Ekológia (Bratislava) - Journal of the Institute of Landscape Ecology, Slovak Academy of Sciences Vol. 43, No. 2, p. 120–130, 2024
DOI:10.2478/eko-2024-0012

ASSESSING THE STATUS OF SOIL SEED BANK IN *Parthenium hysterophorus* - INVADED LAND USE TYPES AND ITS SOCIAL ASPECTS IN LOWER HARE WATERSHED, SOUTHERN ETHIOPIA

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Received: 10 July 2023 / **Accepted:** 8 August 2024

Abstract

Minase T., Shiferaw W., Tsegaye G.: Assessing the status of soil seed bank in *Parthenium hysterophorus*-invaded land use types and its social aspects in Lower Hare watershed, southern Ethiopia. Ekológia (Bratislava), Vol. 43, No. 2, p. 120–130, 2024.

In Ethiopia, *Parthenium hysterophorus* (*P. hysterophorus*) is an invasive alien plant affecting various ecosystems. *P. hysterophorus* displaces native plant species and causes a serious threat to biodiversity. With this background, we aimed to assess the soil seed bank of *P. hysterophorus* under major land use types and assess the perception of the community toward the effects of *P. hysterophorus* on social aspects in the lower Hare watershed. For this study, 210 soil samples were collected from 15 transect lines in grassland, cropland, and forest land use types. Statistical analysis using three-way factorial analysis of variance (ANOVA) was used to analyze the difference in density of *P. hysterophorus* among various land uses soil depths and sites ($P < 0.05$). For assessing the perception of local communities regarding the effects of *P. hysterophorus*, a total of 117 respondents were enrolled and semi-structured and close-ended questionnaires were used for data collection. It was found that all factors, that is, land use, site, and soil depth, significantly affected the soil seed bank density in the lower Hare watershed ($P < 0.05$). Results indicated that the mean density of seeds was the highest in croplands among the 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 Kola Shera. Moreover, 38.5% of households in Kola Shera and 21.4% of households in Kola Cheliba, but 8.5% of households 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 for possible solutions such as mechanical control methods in terms of abortion of its seed set and weeding in early vegetative period 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.

Key words: density, invasive alien plants, *Parthenium hysterophorus*, social aspect, soil seed bank.

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 America, and South America (Masum et al., 2022). *P. hysterophorus* was accidentally introduced into Kenya and Ethiopia in the early 1970s (Ojong et al., 2021). *P. hysterophorus* was accidentally introduced to Ethiopia possibly with contaminated wheat seeds from Australia (Tana, Milberg, 2004; Gebeyehu, 2008; 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 with contaminated grain for food aid (Tamado et al., 2000; Fessehaie, Walcott, 2005). It has spread to several parts of Ethiopia at alarming rates 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 coexisted with other plants that affected native forage cover, such as natural pasture and other forage legumes in the invaded areas (Ojija, Ngimba, 2021; Ojija, 2022; Ojija, 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 on crop yield, forage production, and plant species diversity and composition. For instance, a study by Karim et al. (2017) showed that soil seed bank declined below 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 of several crops up to 40 and 90% loss of forage production

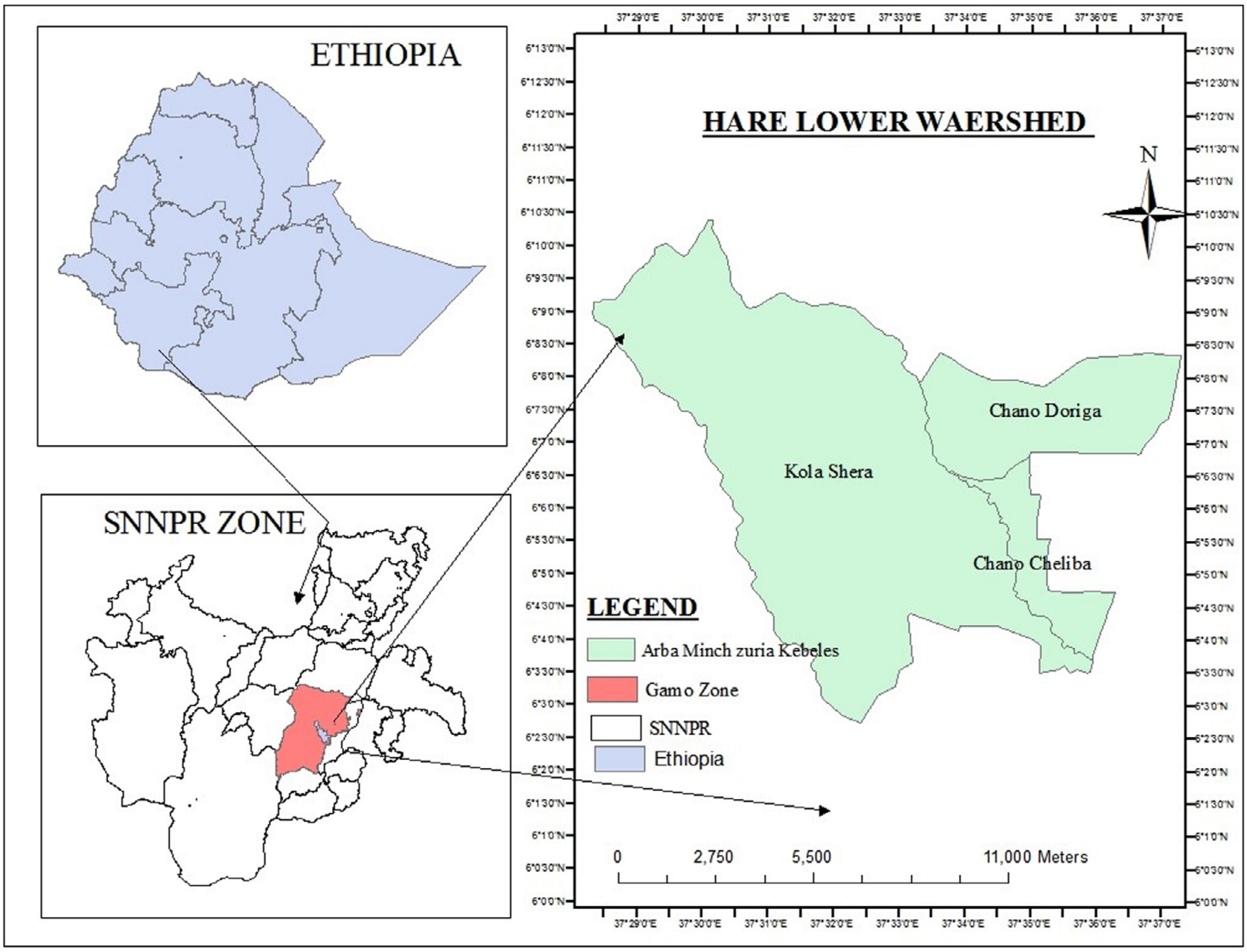

Fig. 1. Map of the study area (Source: own map drawn in ArcGIS).

(Gnanavel, 2013). In Ethiopia, the invasive alien plants displaced native plant species in different ecosystems (Wubneh, 2019) and caused a serious threat to biodiversity (Akter, Juberi, 2009). Allopathic effects of *P. hysterophorus* inhibited seed germination and growth of a variety of crops and pasture species (Msafiri 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, Cheng, 2015). McConnachie et al. (2010) reported that the seeds could be transferred to urban green spaces, national parks, and other land uses and damage 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. 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 ha of land was 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 ha of land were invaded by *P. hysterophorus* (Birhanu, Khan, 2018). The species was also a serious problem in the Oromia region. In this region, it was spreading at an alarming rate in East Shewa, Arsi, Ziway, and Bale (Bufebo, Eyasu, 2018).

In Ethiopia, this study is particularly important for areas in which the invasion of *P. hysterophorus* is alarmingly increasing and for smallholder farmers who are highly vulnerable to its invasion, as their livelihoods depend heavily on the quality of natural resources (Greiner et al., 2013). 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 who achieved success in plugging *P. hysterophorus* in the rosette stage before seeds, this must be followed by sowing a crop or direct seeding the perennial pasture (Talemos et al., 2013). Talemos et al. (2013) also argued that management of *P. hysterophorus* was tried using various practices like manual uprooting, which should be handled with care, and a person should make sure that protective gear such as gloves and masks is in place to prevent health hazards. Its invasion and had an impact on grazing, crop production, and biodiversity as well as human and animal health (Dhileepan, Strathie, 2009; Adkins, Shabbir, 2014).

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 their 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, 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 the community perception toward the effects of *P. hysterophorus* on social aspects of the study areas. The research hypotheses of this study were (1) densities of soil seed bank were not different under major land use types and (2) local community did not perceive the effects of *P. hysterophorus* on social aspects in lower Hare watershed.

Material and methods

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 (Fig. 1). The district town is located 454 km away from the country's capital city Addis Ababa (Arba Minch Town Transport Offices, 2021).

Climate

Hare watershed is located in tropical highland, midland, and lowland agro-climatic zones. Our study area was lower part of the watershed, which is the lowland agro-climate zone in which this watershed is located. The average amount of rainfall 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 extending from the month of March to June. The second season extended from August to October. The agro-climatic regime of the watershed is characterized by an average length of growing period ranging from 120 to 240 days per year. The lower part of Hare watershed is classified into highlands and midlands. The altitude ranges from 1500 m to 3490 m a.s l. (Arba Minch Zuria District Agricultural Office, 2021).

Land use and land cover and population of the watershed

A total of 25,000 people lived in the Hare watershed, of which 13,100 were females and 11,900 were males. In the watershed, of 2389 household heads, 201 (8%) were female-headed households 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, 2021).

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. hysterophorus* 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. hysterophorus* in different sites of the study watershed. Later, a second formal survey was conducted to gather data by catching images such as photographs and videos about the invasion and impacts of *P. hysterophorus* on other plant species.

Selection of sites and land use types

The watershed was selected purposively because the area was severely invaded by *P. hysterophorus.* There were 10 rural kebeles in the Hare watershed, of which three kebeles were selected purposively based on high exposure to *P. hysterophorus* (Ariba Minch Zuria Worda Agricultural Offices, 2021). 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.

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 1×1 m (1 m^2) was considered and the distance between the big plots was 25 m. In the 1 m^2 plot, small plots of 15×15 cm (225 cm^2) were selected. To cover better area for the 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 were 90 samples (180 soil samples). This means 30 soil samples each 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 (Fig. 1). The germination method was used to separate seeds from soil samples (Fig. 6). The soil samples were taken to the lath house for germination (Fig. 2). The lath house was covered with plastic, which protected the samples from the arrival of

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

other materials or seeds (Fig. 7). All plants germinated in the lath house on plastic trays. In week interval, on each plastic tray, the germinated seeds were counted and recorded including *P. hysterophorus*. The counting and recording 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. hysterophorus* and other plant species, which were used to identify the status of *P. hysterophorus* and other native plant species within the lower Hare watershed.

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 were entered into Microsoft Excel, the 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 lived 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 the samples in selected kebeles:

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

where n = sample size, N = total number of households, and 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).

Social data analysis

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

Results

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 and three perennial types, and comprised 14 herbs, three grass types, and sedge. About

Table 2. Taxonomical characteristics and economic uses of plant species in lower Hare watershed.

Scientific name	Family name	Life form	Life cycle	Economic use
Hygrophila schulli Parmar	Acanthaceae	Herb	Annual	Medicinal purposes (Teklu et al., 2020)
Amaranthus spinosus L.	Amaranthaceae	Herb	Annual	Antidepressant activity (Fariba, 2017)
Bidens pilosa L.	Asteraceae	Herb	Perennial	Pharmacologic potential (Kumar et al., 2017)
Galinsoga parviflora Cav.	Asteraceae	Herb	Annual	Wound healing (Studzinska-Sroka et al., 2018)
Xanthium strumarium L.	Asteraceae	Herb	Annual	Medicinal purposes (Fan et al., 2019)
Parthenium hysterophorus L.	Asteraceae	Herb	Annual	Compost, biogas, green manure; health benefits (Patel, 2011)
Crassocephalum rubens Juss	Asteraceae	Herb	Annual	Antidiabetic activity (Tran et al., 2020)
Ipomea eriocarpa R.Br.	Convolvulaceae	Herb	Annual	Physicochemical use (Rajiv et al., 2011)
Cyperus rotundus L.	Cyperaceae	Siege	Perennial	Pharmacologic activities (Pirzada et al., 2015)
Euphorbia heterophylla L.	Euphorbiaceae	Herb	Annual	Traditional medicinal uses (Kumar et al., 2010)
Ocimum basilium L.	Lamiaceae	Herb	Annual	Treatment of headaches (Joshi, 2014)
Corchorus trilocularis L.	Malvaceae	Herb	Annual	Treatment of environmental pollution (Kabir et al., 2010)
Eragrostis cilianensis Bellardi	Poaceae	Herb	Annual	Feed for livestock, other soil and water conservation
Phalaris paradoxa L.	Poaceae	Herb	Perennial	Feed of livestock and other soil and water conservation
Digitaria abyssinica Hochst	Poaceae	Herb	Perennial	Feed of livestock and other soil and water conservation
Rumex abyssinicus Jacq.	Polygonaceae	Herb	Perennial	Antidiabetic activity (Adugna et al., 2022)
Xanthium spinosum L.	Solanaceae	Herb	Annual	Medicinal purposes (Fan et al., 2019)
Tribulus terrestris L.	Zygophyllaceae	Herb	Annual	Prevents human nutraceutical impacts (Gunarathne et al., 2023)

Table 3. The overall plant species composition percentage and their mean seed/ in lower Hare watershed.

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

Note: Density of soil seed bank (SSB).

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

Source	Degree of freedom	Type III sum square	Mean square	F	Pr > F
Land use	2	73,715.62	36,857.81	4.61	0.01
Site	2	358,067.07	179,033.53	22.41	<0.0001
Soil depth (cm)	2	5,822,759.87	2,911,379.94	282.13	<0.0001
Land use × Site	2	40,425.63	20,212.82	2.53	0.0798
Land use × Soil depth	4	107,985.405	26,996.35	3.38	0.0091
Site × Land use	4	246,943.113	61,735.778	7.73	<0.0001
Land use × Site × Soil depth	4	25,065.923	6266.481	0.78	0.5351

13 families of weed species were identified, including Poaceae, Cyperaceae, Amaranthaceae, Lamiaceae, Asteraceae, Euphorbiaceae, Convolvulaceae, Polygonaceae, and Zygophyllaceae. Most of the species belonged to the Asteraceae family, followed by the Poaceae family. The economic uses of *P. hysterophorus* in the local areas were in compost making, biogas, and as a green manure (Table 2).

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*, and *Euphorbia heterophylla*. These five species represented 58.35% of the total plant population in the lower Hare watershed (Table 3).

The density of soil seed bank

Results presented in Table 4 show that all factors, that is, 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 ± 3.9 seeds/m^2) was identified under the cropland system, but the lowest density of seeds (52 ± 2.68 seeds/m^2) was identified under grazing land (Fig. 2, Appendix 1).

Meanwhile, the highest density of seeds (130 ± 4.79 seeds/m^2) was identified in 0–10 cm soil depth, but the lowest density of seeds (21.9 ± 1.6 seeds/m^2) was identified in 10–15 cm soil depth. The highest density of seeds (90.9 ± 7.3 seeds/m^2) was identified at Chano Cheliba, but the lowest density of seeds (52.15 ± 2.62 seeds/m^2) was identified at sites of Kola Shera (Fig. 3, Appendix 1).

In this study, the highest seeds of plant species emerged in the soil seed banks of forest land (62 ± 3 seeds/m^2), but the lowest seeds (52.9 ± 2.8 seeds/m^2) were recorded in grazing lands in the

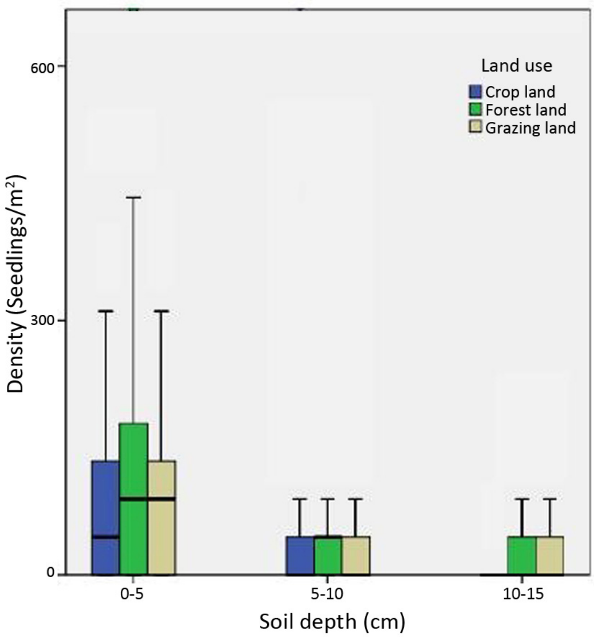

Fig. 2. Density of soil seed bank (seeds) by land use type in lower Hare watershed.

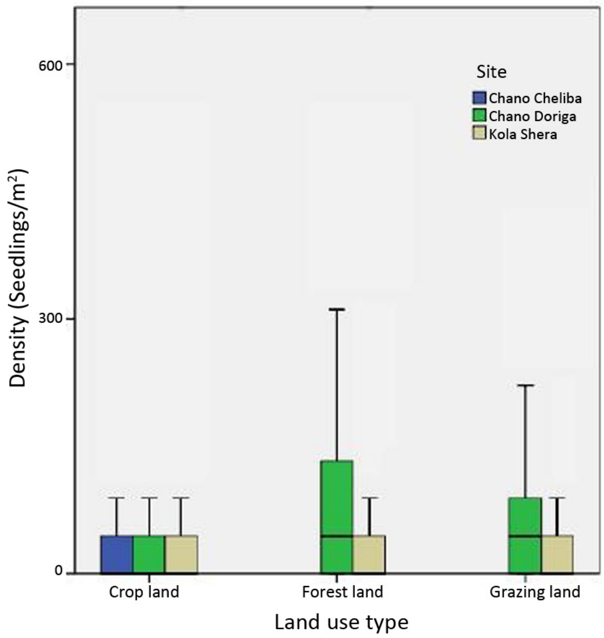

Fig. 3. Density of soil seed bank (seeds) in different sites in the lower Hare watershed.

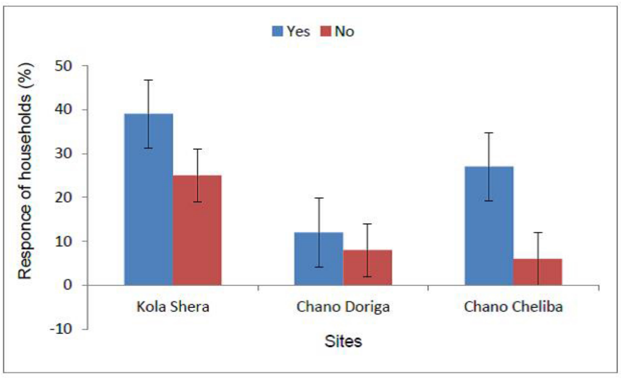

Fig. 4. Percentage of the awareness of the negative effect of *Parthenium hysterophorus* on agricultural production.

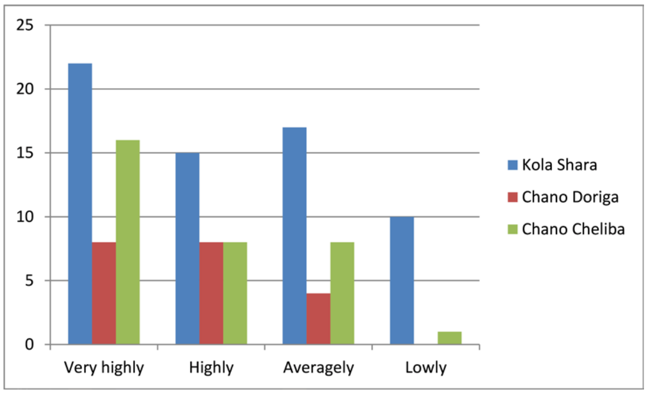

Fig. 5. The severity of invasion of *Parthenium hysterophorus* and its effects on crop and livestock production in the lower Hare watershed.

lower Hare watershed (Fig. 2). Meanwhile, the highest seeds of plant species emerged in the soil seed bank at the site of Chano Doriga (65.2 ± 2.7 seeds/m^2), but the lowest seeds (45.3 ± 2.23 seeds/m^2) were recorded at Kola Shera of the lower Hare watershed (Fig. 3, Appendix 1).

Furthermore, the highest seeds of plant species emerged in the soil seed bank at a soil depth of 0–5 cm (111.9 ± 3.8 seeds/m^2), but the lowest seeds (13.9 ± 0.8 seeds/m^2) were identified in the soil depth of 10–15 cm (Fig. 3).

The overall results showed that Chano Doriga site and the forest land use system had the highest density of seeds/m^2 of plant species in the soil depth of 0–5 cm (Fig. 2, Appendix 2). The highest densities of seeds were identified from the soil depth of 0–5 cm and in Kola Shera and Chano Cheliba sites (Appendix 2, Fig. 2). Under a forest land use system and soil depth of 5–10 cm, *P. hysterophorus* was found to be highly invading at the site of Chano Doriga. In the grazing land use system, the invasion of *P. hysterophorus* was relatively low in the soil depth of 10–15 cm at Chano Doriga site (Appendix 2).

Perception of local people toward the effects of the invasion of Parthenium hysterophorus

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

The majority of household respondents (68.4%) pointed out that *P. hysterophorus* had no benefits and it affected crop and livestock production. But the rest of them suggested that *P. hysterophorus* had benefits for the ecosystem (Fig. 4). Therefore, even though *P. hysterophorus* weed is a highly aggressive as well as invasive alien species, it also has positive impacts on the ecosystem, as it covers the land for soil and water conservation. For instance, 38.5% of households in Kola Shera and 21.4% of households in Kola Cheliba, but only 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. hysterophorus* 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 (Appendix 2). Results showed that it affected largely in Kola Shera (18.8%) and Chano Cheliba (13.7%) sites. But it affected the lowest in the Chano Doriga site of the lower Hare watershed (Fig. 5).

Discussion

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 the 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 authors 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*, *Ocimum basilium*, *Phalaris paradox*, and *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 *Parthenium hysterophorus* (Ojija, 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*, *Xanthium* strumarium, *X. spinosum, Ipomea eriocarpa*, and *Digitaria abyssinica* were less dominant in many sampling sites. This might be attributed to the negative effects of *Parthenium hysterophorus* invasion due to its allelopathic properties and competitive replacement (Timsina, 2011; Ojija, 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 Murono et al. (2018) and Auma (2021), which 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.

The density of Parthenium hysterophorus *under various land use types*

In this study, the soil seed bank of *P. hysterophorus* varied from one land use type to the other. This could be the computation ability of the species to various disturbances and management levels (Boja et al., 2022). The soil seed bank could tell land managers for management decision 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 cause of its high and fast distribution is the ability of the seed to stay for a longer period of time in the soil. The other causes are its ability to outcompete native plant species, its ability to withstand drought, its ability to grow in different soil types, and its reproductive ability to produce 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 is more vulnerable to *P. hysterophorus* invasion. High invasion of *P. hysterophorus* in different land use types was observed due to the ecological and morphologic 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, up to 25,000, which are small and light in weight (Lorraine, Lin, 2015). Thus, the seeds can spread easily over long distances through moving water, wind, animal, and human dispersal (Mao, 2023). 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.

P. hysterophorus may, therefore, attain the status of the most dominating weed in the watershed and the surrounding areas in the near future. This is because once it invades, the weed dominates after a few years and continues to persist as a pure stand until it is managed (Murono, Abuto, 2019). Alien plant invasion could reduce the density of the seed bank of other native plants in the invaded communities (Gioria, Pysek, 2016). In addition, the invasion of different land use types by an exotic *P. hysterophorus* is 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 finding of Boja et al. (2022) in Ginir district of Southeast Ethiopia.

Fig. 6. Photo showing soil sampling in the field.

Fig. 7. At the start of the trial and seeds germinated in the lath house trial for the soil seed bank.

Conclusion

In this study, the soil seed bank of the lower Hare watershed was different by various land uses, soil depths, and location. It was found 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 abandoned farmlands, grazing areas, roadsides, farmlands, and riverbanks than in other areas which needed for policy makers to alert natural resource managers and land managers for the control of *P. hysterophorus*. *P. hysterophorus* is spread through wind, water, currents, vehicles, animals, and humans. *P. hysterophorus* weed causes 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 findings of this study will inform policymakers for taking management decisions on *P. hysterophorus* in the region and in similar agro-ecologies.

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Appendix 1. Status of the density of seedlings/m^2 by land use type, site, and soil depth (seedling densities of *Parthenium hytrophorus* are included in data analysis).

Independent factor*soil seed bank		
Land use	**N**	**Mean ± SE**
Crop land	1598	78.2±3.93^a
Grazing land	1136	52±*2.68*^{b}
Forest land	1046	68.4±*3.29*^{c}
Null hypothesis (*P* < *0.05*)		**
Soil depth		
0-5 cm	1260	130.3±4.79^a
5-10 cm	1260	51.6±2.90^b
10-15 cm	1260	21.9±1.64^c
Null hypothesis (*P* < *0.05*)		**
Site		
Kola Shera	1620	52.15±2.62^a
Chano Dorga	1620	76.08±3.25^b
Chano Cheliba	540	90.9±7.29^c
Null hypothesis (*P* < *0.05*)		**

Appendix 2. Effect of *Parthenium hytrophorus* on soil seed banks of native plant species (seedlings/m^2) (seedling densities of *P. hytrophorus* are excluded from data analysis).

Independent factor*Soil seed bank		
Land use	**N**	**Mean ± SE**
Crop land	1530	54.9±*2.7*^{a}
Grazing land	1020	52.9±*2.8*^{b}
Forest land	1020	62.4±*3.1*^{c}
Null hypothesis (*P* < *0.05*)		**
Soil depth		
0-5 cm	1190	111.9±3.8^a
5-10 cm	1190	43.4±2.3^b
10-15 cm	1190	13.9±0.8^c
Null hypothesis (*P* < *0.05*)		**
Site		
Kola Shera	1530	45.3±2.23^a
Chano Dorga	1530	65.2±2.7^b
Chano Cheliba	510	63.4±4.9^c
Null hypothesis (*P* < *0.05*)		**