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Spatial Distribution of *Parthenium hysterophorus*: Impact on Plant Species Diversity and Soil Characteristics in Gamo Zone, Southern Ethiopia

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ABSTRACT

The invasions are severe and have an impact on pasture lands, farmlands, and conservation areas. However, there is little data on *Parthenium hysterophorus* L. (*Parthenium*) mapping using GIS in the Southern Region of Ethiopia. The objective of this study was to map the spatial distribution of *Parthenium* which affects the diversity of plant species and physicochemical characteristics of the soil. For the study, three districts in the Gamo Zone like Arba Minch Zuria, Kucha, and Dara Mallo were selected. *Parthenium* abundance and point data were collected randomly from 400 m² square quadrats from nine sites on 15 transects and 101 sampling quadrats. Then, abundance and presence of the items were observed and recorded. Meanwhile, plant species and soil samples (0–15 and 15–30 cm depths) collected from invaded and non-invaded lands were collected in cultivated, grazing, and woodlands. *Parthenium* was found to be abundant in cultivated lands, along roadsides, and on grazing lands. However, the density of *Parthenium* was the lowest on forest lands. The non-invaded cultivated areas had higher Shannon diversity index (1.82), species richness (9), and Shannon evenness (0.85) than the invaded lands. Meanwhile, the invasion of *Parthenium* had no effects on soil properties across sites or between invaded and non-invaded areas. However, the invasion of *Parthenium* affected Ca²⁺ across sites that ranged between 1.2 mg/kg at the Dana site of Kucha district to 1.5 mg/kg at the Shara site of Arba Minch Zuria district. This indicates that further research will be needed to confirm the effects of *Parthenium* on plant species diversity and soil properties across sites and in the invaded and non-invaded lands.

1 | Introduction

Parthenium hysterophorus is in the Asteraceae family (Tadesse 2004) and an invasive alien plant species worldwide (EBI 2014). It is an annual herb native to tropical America, but now it is highly spread to several African countries including Somalia, Kenya, Mozambique, South Africa, Swaziland, Ethiopia, and Zimbabwe (Etana et al. 2015). It was introduced to Ethiopia accidentally in the 1970s when drought-induced famine triggered a massive multinational relief effort. It was first reported from Ethiopia in 1988 at Dire Dawa and Harerge, Eastern

Ethiopia, and subsequently found near Dessie, Northeastern Ethiopia as well (Kebede 2008; Seta et al. 2013). The major ecological and morphological characteristics that contribute to its severe invasiveness could be its adaptability to wide climatic and soil conditions, production of alleopathic chemicals, and ability to produce a large number of seeds that are small in size and light in weight to travel long distances by wind, water, and other means (Navie et al. 1996).

Parthenium can cause severe crop yield losses. In India, for instance, a yield reduction of 40% in crops and a 90% reduction

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in forage production in grasslands were reported (Taye 2001). In Eastern Ethiopia, Tana (2001) reported that *Parthenium* caused sorghum grain yield reduction by 40%–97% depending on the year and the location. Invasion of *Parthenium* can also degrade natural ecosystems and outcompete native species (Ramachandra et al. 2010). The species is also a threat in several nature reserves (e.g., in Australia, Ethiopia, India, Pakistan, South Africa, and Zimbabwe) (Dhileepan 2009). Because the plant contains sesquiterpenes and phenolics, it is toxic to cattle (Navie et al. 1996). In addition, meat and milk produced from livestock that has consumed *Parthenium* can be spoiled (Towers and Subba 1992). Frequent contact with the plant or its pollen can produce serious allergic reactions such as dermatitis, hay fever, and asthma in humans and livestock (McFadyen 1995).

Invasion of *Parthenium* is observed in low lands of Gamo Zone with severe invasions and impacts on pasture lands, farmlands, conservation areas, roadsides, and green areas (Gebrehiwot and Berhanu 2015). The species suppress crops and livestock pasture that are substantially reducing yield which can provide additional food and feed. Such reduction impacts production and productivity on agricultural lands which might harm the livelihoods of smallholder farming systems, especially in arid and semiarid areas, where human food and livestock feed are commonly scarce.

The service values of recreational and conservation areas/parks are reduced in terms of monetary return in the invaded areas. *Parthenium* is affecting plant species diversity, human and animal health, and spoils the quality of milk and meat in most invaded areas of Ethiopia. Plant species diversity was highly affected by *Parthenium* in sites of Arba Minch, Mole, Shelle, and Brbr in Gamo Zone (Gebrehiwot and Lemma 2015). *Parthenium* invasion reduces plant species diversity within conservation areas in the invaded areas of Queen Elizabeth National Park, Uganda (Nuwagira et al. 2020), decreased species richness and evenness indices both in the above-ground vegetation and soil seed bank in rangelands of Southeast Ethiopia (Shashie et al. 2014; Saha and Bangadkar 2015; Auma 2019). Moreover, *Parthenium* has a tendency to affect soil major nutrients and microbial traits in invaded areas of southeast Queensland (Osunkoya et al. 2017).

Nowadays, GIS tool becomes the cost-effective way to assess the distribution of invasive species and monitor their extent (Huang and Asner 2009). Furthermore, it enables evaluating areas that are difficult to access. In the past, various attempts have been made to map *Parthenium* using GIS approaches (Rembold et al. 2015). Based on the increasing problems caused by *Parthenium* invasion as well as the reported observation that the plant has a distinct spectral response compared to surrounding native vegetation, several mappings have been carried out worldwide. In Ethiopia, Wakie et al. (2014) have used Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices and topo-climatic predictors to map the current distribution of *Prosopis juliflora*, for example, using maximum entropy modeling software. However, in the southern part of Ethiopia, there is limited information on the mapping of *Parthenium* using GIS. Traditional field surveys for assessing the invasion of *Parthenium* alone are

insufficient in the study areas. In the study areas, quantitative and updated information is lacking using GIS. Moreover, the suppressive action caused by *Parthenium* on plant species diversity and its soil physicochemical properties in the invaded areas of Gamo Zone.

Therefore, the purpose of this study was to map the spatial distribution of the species that are invading and affecting areas of the Gamo Zone, examine the effects of *Parthenium* on the diversity of plant species in specific districts of Gamo Zone, and assess the effects of *Parthenium* on selected soil physicochemical properties in selected districts of Gamo Zone. This paper can address the following research questions: What was the current spatial distribution of *Parthenium* in the Gamo Zone? Did *Parthenium* impact the diversity of plant species in specific Gamo Zone districts? and How did *Parthenium* affect the physicochemical characteristics of soil in particular districts of Gamo Zone? The outcomes may serve as baseline information for the management plan of the species in the Gamo Zone. *Parthenium* distribution is a major issue in the Gamo Zone, and this can be resolved by identifying hotspot areas where the species is having a significant impact on future management plans.

2 | Materials and Methods

2.1 | Description of the Study Area

2.1.1 | Location

The study sites are situated between 5°25'0"N–6°40'0"N and 37°0'0"E–37°40'0"E in the Gamo Zone of South Ethiopia Regional Government. Gofa Zone on the west, Wolayita Zone on the north, Guji, Amaro, and Derashe Zones on the southwest, and South Omo and Alle Zones on the south are the zones that border this area. The districts of Arba Minch Zuriya, Kucha, and Dara Malo in the Gamo Zone were chosen (Figure 1). The spatial distribution of *Parthenium* and mapping were done in the Gamo Zone. However, three locations from each district were chosen to examine how *Parthenium* affected the diversity of plants and the soil. Menena, Hoya Dengeze, and Domia from Dara Mallo district; Ganta Kanchama Ocholo, Shara, and Lante from Arba Minch Zuria; and Kabisa, Wezeta, and Dana sites from Kucha district were chosen for investigations of soil and plant species.

2.1.2 | Climate

The Intertropical Convergence Zone's (ITCZ) yearly migration affects the region's climate, resulting in shorter springtime rains (Belg) and longer summertime rains (Kiremt) (June–September). The month of February marks the end of the dry season. The average yearly temperature in the lowlands and highlands were 23°C and 14°C, respectively (Figure 2). The average annual rainfall increases with altitude up to 2000 m a.s.l., although there are no trustworthy data above this level (Coltorti et al. 2019).

In the higher elevations of the study area, volcanic rocks (basalt) and volcanic tuff gave rise to predominant soils of the districts, which are clay or clay loams. Cambisols and nitisols are the two main types of soil (FAO 1990).

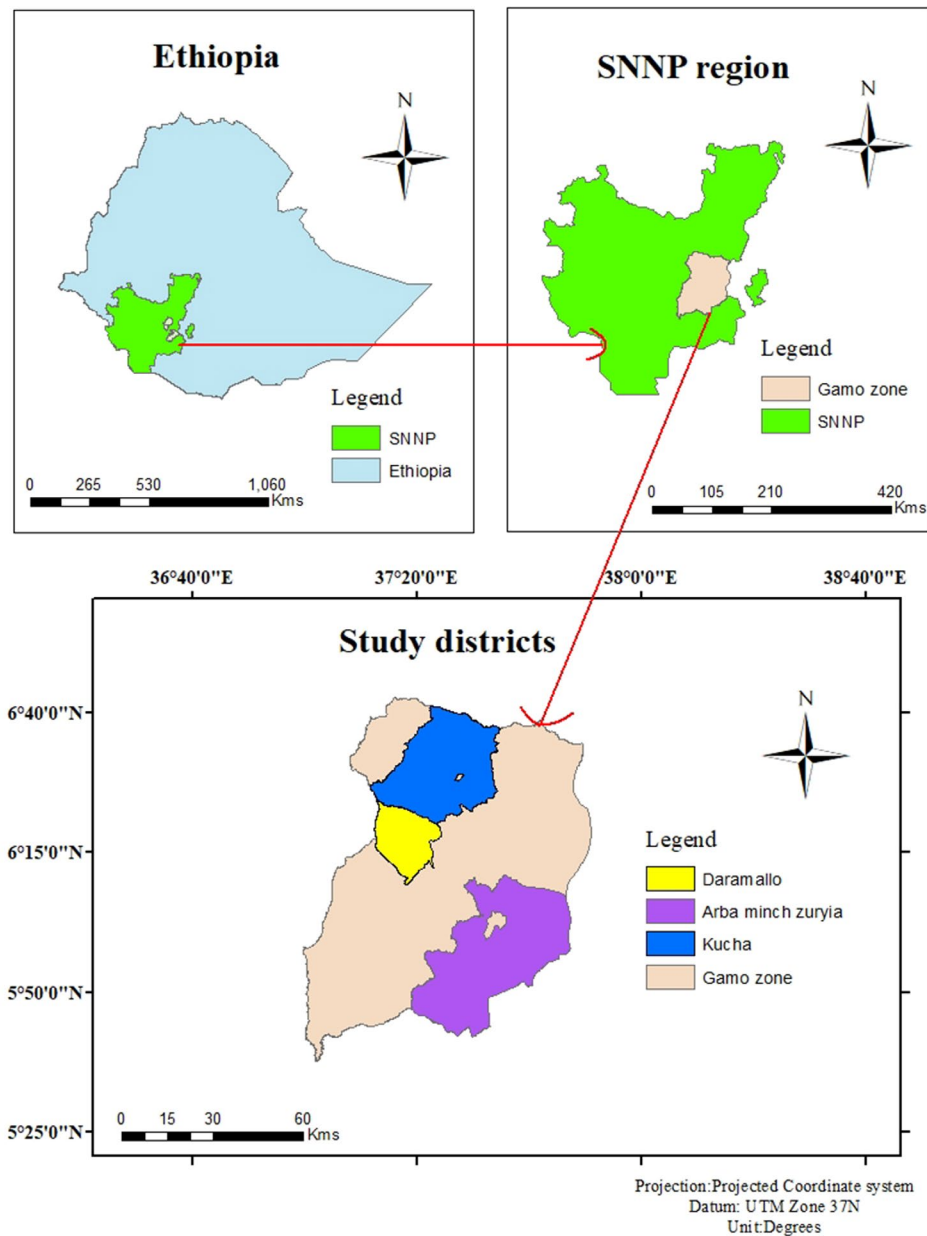


FIGURE 1 | Map of the study area.

2.1.3 | Topography

The altitudinal range of the study sites, as depicted, is 1344–1421 m a.s.l. Steep scarps interspersed with softer surfaces define the stepped slopes. The southwest shores of Lake Abaya, which is situated in the southern portion, make up the lowest portion of the region.

2.1.4 | Vegetation

The population density and the slope geometries have a significant impact on the vegetation mosaic. The *Combretum terminalia*, Dry Afromontane Forest, and other vegetation types dominate the savannah-type vegetation near the lakeshores (Friis et al. 2010). Mango, papaya, banana, enset, and papaya plantations were among the many heavily farmed flat areas

surrounding Lake Abaya and Chamo. The crop areas are divided by rows of trees and shrubs. On family farms, the gentler slopes were typically used for intensive cultivation (teff, barley, beans, enset, potatoes, etc.), with plows and hoes drawn primarily by oxen (Coltorti et al. 2019).

2.2 | Study Period and Design

From October to February 2022, a *Parthenium* spatial assessment was carried out in the Gamo Zone. Data on sample points were gathered from three districts that were specifically chosen (i.e., Arba Minch Zuria, Kucha, and Dara Mallo). Point data were gathered from randomly positioned, 20 m × 20 m (400 m²) square quadrats on transects with different elevations. Two consecutive square quadrats were separated by a distance of 25 m. Next, a handheld GPS was used to record the altitude and longitude of

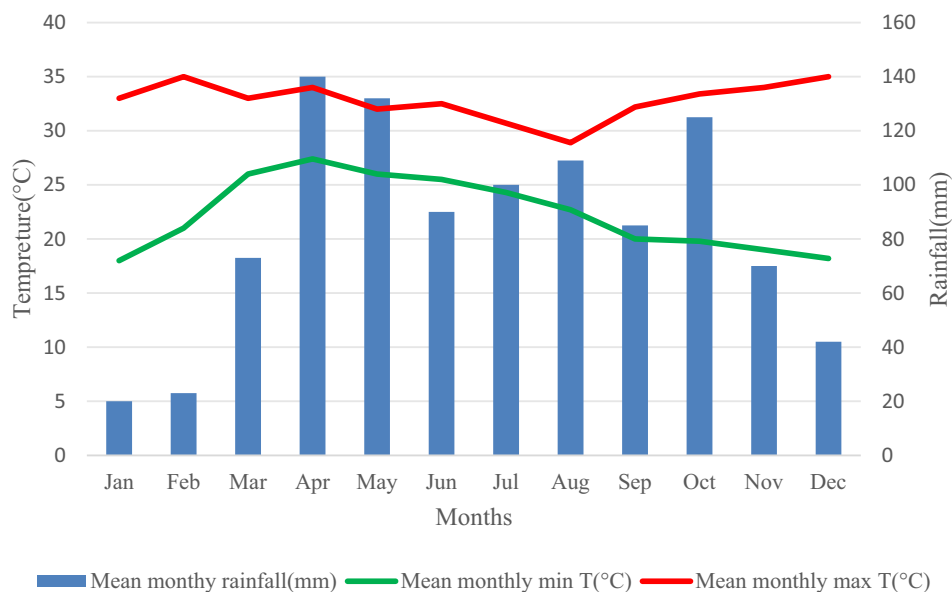


FIGURE 2 | Mean annual climate data of the study districts (1983–2022).

the locations, and at the same time, the abundance and presence (prevalence) of the items were observed and recorded on the data collection sheet. Thus, the abundance scale (Table 1) was utilized to determine abundance by modifying the techniques employed by Hundessa et al. (2016).

After a reconnaissance survey in the invaded and non-invaded areas of *Parthenium*, parallel transect line intervals between lines were laid across the land uses in each site of the districts. In the aforementioned sites (kebeles) of the districts, quadrats of 1 m × 1 m (1 m²) were placed systematically on transects with some altitude changes for grassland and farmlands. Data for soil and plant were collected in forestland areas of 5 m × 5 m (25 m²) and 20 m × 20 m (400 m²) quadrats designed for shrubs and tree species, respectively.

2.3 | Spatial Distribution Mapping

The district boundary, town, and road layers, along with other field data gathered from the previously mentioned districts, were prepared in Microsoft Excel and imported into Arc GIS software to create an abundance map and point distribution map of the study area. The percentage of area coverage estimation data was prepared in Microsoft Excel and transferred to Arc GIS software. Then, topographic maps were prepared from those points through on-screen digitizing method in Arc GIS version 10.8. As a result, the district level compiled the field data gathered from each village level, and the zonal level produced an abundance map based on this data. The process of creating a map is generally depicted in Figure 3 below.

2.4 | Vegetation Sampling and Analysis

For vegetation sampling, a total of 54 quadrats (2 invasion status × 3 land use types × 9 sites) were sampled to check effects of *Parthenium* on plant species diversity. Visual estimation was used in each quadrat area to record the percentage of each

species present or absent in both invaded and non-invaded areas. A clinometer was used to measure slopes, and GPS was used to georeference all quadrats for coordinates and altitudes. Forbs, herbs, and climbers were pressed, coded, and grouped according to their names in every quadrat. Identification of scientific names was done using volumes 1–8 of the published flora of Ethiopia and Eritrea (Hedberg and Edwards 1989; Hedberg et al. 2006, 2009; Tadesse 2004; Edwards et al. 1995, 1997, 2000).

Equation (1) can be used to calculate species richness and the Shannon-Weiner diversity index for plant diversity indicators (Magurran 2004). Pielou (1966) provided the Equation (2) for calculating evenness (E'), which was derived from the ratio of observed diversity to maximum diversity. A Braun-Blanquet scale, modified 1–9 in accordance with Van der Maarel (1979), was used to visually estimate the cover/abundance values of all plant species in each plot.

2.5 | Soil Sampling and Analysis

Soil samples were collected from selected sites of Kucha, Arba Minch Zuria, and Dara Malo districts. The soil samples were collected in an “X” design in both land uses (grazing, forest, and croplands). The soil samples were collected from 0 to 15 cm and 15 to 30 cm soil depths in *Parthenium* invaded and non-invaded areas which were adjacent to each other. Then, composite soil samples were made for each soil depth. Finally, 27 composite soil samples for each soil depth, 18 composite soil samples from each habitat and 12 composite soil samples from each site, 500 g of the representative total of 108 (2 invasion status × 3 land use types × 3 sites × 3 districts × 2 soil depths) soil samples were labeled and sealed with a plastic bag and taken to a soil laboratory for physiochemical analysis. Sites were taken as replications of soil samples. In each district, three replications of soil samples were considered for data collection.

Equation (3) was used to calculate the soil moisture content (SMC %) on a dry mass basis, which was expressed as

TABLE 1 | Abundance scale of *Parthenium*.

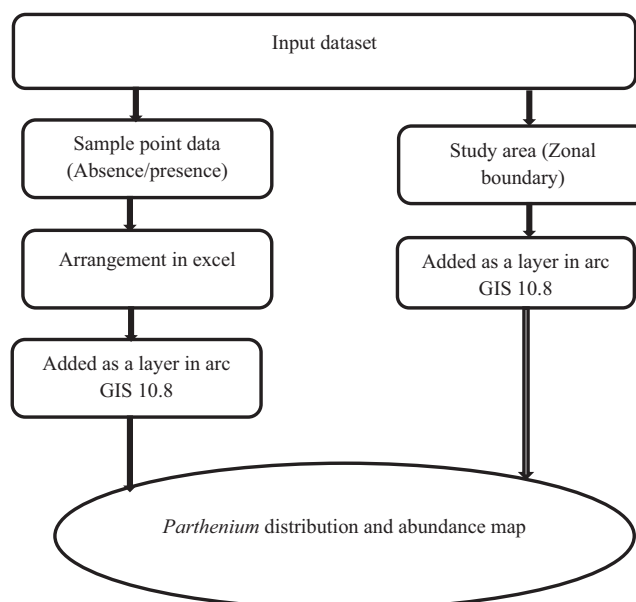
No.	Level of abundance	Character	Cover percent
1	Very abundant	When the area within 400 m ² was covered by extensive stand	> 90
2	Abundant	When the area within 400 m ² was covered by many clumps	80–89
3	Frequent	When the area within 400 m ² was covered by many sightings of single plants or small groups	60–79
4	Occasional	When the area within 400 m ² was covered by a few sightings of one or a few plants	45–59
5	Rare	When the area within 400 m ² was covered by one or a few plants	20–44
6	Present	When the area within 400 m ² was abundant uncertain	1–19
7	Absent	No <i>Parthenium</i> found	0

Source: Beyene and Tessema (2015) and Hundessa et al. (2016).

percentages by mass with an accuracy of 0.1% (m/m). The soil sample used for bulk density analysis was the source of the data. The M0 mass of the empty container with a lid (g), M1 mass of the container filled with field-moist or air-dried soil (g), and M2 mass of the container filled with soil that has been oven-dried (g) at 105°C for a full day are recorded (Wilson 2005).

Van Reeuwijk (1992) used an atomic absorption spectrophotometer to quantify the extract's Ca and Mg content, and flame photometry to assess the contents of Na and K. The CEC of the soil was calculated using the modified Kjeldahl approach (Chapman 1965) and represents cation exchange capacity of the soil. In Equation (6), the percentage of base saturation was computed as a percentage CEC of the soil using the sum of exchangeable bases (Appendix S1).

The equivalent fraction of exchangeable Na⁺ to cation exchangeable capacity multiplied by 100 is the exchangeable sodium percentage (Equation 4). In Equation (5), Sodium absorption ratio

**FIGURE 3** | Mapping process flowchart.

(SAR) was also computed using Cannon et al. (2007). By introducing basic cations, Cation Exchangeable Capacity (CEC) was also examined in the lab. Following laboratory analyses of Ca, Mg, and K, the following CEC computation was possible (Ross and Ketterings 2011).

Total N was determined using the Jackson (1958) outlined Kjeldahl technique. Using a pH metre, the sieved and preserved samples were measured for pH in a 1:2.5 soil-to-water ratio. The soil-to-water ratio of 1:5 was used to assess electrical conductivity (Ec) in water. The hydrometer approach was used to determine the soil particle size distribution (Dewis and Freitas 1984). The wet oxidation method was used to quantify the amount of organic carbon (Walkley and Black 1934). The estimation of organic matter involved multiplying organic carbon by 1.724. Using Equation (7), Soil Organic Carbon was computed (Appendix S1).

The Amount of Ca and Mg in the leachate were analyzed by the 1 N NH₄Ac extraction methods (ICARDA 2013). K and Na were analyzed by flame emission spectroscopy using a flame photometer. The exchangeable Na⁺ shown here was already after the subtraction of the soluble fraction. The textural analysis was analyzed using the hydrometer method (g/cm) using the USDA textural triangle (Bouyoucos 1962). Soil sample parameters were analyzed at Arba Minch University, College of Natural and Computational Sciences, soil and plant analysis laboratory, Abaya Campus, Ethiopia.

2.6 | Data Analysis and Statistics

Data were entered and arranged on an Excel Microsoft datasheet to facilitate the analysis of vegetation patterns in *Parthenium*-invaded and non-invaded areas. Data were analyzed using GIS overlay for spatial distribution mapping. For effects of *Parthenium* on soil and plant species diversity, GLM was used to analyze in SAS Software version 9.0.

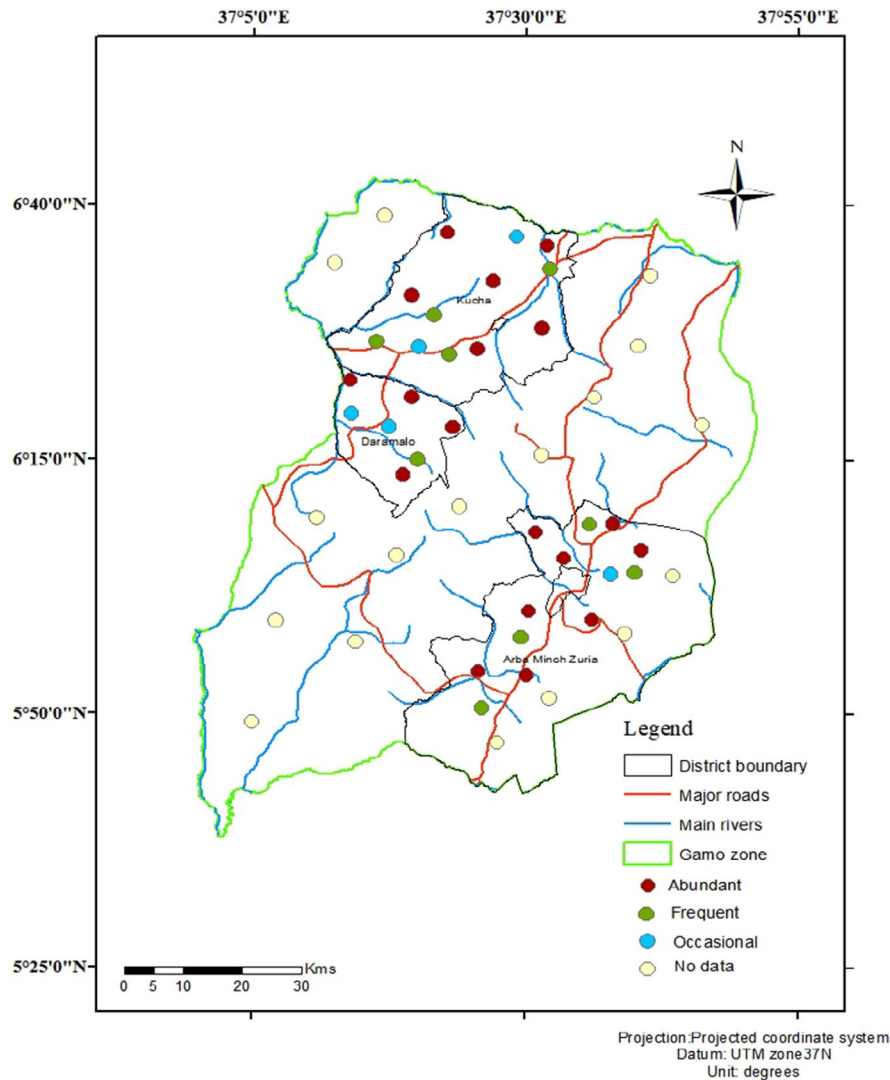


FIGURE 4 | The distribution and abundance map of *Parthenium* in Gamo Zone.

3 | Results

3.1 | Spatial Distribution of *Parthenium*

Invasive species maps are essential for identifying affected areas and planning management strategies (Figure 1). This map benefits researchers, decision-makers, and stakeholders. Out of 101 sampling points collected from 15 transect lines, *Parthenium* was found in 34 points, or 34% of frequency. It has aggressively invaded cultivation lands, grazing lands, and roadsides in Kucha, Dara Mallo, and Arba Minch Zuria districts as shown in the Figure 4 below.

Table 2 presents data on the presence and abundance of *Parthenium* species across different kebeles. In Arba Minch Zuria, the species was abundant in Lante (0.96%) and Shara (0.81%), while it is frequent in Ganta Kanchama Ocholle (0.70%). In Dara Mallo, the species was abundant in Manana (0.84%) and frequent in Hoya Degeza (0.78%) and Domia (0.66%). In Kucha, it was occasional in Kapisa (0.50%) and frequent in Dana (0.63%). The invaded land use types across all districts include croplands, grazing lands, and forest lands, with variations in specific locations.

3.2 | Frequency of *Parthenium* Distribution in Relation to Land Use Types

In Figure 5 below, the density of *Parthenium* varied across different land uses, with the highest occurrence in cultivation land (34%), likely due to soil disturbances and agricultural activities that facilitated its spread. Grazing land (22%) also shows a significant presence, potentially impacting livestock and pasture quality. In contrast, forest land (11%) has the lowest *Parthenium* density, possibly due to canopy cover and lower human disturbance limiting its growth. These variations highlight the adaptability of *Parthenium* to disturbed environments, making its management crucial in high-density areas.

3.3 | Density of *Parthenium* in Two Different Survey Seasons

As shown in Figure 6, the distribution and density of *Parthenium* were assessed during two different survey seasons: October and March. The mean density of *Parthenium* was found to be

23 individuals per unit area in October, while it increased to 28 individuals per unit area in March. This indicates a higher abundance of *Parthenium* during the March survey season compared to October. The increase in density may be attributed to favorable environmental conditions, such as rainfall and temperature, which promote the growth and spread of *Parthenium* during this period.

3.4 | Effect of *Parthenium* on Plant Species Diversity

In this study, 112 plant species that were contained in 37 families were collected and associated with *Parthenium* (Appendix S2). Results in Table 3 show that in the study areas, *Parthenium* did not have a significant effect on the Shannon

TABLE 2 | The average frequency and abundance of *Parthenium* distribution in the study kebeles.

No	District	Kebeles	Presence/ absence	Frequency (%)	Abundance level	Invaded land use types
1	Arba Minch Zuria	Lante	+	0.96	Abundant	Cl and Gl
		Shara	+	0.81	Abundant	Cl, Gl, and Fl
		Ganta Kanchama Ochole (GKO)	+	0.70	Frequent	Cl, Gl, and Fl
2	Dara Malo	Hoya Degeza	+	0.78	Frequent	Cl, Gl, and Fl
		Manana	+	0.84	Abundant	Cl and Gl
		Domia	+	0.66	Frequent	Cl, Gl, and Fl
3	Kucha	Kapisa	+	0.50	Occasional	Cl and Gl
		Dana	+	0.63	Frequent	Cl, Gl, and Fl

Note: Fl is Forest land, Gl is Grazing land, and Cl is Cultivation land.

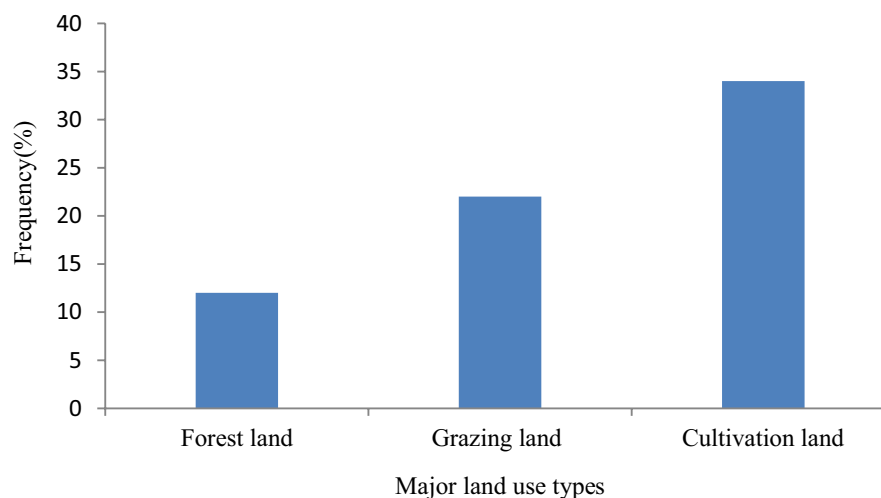


FIGURE 5 | Frequency of *Parthenium* distribution in different land use types.

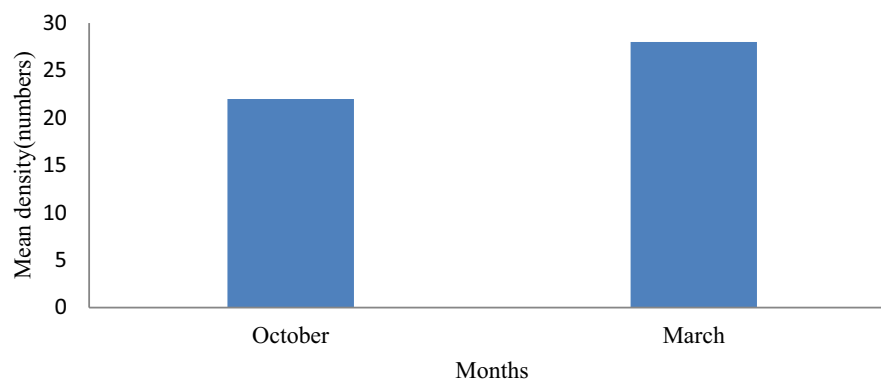


FIGURE 6 | Mean density of *Parthenium* during two surveys in October and March 2022.

diversity index, species richness, and Shannon evenness both in the invaded and non-invaded cultivated and grazing lands ($p > 0.05$). Numerically, the computed Shannon diversity index, species richness, and Shannon evenness in non-invaded cultivated lands were 1.82, 9, and 0.85, respectively, which were higher than in the invaded lands. However, the computed Shannon diversity index, species richness, and Shannon evenness in non-invaded grazing lands were 1.66, 8, and 0.85, respectively, which were less than those of invaded grazing lands (Table 3).

Findings in Table 4 demonstrate that species richness, Shannon evenness, and the Shannon diversity index were not significantly impacted by *Parthenium* invasion ($p > 0.05$). Results indicate that the Shannon diversity index, species richness, and Shannon evenness varied between 1.71 in Domia and 1.77 in Manana, 7 in Domia and 9 in Hoya Dengeza, and 0.79 in Hoya Dengeza to 0.90 in Domia in Dara Malo woreda. The findings showed that the Shannon diversity index, species richness, and Shannon evenness varied from 1.66 in Dana to 2.25 in Kapisa, 8 in Dana to 14 in Kapisa, and 0.84 in Dana to 0.88 in Kapisa, respectively in Kucha woreda. In the meantime, In Arba Minch Zuria woreda, the Shannon diversity index, species richness, and Shannon evenness varied from 1.37 in Lante to 1.76 in Shara, 6 in both Lante and Ganta Kanchama Ocholo to 8 in Shara, and 0.88 in Shara to 0.90 in both Lante and Ganta Kanchama Ocholo, respectively (Table 4). With exception of

Lante site, the higher Shannon diversity index in most of the sites could be the consequence of resistance exhibited by other native plant species against invasion of *Parthenium*.

3.5 | Effect of Invasion of *Parthenium* on Soil Physicochemical Properties

3.5.1 | Effect of Invasion of *Parthenium* on Soil Physical Properties

Based on results of Table 5, it could be observed that the sites had a significant impact on clay ($p < 0.05$) but no effect on silt or sand ($p > 0.05$). As shown in Table 5, the Kucha woreda site at Wezeta had the highest percentage of clay (55%) while the Arba Minch Zuria woreda site at Lante had the lowest percentage of clay (13%).

Parthenium invasion and soil depth had no effects on the clay, silt, and sand content of the soil in the Gamo Zone study woredas ($p > 0.05$). According to the study, the clay content of the invaded areas was lower than that of the non-invading areas. Conversely, the amounts of silt and sand in the soil were higher in the invaded areas (Table 6).

3.5.2 | Effect of Invasion of *Parthenium* on Soil Chemical Properties

In this study, *Parthenium*-invaded sites did not significantly affect soil pH, OC, total N, available P, Mg^{2+} , Na^+ , K^+ , CEC, ESP, and SAR ($p > 0.05$). On the other hand, sites in the research areas had a significant impact on soil Ca^{2+} ($p < 0.05$). According to the results, the soil of Lante (8.2) in Arba Minch Zuria was found to have the highest pH, while the soils of Kapisa and Dana (7.0) in Kucha woreda had the lowest pH. The highest OC was found in the soils of Domia in Arba Minch Zuria and Wezeta in Kucha woreda. However, the soil of Shara in the Arba Minch Zuria woreda had the lowest OC. In the meantime, the soils of the three Gamo Zone sites had comparable total N (%) values; the soil of the Ganta Kanchama Ocholo site in Arba Minch

TABLE 3 | Effect of *Parthenium* on plant species diversity in selected districts of Gamo Zone.

Land use types	Shannon diversity index ($n = 54$)	Richness ($n = 54$)	Shannon evenness ($n = 54$)
ICL	1.59	7	0.88
NICL	1.82	9	0.85
IGL	1.82	8	0.90
NIGL	1.66	8	0.85

TABLE 4 | Plant species diversity in selected sites of Gamo zone.

District	Site	Shannon diversity index	Richness	Shannon evenness
Dara Malo	Hoya Dengeza	1.68ab	9ab	0.79b
	Domia	1.71b	7b	0.90a
	Manana	1.77b	8b	0.87ab
Kucha	Kapisa	2.25a	14a	0.88a
	Dana	1.66ab	8b	0.84a
	Wezeta	1.56ab	8b	0.83a
A/M/Zuria	Ganta Kanchama Ocholo	1.59ab	6a	0.90a
	Lante	1.37b	6a	0.90a
	Shara	1.76ab	8ab	0.88ab
LSD ($p = 0.05$)		ns	ns	ns

Note: A/M/Zuria is Arba Minch Zuria.
Abbreviation: ns, non-significant.

Zuria woreda had the lowest Ava P mg/kg, while the soil of Dana in Kucha woreda had the highest (Table 7). The sites with the highest Mg^{2+} (5.3 g/kg) in soil samples were Hoya Dengeza in Dara Malo woreda, Kapisa in Kucha woreda, and Shara in Arba Minch Zuria woreda. On the other hand, the sites with the

lowest Mg^{2+} (5.0 g/kg) were Dana and Wezeta in Kucha woreda and Manana in Dara Malo woreda. In contrast, Dana of Kucha woreda had the lowest mean value of Ca^{2+} (1.2 g/kg) and the highest Ca^{2+} (1.5 g/kg) in the soil (Table 7).

TABLE 5 | Effects of invasion of *Parthenium* on soil physical properties by sites.

Site	Clay (%)	Silt (%)	Sand (%)
Hoya Dengeza	45.0ab	20.0	35.0abc
Domia	47.1ab	28.6	24.3bc
Menana	50.0ab	20.0	30.0abc
Kapisa	25.0bc	30.0	45.0ab
Dana	30.4abc	30.0	39.6abc
Wezeta	55.0a	30.0	15.0c
Shara	40.0ab	27.5	32.5abc
Ganta Kanchama Ocholo	52.5a	25.0	22.5bc
Lante	13.5c	32.5	54.0a
LSD ($p = 0.05$)	ns	ns	ns

Abbreviation: ns, non-significant.

TABLE 6 | Effects of invasion of *Parthenium* and soil depth on soil physical properties ($n = 54$).

Status of <i>Parthenium</i>	Clay (%)	Silt (%)	Sand (%)
Invaded	37.5	28.2	34.4
Non-invaded	41.5	26.0	32.5
Soil depth (cm)			
0–15	41.1	26.1	32.8
15–30	37.2	28.4	34.4

Results show that soil in Lante, Arba Minch Zuria woreda, had the highest Na^+ content (5.1 mg/kg), while soil in Kapisa, Kucha woreda, had the lowest Na^+ content (2.9 mg/kg). Table 5 shows that soil in Hoya Dengeza, Dara Malo woreda, had the highest K^+ value (4.8 mg/kg), while soil in Lante, Arba Minch Zuria woreda, had the lowest K^+ value (3.2 mg/kg).

The soil of Hoya Dengeza in Dara Malo woreda had the highest mean CEC value (11.3 mg/kg), while the soil of Lante in Arba Minch Zuria woreda and the Dana site in Kucha woreda had the lowest CEC (9.9 mg/kg) (Table 7). The soil of Lante in Arba Minch Zuria woreda had the highest mean ESP value (52.3), while the soil of Kapisa in Kucha woreda had the lowest ESP value (28.3). The soil of Lante in Arba Minch Zuria woreda had the highest SAR (2.8), while the soil of Kapisa in Kucha woreda had the lowest SAR (1.6) (Table 7).

The findings presented in Table 8 indicate that the study areas' soil chemical properties were not significantly affected by *Parthenium* invasion ($p > 0.05$). In terms of numbers, both invaded and non-invaded areas had mean pH and total N (%) values that were comparable. Compared to *Parthenium* that was not invaded, the mean OC (3.9) value in the invaded areas was higher. On the other hand, non-invaded areas had a higher value of Ava P (4.5 mg/kg) than invaded areas. The study found that the soils of invaded areas had higher mean values of Mg^{2+} (5.29 mg/kg), Ca^{2+} (1.35 mg/kg), Na^+ (4.16 mg/kg), K^+ (4.1 mg/kg), ESP (10.73 mg/kg), and SAR (2.28) compared to non-invaded areas (Table 8).

The findings indicate that the chemical properties of the soil taken into consideration in the study areas were not significantly affected by the depths of the soil ($p > 0.05$). Here, soil depths of 15–30 cm yielded higher pH (7.9) and Ava P (4.6 mg/kg) than soil depths of 0–15 cm. However, soil depths of 0–15 cm yielded

TABLE 7 | Effects of site on soil chemical properties.

Site	pH	OC	TN	Ava P	Mg^{2+}	Ca^{2+}	Na^+	K^+	CEC	ESP	SAR
Hoya Dengeza	7.9ab	3.5	0.2	4.3	5.3	1.3bc	4.2	4.8	11.3	35.7ab	2.3
Domia	7.9ab	4.3	0.2	4.5	5.2	1.3bc	3.7	4.1	10.6	34.9ab	2.1
Menana	7.9ab	4.1	0.2	4.4	5.0	1.3bc	3.4	4.3	10.6	31.8ab	1.9
Kapisa	7.7b	4.0	0.2	4.1	5.3	1.3abc	2.9	3.8	10.3	28.3ab	1.6
Dana	7.7ab	3.4	0.2	5.1	5.0	1.2c	3.8	3.7	9.9	38.5ab	2.2
Wezeta	8.0ab	4.3	0.1	4.6	5.0	1.3bc	3.7	4.5	10.7	34.9ab	2.1
Shara	8.0ab	3.3	0.2	4.7	5.6	1.5a	4.1	3.8	10.8	37.7ab	2.2
GKO	7.7ab	3.6	0.2	4.0	5.1	1.3abc	3.8	4.3	10.8	35.9ab	2.1
Lante	8.2a	4.1	0.2	4.1	5.3	1.4ab	5.1	3.2	9.9	52.3a	2.8
LSD ($p =$)	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns

Note: Unit: Ava P = mg/kg, Mg^{2+} = mg/kg, Ca^{2+} = mg/kg, Na^+ = mg/kg, K^+ = mg/kg, ns = non-significant, * = significant.
Abbreviation: GKO, Ganta Kanchama Ocholo.

higher Mg^{2+} (5.3 mg/kg), Na^+ (4.2 mg/kg), K^+ (4.5 mg/kg), CEC (11.1 mg/kg), and SAR (2.3). In the meantime, comparable mean values of Ca^{2+} , TN (%), and %OC were found for the soil depths of 0–15 and 15–30 cm (Table 6).

4 | Discussion

4.1 | Spatial Distribution of *Parthenium*

Parthenium is highly present along roadsides in the study areas invading rapidly from roadsides to various habitats (farmlands, grazing lands). The reasons could be due to road construction vehicles causing its dispersal and even animals contributing to its spread (Abdulkirim-Ute and Legesse 2016; Boja et al. 2022). Moreover, its seed abundance could be high in farmlands due to farm machinery (Kumari et al. 2014). The results of this study indicate that *Parthenium* is distributed across the different land uses of Gamo Zone, particularly in cultivation and grazing lands, with comparatively the lowest invasion in forest lands. This finding is in line with previous studies that identify *Parthenium* as a highly aggressive invasive species that preferentially colonizes disturbed environments, including agricultural lands, grazing lands, and wastelands (Adkins and Shabbir 2014).

4.2 | Frequency of *Parthenium* Distribution in Relation to Land Use Types

The higher frequency and abundance of *Parthenium* in cultivation lands compared to grazing and forest lands could be due to frequent soil disturbance, crop harvesting practices, and livestock movement, which helped seed dispersal and germination. This is in line with Tamado and Milberg (2000) in eastern parts of Ethiopia where the invasion of *Parthenium* is strongly associated with intensive agricultural activities and open landscapes. Even though forest lands exhibited relatively lower infestation levels, likely due to closed canopy cover, reduced light availability, and lower levels of disturbance, which limit the establishment and growth of *Parthenium* (Boja et al. 2022).

Local environmental conditions and land management practices highly influence invasion intensity, which in turn leads to spatial variation in invasion levels among kebeles. For example, high abundance of the species recorded in Lante, Shara, and Manana kebeles may be linked to closeness to farmlands, grazing routes, and settlement areas, which are known pathways for *Parthenium* spread through contaminated crop seed, livestock

movement, and vehicular transport (Adkins and Shabbir 2014). This heterogeneous distribution pattern is accordant with Taye et al. (2019) work on patchy but expanding infestations across Ethiopian agro-ecosystems.

4.3 | Density of *Parthenium* in Two Different Survey Seasons

Seasonal variation in *Parthenium* density was also evident, with higher mean density recorded during the March survey compared to October. This increase is likely related to increased rainfall and suitable temperatures particularly that can lead to improved germination, growth, and reproductive success. Seasonal changes in *Parthenium* abundance have been widely studied, with peak densities commonly occurring during moist and warm periods (Bajwa et al. 2016). The implications of this finding emphasize the role of timing management interventions before peak growth and flowering stages to reduce seed bank accumulation.

4.4 | Effect of *Parthenium* on Plant Species Diversity

The affinity of impact on other species in cultivable lands may be due to resistance of *Parthenium* to drought and its broader climate adaptation (Boja et al. 2022). In this study, Shannon diversity index, species richness, and Shannon evenness in non-invaded grazing lands were less than those of invaded grazing lands. These results disagreed with those of Boja et al. (2022) and Etana et al. (2011), who found that areas invaded with *Parthenium* had lower species diversity than areas that were not invaded. Results reveal that diversity indicators in the study areas were similar to those stated by Seta et al. (2013) and Gebrehiwot and Berhanu (2015). Species richness in the invaded sites was, however, far lower in the current study than it was in findings of Seta et al. (2013).

The widespread presence of *Parthenium* across productive land uses has serious ecological and socioeconomic impacts. The weed is known to diminish crop yields, compete with native plant species through allelopathic effects, degrade grazing lands, and pose health risks to humans and livestock (Nigatu et al. 2017). Many studies in Ethiopia have reported significant reductions in plant species richness and diversity in *Parthenium*-invaded areas compared to non-invaded sites, highlighting its threat to plant diversity (Boja et al. 2022).

TABLE 8 | Effect of invasion of *Parthenium* and soil depth on soil chemical properties ($n = 54$).

Status of <i>Parthenium</i>	pH	OC	TN	Ava P	Mg^{2+}	Ca^{2+}	Na^+	K^+	CEC	ESP	SAR
Invaded	7.9	3.9	0.2	4.4	5.29	1.35	4.16	4.09	10.73	39.02	2.28
Non-invaded	7.9	3.8	0.2	4.5	5.07	1.28	3.42	3.91	10.27	33.53	1.93
Soil depth (cm)											
0–15	7.8	3.9	0.2	4.3	5.3	1.3	4.2	4.5	11.1	37.8	2.3
15–30	7.9	3.9	0.2	4.6	5.1	1.3	3.5	3.6	10.0	35.8	2.0

4.5 | Effect of Invasion of *Parthenium* on Soil Physicochemical Properties

The invasion of *Parthenium* did not significantly alter the physicochemical characteristics of the soil in this investigation, with the exception of the influence of *Parthenium* on Ca^{2+} among the study sites. Invaded lands had better soil chemical properties than non-invaded lands, with the exception of soil pH, OC, TN, and Ava P. The invasion of the lands by *Parthenium* is probably the cause of the reason, and this species had no computation problem with soil nutrients (Etana et al. 2015). However, there are significant distinctions between the invaded and non-invaded areas (Feyisa and Shimelse 2023). Furthermore, research by Osunkoya et al. (2017) demonstrates that the way the soil responded to the *Parthenium* invasion differed greatly between locations and types of land use types.

4.6 | Limitations of the Study and Future Research Directions

In this study, due to financial constraints, the number of quadrats for plant specimen and soil samples was low. In the future, more plant and soil samples will be taken and analyzed across sites, land use types, and in more districts to compare the effects of *Parthenium* invasion on plant diversity and soil properties.

5 | Conclusion

Parthenium has shown a strong relation with disturbances caused by plowing during cultivation transformation across the study area, with frequently transformed soils being prone to *Parthenium* spread than infrequently changed landscapes like forestland. It was apparent that *P. hysterophorus* is found densely populated on cultivated lands, roadsides, and grazing lands. However, the density of *Parthenium* showed the lowest in forest lands. There was not much effort done by all responsible bodies including farmers. *Parthenium* was observed to grow in any season of the year at different stages, which are at shattering stage, at flowering, and seedling stages. This implies that any intervention intending to control *Parthenium* should take into consideration the ability of *Parthenium* to grow at every season of the year.

In this study, effects of *Parthenium* did not show significant effects on plant species patterns and soil properties across sites and in the invaded and non-invaded areas. This indicates that further research will be needed to confirm the effects of *Parthenium* on plant species diversity and soil properties across sites and in the invaded and non-invaded areas.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that supports the findings of this study are available in the [Supporting Information](#) of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** Equations. **Appendix S2:** Species list of Gamo Zone, South Ethiopia Regional Government.