreover, the soil seeds varied across sites in Batang Kali, Selangor of Malaysia and in Central Queensland of Australia (Karim et al., 2017).

In India, the invasion of *P. hysterophorus* caused yield losses up to 40% of several crops and 90% loss in forage production (Gnanavel, 2013). In Ethiopia, the invasive alien plants displaced native plant species in different ecosystems and caused a serious threat to biodiversity (Wubneh, 2019). Allopathic effects of *P. hysterophorus* inhibited seed germination and growth of a variety of crops and pasture species (Clarence et al., 2013). Moreover, *P. hysterophorus* has considerable negative impact on the native grassland flora (Khatri-Chettri et al., 2022). Allelopathy is a common biological phenomenon by which one organism produces biochemicals that influence the growth, survival, development, and reproduction of other organisms (Cheng and Cheng, 2015). McConnachie et al. (2010) reported that the seeds could be transferred to urban green spaces, national parks, and other land uses and damages the landscape in urban areas, disturbed habitats such as roadsides, railway tracks, stockyards, around buildings, and fallow agricultural lands which are particularly suitable for its growth. In order to manage its invasion, *P. hysterophorus* can be used either as green manure or after composting. Industrially it can be used for producing various value-added products (Saini et al., 2014). In Amhara region of Ethiopia for instance, it was estimated that about 37,105 hectares of land were invaded by *P. hysterophorus* (Wubneh, 2019). In addition, it is well established in many districts of South, North, and Central Tigray. In Alamata district in Tigray region alone, about 10,000 hectares of land were invaded by *P. hysterophorus* (Birhanu and Khan, 2018).

In Ethiopia, this study is particularly important for areas in which the invasion of *P. hysterophorus* is alarmingly increasing, for smallholder farmers that are highly vulnerable to its invasion, and their livelihoods depend heavily on the quality of natural resources. In the invaded areas, intervention in management of *P. hysterophorus* such as manual uprooting before flowering and seed set were tried but failed. This is due to the fact that uprooting the species after seed setting led to seed dropping and hence increased the area of invasion (Kaur et al., 2014; Wubneh, 2019). Although there were some landholders that achieved success in plugging *P. hysterophorus* in the rosette stage before seeds, this must be followed up by sowing a crop or direct seeding the perennial pasture. The study reported by Dhileepan and Strathie (2009 and Adkins and Shabbir (2014) also argued that management of *P. hysterophorus* was tried using various practices like manual uprooting should be handled with care and a person should make sure that protective gear such as gloves and masks are in place to prevent health hazards its invasion and had an impact on grazing, crop production, and threaten biodiversity as well as human and animal health due to severe allergic reactions like respiratory and allergies of skin

Soil seed bank studies can help to detect or map population of *P. hysterophorus* in the soils of land use types under investigation and for its management decisions (Rokaya et al., 2020; Costello et al., 2022). In the lower Hare watershed, the species was invading at an alarming rate which further aggravated the risk of expansion and reduced the production of crops (Arba Minch Zuria Woreda Agricultural Office Report, 2020). However, except for the effects of *P. hysterophorus* on plant species diversity (Gebrehiwot and Lemma, 2015); no studies were carried out about the status of *P. hysterophorus* in the lower Hare watershed. We hypothesized that the densities of *P. hysterophorus* invasion did not vary by land use type, site, and soil depths, and its effect on the density of native plant species did not vary with land use types, site, and soil depth. Therefore, this study aimed to assess the soil seed bank of *P. hysterophorus* under major land use types and sites and assess community perception towards the effects of *P. hysterophorus* on social aspects y of the study areas.

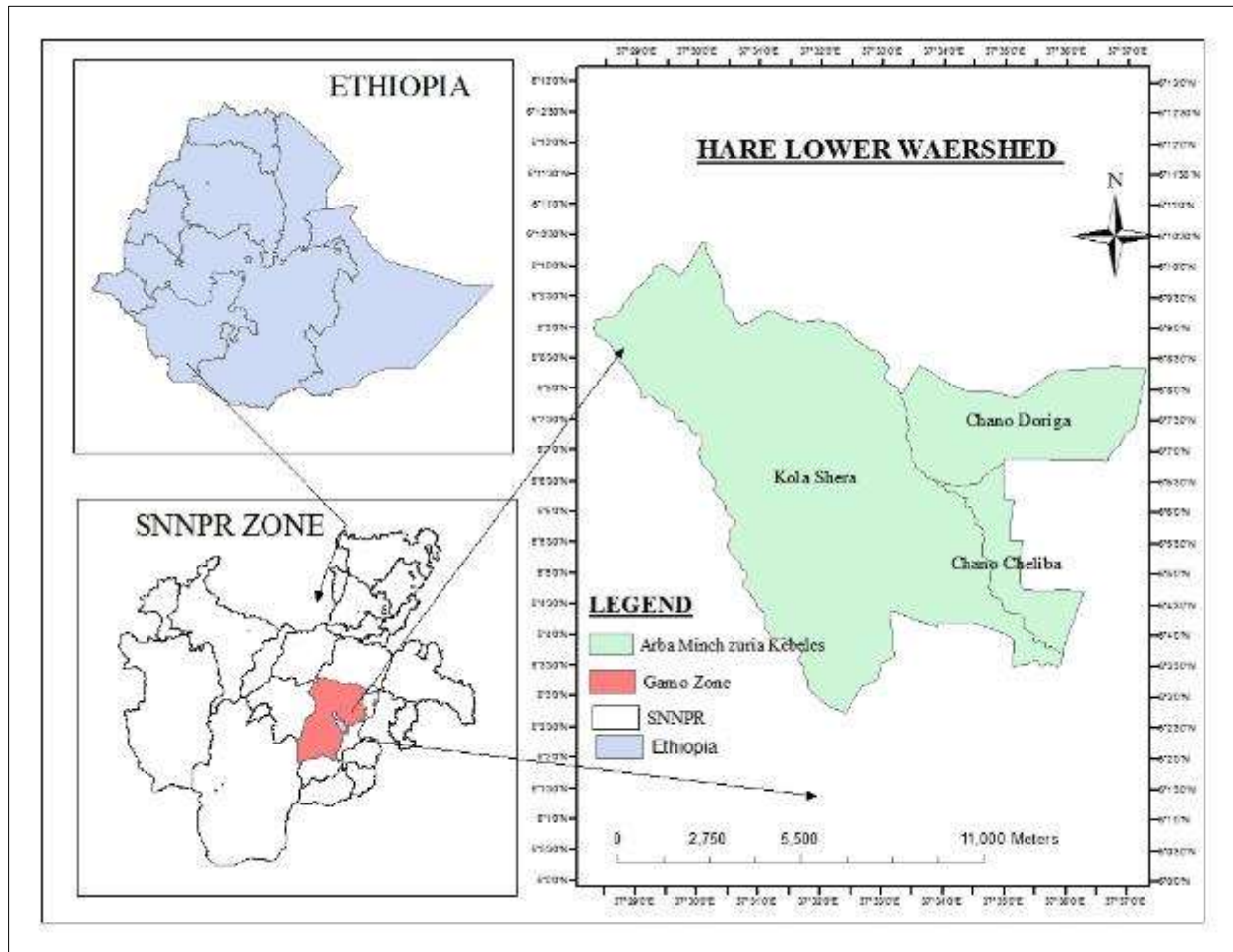
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## 2. Materials and Methods

### 2.1. Description of the study area

The study was conducted in Hare watershed, which is located between 37° 29' 00" to 37° 37' 00" N and 6° 00' 00" to 30° 13' 0" E. The watershed is located in Arba Minch District, Gamo Zone of Southern Ethiopia along the Northwestern

margin of the Great East African Rift Valley (Figure 1). The district town is located 454 km away from the country's capital city Addis Ababa (Arba Minch Town Transport Offices, 2021).



**Figure 1** Map of the study area (Source: own map drawn in ArcGIS)

### 2.1.1. Climate

Hare watershed had a climatic agro-climatic zone of highland, midland, and lowland in the tropical climate. Our study area was lower part of the watershed which was the lowland agro-climate zone in which this watershed is located. The average rainfall amount of the watershed was 1540 mm and the maximum rainy season was more than 120 days. The rainfall pattern was predominantly bimodal with a long rainy season category extended from the months of March to June. The second season was extended from August to October. The agro-climatic regime of the watershed was characterized by an average length of growing period ranging from 120-240 days per year. The lower parts of Hare watershed were classified into highlands and midlands. The altitude is ranging from 1500 m to 3490 meters above sea level (Arba Minch Zuria District Agricultural Office, 2020).

### 2.1.2. Land use and land cover and population of the watershed

A total of 25,000 people were living, of which 13100 were females and 11900 were males in the Hare watershed. In the watershed, from 2389 household heads, 201 (8%) were female-headed and the remaining 2188 (92 %) were male-headed households. Economic Activities in the area were based on mixed farming like crop production and livestock rearing (Arba Minch Zuria District Agricultural Office, 2020). The cropping system was perennial-based production with low use of external inputs and dominated only by a few crops (Arba Minch Zuria District Agricultural Office, 2020).

### 2.1.3. Section 1: Assessment of soil seed bank

Reconnaissance survey was carried out in April 2021 after a short rainy season in three sampling sites to get preliminary information in each site. These sites were chosen on the basis of the severity of invasion of *P. hystrophorus* and habitat

heterogeneity. This study consisted of three stages for soil seed bank study namely reconnaissance, survey, site selection, and soil samplings.

A preliminary survey was conducted before the actual research work for observation of the invasion of *P. hystrophorus* in different sites of the study watershed. Later, a second formal survey was done to gather data by catching images such as photographs and videos about the invasion and impacts of *P. hystrophorus* on other plant species.

## 2.2. Selection of sites and land use types

The watershed was selected purposively because the area was severely invaded by *P. hystrophorus*. There were 10 rural kebeles in the Hare watershed of which 3 kebeles were selected purposively based on high exposure to *P. hystrophorus* (Ariba Minch Zuria Worda Agricultural Offices, 2019). Kola Shera, Chano Doriga, and Chano Cheliba were selected among the 10 rural kebeles (sites) in the study district. Then, in the invaded sites, cropland, grazing land and forest land use types were selected for the data collection in the watershed.

## 2.3. Soil sampling

For soil sample collection, major land use types mainly grassland, croplands, and forest land use types were selected. The soil samples were collected in June 2021. The sampling period was considered to represent the end of the growing season (i.e., after seed production events) for most of the species encountered in the lower Hare watershed.

For each land use type, a big plot of 1m x 1m (1 m<sup>2</sup>) was considered and the distance between the big plots was 25 m. In the 1 m<sup>2</sup> plot, small plots of 15 cm x 15 cm (225 cm<sup>2</sup>) sampling were selected. In order to cover better area cover for soil samples, zigzag soil sampling method was used in each site at three soil depths of 0–5, 5–10, and 10–15 cm. The number of soil samples taken from Chano Doriga and Kola Shera each was 90 samples (180 soil samples). That meant 30 soil samples were collected in cropland, grazing and forest land types. But, due to the lack of forest and grazing lands in Chano Cheliba site, only 30 soil samples were collected in cropland type. Then, a total of 210 soil samples were collected in the lower Hare watershed (Plate 1). The germination method was used to separate seeds from soil samples. The soil samples were taken to the lath house for germination (Plate 2). The lath house was covered with plastic that protected from the arrival of other materials or seeds on the plastic trays. All plants that were germinated in the lath house on plastic trays. At the interval's week, on each plastic tray germinated seeds were counted and recorded including *P. hystrophorus*. The counting and recordings of seeds were carried out for six consecutive months. The number of individual plant species in each plastic tray was important to characterize the density of *P. hystrophorus* and other plant species which were used to identify the status of *P. hystrophorus* and other native plant species within the lower Hare watershed.



**Figure 2** Photo showing soil sampling in the field



**Figure 3** At the start of the trial and seeds germinated in the lath house trial for the soil seed bank

#### 2.4. Data analysis for density of soil seed bank

The different species of plants that were counted and recorded were identified using Ethiopia and Eritrea flora books which were found in volumes 2–7. After data for both seeds and social surveys entered into Microsoft Excel, then density of species in the soil seed bank was analyzed using SAS version 9.0.

##### Section 2: Social survey

Out of 45,000 people, 2389 household heads were existed in the watershed of which 117 household heads were selected using stratified random sampling techniques in selected sites of Kola Shera, Chano Doriga, and Chano Cheliba as follows.

Yamane’s formula (1967) was used to determine the size of households for sample in selected kebeles.

$$n = N / (1 + N (e^2))$$

Where;  $n$  = sample size

$N$  = total number of households

$e$  = margin of error set at 9%

Based on stratified random sampling techniques 117 household respondents were selected from the total households ( $N = 2389$ ). These 117 households were selected from the lower section of the watershed (Table 1).

**Table 1** Sample size of farmers from the three sections

Number	Kebeles	Total population	Sampled households
1	Kola Shera	1299	64
2	Chano Doriga	410	20
3	Chano Cheliba	680	33
Total		2389	117

## 2.5. Social data analysis

Social data were analyzed with SPSS version 24. Since the data for number of seeds germinated were large in number F statistics were used for mean separation. For social surveys, descriptive statistics were used for data analysis to show simple relationships with invasion of *P. hysterophorus*.

## 3. Results

### 3.1. Composition of the soil seed bank

In the lower Hare watershed, the results revealed that in the soil seed bank, 18 plant species were identified from soil samples. This study showed that the seeds recorded in the sample plots were composed of 15 annuals, 3 perennial types, and comprised 14 herbs, 3 grass types, and sedge. About 13 families of weed species were identified, including *Poaceae*, *Cyperaceae*, *Amaranthaceae*, *Lamiaceae*, *Asteraceae*, *Euphorbiaceae*, *Convolvulaceae*, *Polygonaceae*, and *Zygophyllaceae*. Most of the species belong to the *Asteraceae* family followed by the *Poaceae* family. The economic use of *P. hysterophorus* in the local areas was compost making, biogas, and green manure (Table 2).

**Table 2** Plant species taxonomical characteristics and economic uses in lower Hare watershed

Scientific name	Family name	Life form	Life cycle	Economic use
<i>Hygrophila schulli</i> Parmar	<i>Acanthaceae</i>	Herb	Annual	Medicinal purposes (Teklu et al., 2020)
<i>Amaranthus spinosus</i> L.	<i>Amaranthaceae</i>	Herb	Annual	Antidepressant activity (Fariba, 2017)
<i>Bidens pilosa</i> L.	<i>Asteraceae</i>	Herb	Perennial	Pharmacological potential (Kumar et al., 2017)
<i>Galinsoga parviflora</i> Cav.	<i>Asteraceae</i>	Herb	Annual	Wound healing (Studzinska-Sroka et al., 2018)
<i>Xanthium strumarium</i> L.	<i>Asteraceae</i>	Herb	Annual	Medicinal purposes (Fan et al., 2019)
<i>Parthenium hysterophorus</i> L.	<i>Asteraceae</i>	Herb	Annual	Compost, bio-gas, green manure. Health benefits (Petel, 2011).
<i>Crassocephalum rubens</i> Juss	<i>Asteraceae</i>	Herb	Annual	Anti-diabetic activity (Olajumoke et al., 2020)
<i>Ipomea eriocarpa</i> R.Br.	<i>Convolvulaceae</i>	Herb	Annual	Physicochemical use (Rajiv et al., 2011)
<i>Cyperus rotundus</i> L.	<i>Cyperaceae</i>	Siege	Perennial	pharmacological activities (Pirzada et al., 2015)
<i>Euphorbia heterophylla</i> L.	<i>Euphorbiaceae</i>	Herb	Annual	Traditional medicinal uses (Kumar et al., 2010)
<i>Ocimum basilium</i> L.	<i>Lamiaceae</i>	Herb	Annual	Treatment of headaches (Joshi, 2014)
<i>Corchorus trilocularis</i> L.	<i>Malvaceae</i>	Herb	Annual	Treatment of environmental pollution (Kabir et al., 2010)

<i>Eragrostis cilianensis</i> <i>Bellardi</i>	<i>Poaceae</i>	Herb	Annual	Feed of livestock and other soil and water conservation
<i>Phalaris paradoxa</i> L.	<i>Poaceae</i>	Herb	Perennial	Feed of livestock and other soil and water conservation
<i>Digitaria abyssinica</i> Hochst	<i>Poaceae</i>	Herb	Perennial	Feed of livestock and other soil and water conservation
<i>Rumex abyssinicus</i> Jacq.	<i>Polygonaceae</i>	Herb	Perennial	Antidiabetic Activity (Adugna et al., 2022)
<i>Xanthium spinosum</i> L.	<i>Solanaceae</i>	Herb	Annual	Medicinal purposes (Fan et al., 2019)
<i>Tribulus terrestris</i> L.	<i>Zygophyllaceae</i>	Herb	Annual	Prevent human nutraceutical impacts (Gunarathne et al., 2022)

The mean density of various plant species was noted in the experimental plots. During the growing periods, frequently occurring plant species were *Parthenium hysterophorus*, *Cyperus rotundus*, *Ocimum basilium*, *Phalaris paradox*, *Euphorbia heterophylla*. These 5 species represented 58.35% of the total plant population in the lower Hare watershed (Table 3).

**Table 3** The overall plant species composition percentage and their mean seed/m<sup>2</sup> in lower Hare watershed

Species name	SSB (seed/m <sup>2</sup> )	%
<i>Parthenium hysterophorus</i>	373.97	28.07
<i>Cyperus rotundus</i>	125.71	9.43
<i>Ocimum basilium</i>	94.81	7.12
<i>Phalaris paradox</i>	91.64	6.88
<i>Euphorbia heterophylla</i>	91.22	6.85
<i>Galinsoga parviflora</i>	86.56	6.50
<i>Rumex abyssinicus</i>	76.61	5.75
<i>Amaranthus spinosus</i>	73.23	5.50
<i>Bidens pilosa</i>	64.76	4.86
<i>Tribulus terrestris</i>	52.06	3.91
<i>Crassocephalum rubeno</i>	35.98	2.70
<i>Eragrostis cilianensis</i>	32.8	2.46
<i>Corchorus trilocularis</i>	31.32	2.35
<i>Hygrophila schulli</i>	26.46	1.99
<i>Xanthium spinosum</i>	26.24	1.97
<i>Xanthium strumarium</i>	18.2	1.37
<i>Ipomea eriocarpa</i>	15.87	1.19
<i>Digitaria abyssinica</i>	15.03	1.13

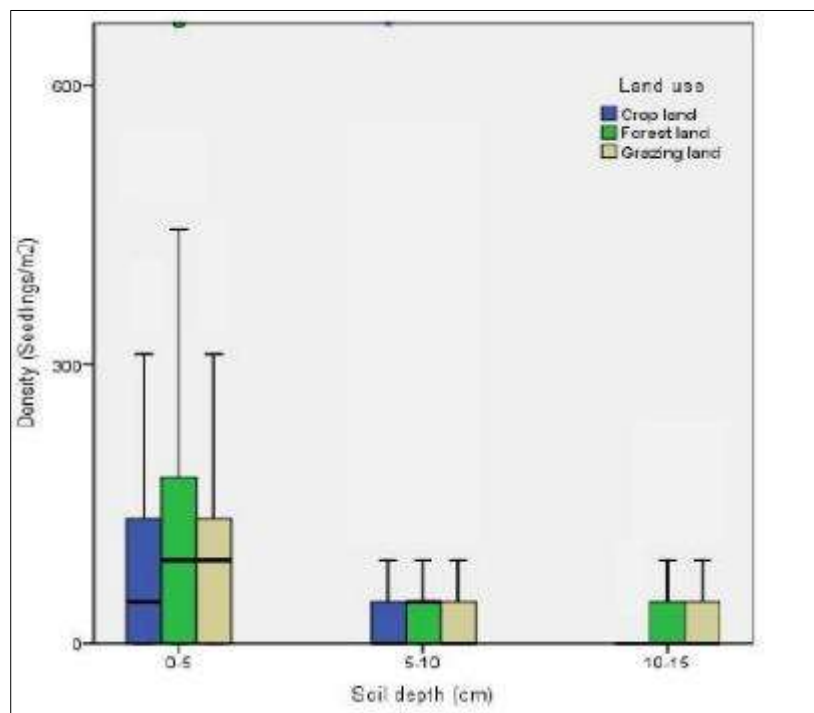
Notes: SSB Density of soil seed bank

### 3.2. The density of soil seed bank

Results in Table (4) show that all factors: land use, site, and soil depth significantly affected the density of the soil seed bank in the lower Hare watershed ( $P < 0.05$ ). But, the interaction effects of land use and site, and the interactions of the three factors (land use, site and soil depth) did not show effects on the densities of soil seed banks in the study areas ( $P > 0.05$ ). In the study sites, the highest density of seeds ( $78 \pm 3.9$  seeds/m<sup>2</sup>) was identified under the cropland system but the lowest density of seeds ( $52 \pm 2.68$  seeds/m<sup>2</sup>) was identified under grazing land (Figure 2).

**Table 4** ANOVA showing the effects of land use system, site, and soil depth on SSB (seed/m<sup>2</sup>) and their interactions

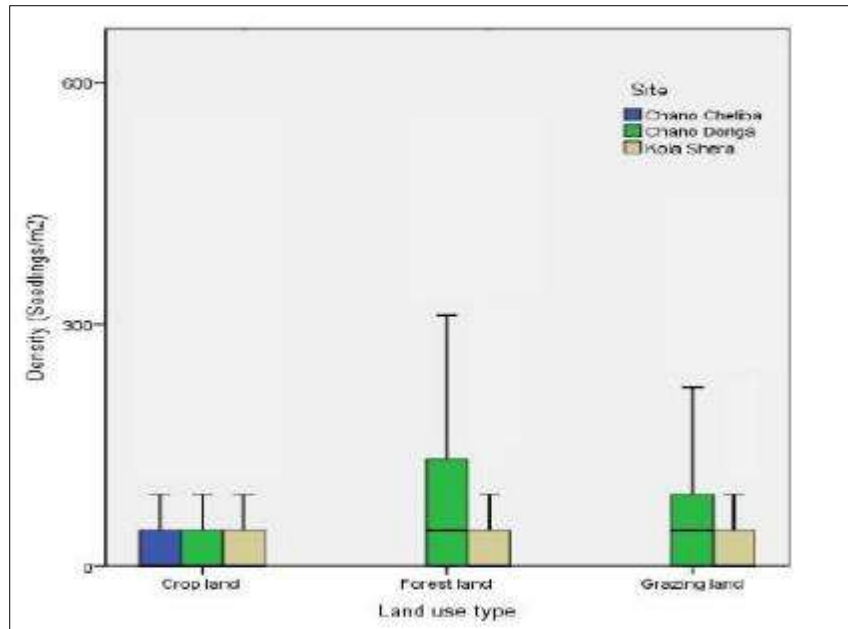
Source	DF	Type III SS	Mean Square	F	Pr > F
Land use	2	73715.62	36857.81	4.61	0.01
Site	2	358067.07	179033.53	22.41	< 0.0001
Soil depth (cm)	2	5822759.87	2911379.94	282.13	< 0.0001
Land use*Site	2	40425.63	20212.82	2.53	0.0798
Land use* Soil depth	4	107985.405	26996.35	3.38	0.0091
Site*Land use	4	246943.113	61735.778	7.73	< 0.0001
Land use*Site*Soil depth	4	25065.923	6266.481	0.78	0.5351



**Figure 4** Density soil seed bank (seeds) by land use type in lower Hare watershed.

Meanwhile, the highest density of seeds ( $130 \pm 4.79$  seeds/m<sup>2</sup>) was identified in 0–10 cm soil depth, but the lowest density of seeds ( $21.9 \pm 1.6$  seeds/m<sup>2</sup>) was identified in 10–15 cm soil depth. The highest seeds ( $90.9 \pm 7.3$  seeds/m<sup>2</sup>) were identified at Chano Cheliba, but the lowest density of seeds ( $52.15 \pm 2.62$  seeds/m<sup>2</sup>) was identified at sites of Kola Shera (Figure 3).





**Figure 5** Density soil seed bank (seeds) in different sites in the lower Hare watershed.

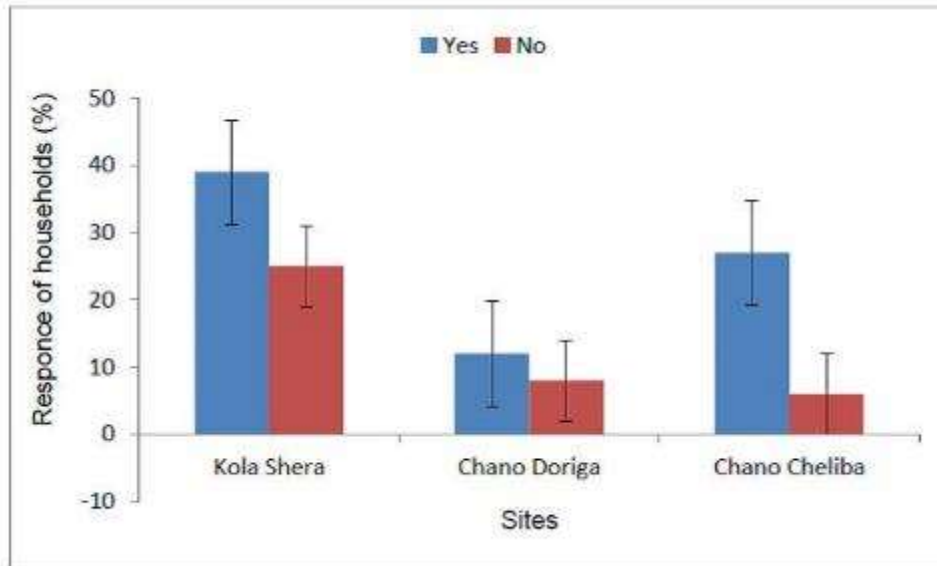
In this study, the highest seeds of plant species emerged in the soil seed banks of forest land ( $62 \pm 3$  seeds/m<sup>2</sup>), but the lowest seeds ( $52.9 \pm 2.8$  seeds/m<sup>2</sup>) were recorded in grazing lands in the lower Hare watershed (Figure 2). Meanwhile, the highest seeds of plant species emerged in the soil seed bank at the site of Chano Doriga ( $65.2 \pm 2.7$  seeds/m<sup>2</sup>), but the lowest seeds ( $45.3 \pm 2.23$  seeds/m<sup>2</sup>) were recorded at Kola Shera of the lower Hare watershed (Figure 3).

Furthermore, the highest seeds of plant species emerged in the soil seed bank at a soil depth of 0–5 cm ( $111.9 \pm 3.8$  seeds/m<sup>2</sup>), but the lowest seeds ( $13.9 \pm 0.8$  seeds/m<sup>2</sup>) were identified in the soil depth of 10–15 cm (Figure 3).

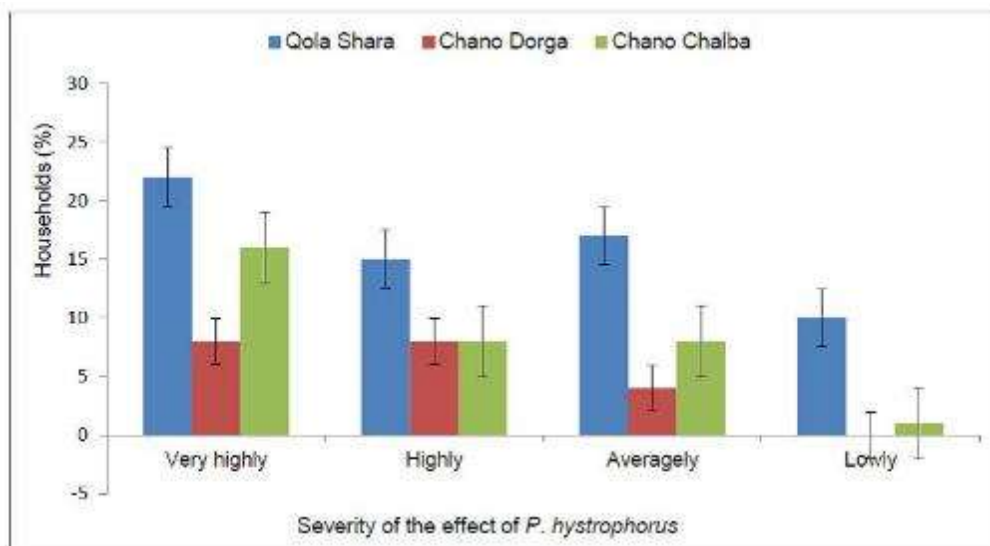
The overall results in (Figure 2) show that Chano Doriga site and the forest land use system had the highest density of seeds/m<sup>2</sup> of plant species in the soil depth of 0–5 cm. The study also confirms the highest densities of seeds were identified from the soil depth of 0–5 cm and in Kola Shera and Channo Chalba sites. Under a forest land use system and soil depth of 5–10 cm, *P. hytrophorus* was highly invaded at the site of Chano Doriga. In the grazing land use system, the invasion of *P. hytrophorus* was relatively low in the soil depth of 10–15 cm at Chano Doriga site. Perception of local people towards effects of the invasion *P. hystrophorus*

The majority of household respondents expressed their views on the impacts of *P. hystrophorus* invasion on crop production. The majority of the household heads had admitted that they were sufficiently aware of the negative effect of *P. hystrophorus* weed on livestock and crop production (Figure 4).

The majority of household respondents (68.4%) of the respondents pointed out that *P. hystrophorus* had no benefits and affected crop and livestock production. But, the rest of them suggested that *P. hystrophorus* had benefits for the ecosystem (Figure 4). Therefore, even if *P. hystrophorus* weed is a highly aggressive as well as invasive alien species, it had also positive impacts on the ecosystem which covers the land for soil and water conservation. For instance, 38.5% of households in Kola Shera, and 21.4% in Kola Chalba, but 8.5% in Kola Dorga said that it had effects on crop and livestock production. The anthropogenic pressures experienced in this region due to the invasion *P. hystrophorus* were the dispersal of its seeds through machinery, farm implements, and transport with other seeds. As a result, the densities of native plants in the soil seed bank were affected (Table S2). Results showed that it had affected very highly in Kola Shera (18.8%) and Chano Chaliba (13.7%). But, it affected the lowest in the Chano Doriga site of the lower Hare watershed (Figure 5).



**Figure 6** Percentage of the awareness of the negative effect of *P. hysterophorus* on agricultural productions



**Figure 7** The severity of invasion of *P. hysterophorus* and its effects on crop and livestock production in the lower Hare watershed

## 4. Discussion

### 4.1. Composition of the soil seed bank

A total of 18 plant species belonging to 13 families were recorded in the study area. This is similar to the study of Auma (2014) who reported 25 herbaceous plants and 12 families from *P. hysterophorus* areas. This is due to their better establishment success of the species than their indigenous counterparts. Globally, several studies have revealed the aggressiveness of *P. hysterophorus*.

In Ethiopia, Ayana et al. (2011) noted that within a few years of the introduction of *P. hysterophorus* into Awash National Park, there was a decline of 69% in the stand density of herbaceous species. The reduction of species richness and diversity with increasing density of *P. hysterophorus* has been well elaborated by Kaur et al. (2014). The same author also reported that *P. hysterophorus* takes the form of a rosette during the early stages and requires a suitable area to establish. *P. hysterophorus*, *Cyperus rotundus*, and *Ocimum basilium*, *Phalaris paradox*, *Euphorbia heterophylla* were the

most dominant herbaceous species as they were present in most of the sampling sites. This might be because the plants have strong competitive vigor with *P. hysterophorus* (Ojija, and Ngimba, 2021) and are also prolific producers of light seeds which are easily blown by the wind (Timsina, 2011).

The study also found that plant species such *Corchorus trilocularis*, *Hygrophila schulli*, *Strumarium*, *Xanthium spinosum*, *Ipomea eriocarpa*, and *Digitaria abyssinica* were less dominant in many sampling sites. This might be attributed to the negative effects of *P. hysterophorus* invasion as a result of its allelopathic properties and competitive replacement (Timsina, 2011; Ojija, and Ngimba, 2021). According to Shiferaw et al. (2018), the abundance of individual native threatened plant species is negatively correlated with the weed species that have invaded their habitat. The current results are in agreement with the findings of Muroño et al. (2018) and Auma (2021) that reported a total habitat change in native grasslands, open woodlands, river banks, and flood plains in Kenya.

From this study, it can be postulated that an increase in *P. hysterophorus* invasion might lead to changes in the structure and species composition of vegetation, thereby affecting the availability of resources. When alien plant species invade, the nature of the resources that are available and the spatial and temporal patterns of resource availability can all be altered (Lachmuth, 2019). Gao et al. (2021) also reported a change in the structure and composition of the native plant communities due to the introduction of exotic plant species.

#### 4.2. The density of *P. hysterophorus* under various land use types

In this study, the soil seed bank of *P. hysterophorus* varied from one land use type to other. This could be the completion ability of the species to various disturbance and management levels (Boja et al., 2022). The soil seed banks tell the management decision the land manager will take for managing the land types and the data in the present study is comparable to the findings of similar studies (Rokaya et al., 2020; Costello et al., 2022). The main causes of its high and fast distribution are the ability of the seed to stay for a longer period of time in the soil. In addition, its ability to outcompete native plant species, its ability to withstand drought, its ability to grow in different soil types, and its reproductive ability by producing a large number of seeds at a time. The soil seed bank study was conducted for gaining information that would assist in determining the land use type that was more vulnerable to *P. hysterophorus* invasion. High invasion of *P. hysterophorus* in different land use types was observed due to the ecological and morphological characteristics of the species, which enabled them to adapt to wide climatic and soil conditions, solar radiation insensitivity, and drought tolerance (Khan et al., 2014). In addition, *P. hysterophorus* produces a large number of seeds of up to 25 000, which are small and light in weight (Lorraine and Lin, 2015), thus the seeds can spread easily over long distances through moving water, wind, animal, and human dispersal. Among the three land use types, cropland had the highest seed densities in the lower Hare watershed. This could be attributed to soil disturbance due to plugging and movement of animal and human activity in the study area. High densities of *P. hysterophorus* along roadsides might have helped in the dispersal and spread of *P. hysterophorus* into other land use types in the study sites. Residential areas recorded the lowest seed bank density and this might be attributed to frequent management of the species through slashing and burning.

*Parthenium hysterophorus* may therefore attain the status of the most dominating weed in the watershed and the surrounding areas in the near future. This was because once it invades; the weed dominates after a few years and continues to persist as a pure stand until its managed (Muroño and Abuto, 2019). Alien plant invasion could reduce the density of the seed bank of other native plants in the invaded communities (Gioria and Psek, 2016). In addition, the invasion of different land use types by an exotic *P. hysterophorus* was a phenomenon that could lead to permanent changes in the structure of the indigenous plant community as indicated by Osunkoya et al. (2017).

Most of the local communities responded that *P. hysterophorus* had negative effects on crop and livestock production. This finding was similar to the study by Boja et al. (2022) in Ginir district of Southeast Ethiopia.

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## 5. Conclusions

In this study, the soil seed bank of the lower Hare watershed was different by various land uses, soil depths, and location. It was shown that soils in the lower Hare watershed were highly affected by *P. hysterophorus* at an alarming rate at different land uses, soil depths, and locations. These resulted in widespread distribution and invasion of the species into uncultivated areas, grazing areas (grasslands), roadsides, farmlands, and river banks, respectively, than other areas which needed for policy makers to alert natural resource managers and land managers for the control of *P. hysterophorus*. *P. hysterophorus* has been spread through wind, water, currents, vehicles, animals, and humans. *P. hysterophorus* weed caused significant impacts on the growth and distribution of plants. The invasion of *P. hysterophorus* might affect crop production; livestock feed, health of animals and their production, and plant species diversity in the study areas. Thus,

long-term and wider research should be conducted on the impacts of *P. hysterophorus* on crop yield and the diversity of above-ground native plant species. In addition, research should be done on how to combat this invasive species and reduce its distribution and impacts. Appropriate discussions should also be conducted among the stakeholders to provide solutions to control the current distribution of *P. hysterophorus* in the study sites. The basic finding of this study will inform policy for management decisions of *P. hysterophorus* in the region and in similar agro-ecologies.

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## Compliance with ethical standard

### Acknowledgments

The authors supply unique gratitude to Southern Agricultural Research Institute (SARI) for the monetary provision.

### Funding

The study was financially supported by Southern Agricultural Research Institute.

### Disclosure of Competing Interests

I declare that the authors have no competing interests as defined by this journals, or other interests that might be perceived to influence the results and/or discussion reported in this paper.

### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### Authors' contributions

- TM- has made significant contribution started from proposal writing, data collection, data analysis and interpretation and the final manuscript preparation.
- WS- has participated in advising, guiding and editing proposal and manuscript preparation process.

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