



Farmer perceptions of the impact and management of parthenium weed in eastern Bhutan

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Received: 20 March 2025 / Accepted: 16 June 2026 / Published online: 22 June 2026
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Abstract Parthenium weed (*Parthenium hysterophorus* L.) is an invasive alien plant that poses serious threats to agriculture, biodiversity, and human health worldwide. Its rapid spread and presence in Bhutan are an emerging concern. To assess awareness, impacts and management practices, a questionnaire-based interviews of 160 farmers was undertaken in four eastern Districts of Bhutan. The assessment revealed that majority of farmers (92%) were able

to identify parthenium weed at young and flowering stages, and 78% observed it mainly during summer. Infestations were most frequently observed along roadsides (89% of farmers), in dryland crops (35%), and in paddy fields (34%), but not around irrigation channels or forests. Most farmers (36%) sighted parthenium weed 6–10 years ago with 88% perceiving an increase over the years, attributing its spread largely to vehicle movement (55% of farmers). Majority of farmers (89%) perceived parthenium weed as invasive. About 29% of farmers perceived crop yield losses, mainly in maize and rice by 12 and 13%, respectively. Livestock grazing on parthenium weed was also noted by 24% of respondents, although only one reported its ill effect (tainted and poor-quality milk). Public health was more widely impacted, with 59% reporting problems, mainly itching (76% of farmers), sneezing (56%), and rashes (53%). Manual removal was the main control method implemented by 97% of the farmers, costing each household about US \$150 per year. Overall, 86% of farmers perceived parthenium weed as a concern with 66% expressing the need for an awareness program. This study identifies an urgent need for the implementation of awareness programs, early detection and control, and develop a policy to prevent further spread and impacts in the country.

Associate Editor: Reuben Keller

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10530-026-03871-x>.

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Keywords Biological invasions · Himalayas ·
Livelihoods · *Parthenium hysterophorus* · Socio-
economic impacts

Introduction

The negative impacts of invasive alien species (IAS) are known worldwide; their spread, facilitated by global trade and tourism, is further exacerbated by climate change (Marsh et al. 2021). While some IAS may provide certain benefits, such as supplemental food sources or raw materials (Kull et al. 2011; Shaanker et al. 2009), the overwhelming majority of them pose severe threats to native ecosystems, economies, and human well-being (IPBES 2023). Following habitat destruction, IAS are considered the second greatest threat to biodiversity and ecosystem functioning globally (Reid et al. 2019). Addressing IAS threats is even more challenging for developing countries where resources and capacity to manage them are often limited (Hulme 2006; Thomas 2023). Despite these constraints, tackling IAS remains critical for developing countries to prevent severe ecological, economic, and health consequences.

One of the most notorious alien invasive plant known is parthenium weed (*Parthenium hysterophorus* L.) (Shabbir et al. 2024). Its unique morphological and physiological characteristics (Mao et al. 2021a) such as strong allelopathic effects, prolific seed production, persistent soil seed bank formation, ease of spread by vehicles and positive response to climate change makes it highly invasive (Belgeri 2013; Navie 2003; Nguyen et al. 2017). The negative impacts caused by parthenium weed on agriculture, environment and health are enormous. For example, in lowland areas of eastern Ethiopia, parthenium weed densities of 100 plants m^{-2} , caused 97% yield loss in sorghum (*Sorghum bicolor* (L.) Moench), and even under three plants m^{-2} , 69% yield loss was reported (Tamado et al. 2002). However, in India, only 40% yield loss was reported in sorghum (Angiras and Saini 1997). In Pakistan, the weed has even been reported in direct-seeded rice (*Oryza sativa* L.), with potential to cause over 10% yield losses (Bajwa et al. 2020). Parthenium weed also causes crop losses indirectly through allelopathy (Bajwa et al. 2016) or by serving as an alternative host to crop pests and diseases (Shabbir 2014; Sharman et al. 2009). Parthenium weed also impacts livestock production by reducing the quality of milk or causing milk to have a strong odour and bitter taste (Lakshmi and Srinivas 2012; Tudor et al. 1982). It is also a serious human health concern as it causes

allergies and respiratory problems (Goldsworthy 2005; Gupta and Chanda 1991; Lonkar et al. 1974). The financial losses associated with parthenium weed are considerable. In India, the cumulative cost of managing this invasive species since its introduction has been estimated about 3.6 billion Indian Rupees (Rs) (Sushilkumar and Varshney 2010), while in Queensland, Australia, estimated losses to farming and pasture range from *ca.* US \$14 to 72 million per year (Adamson 1996).

Given the enormous impact caused by parthenium weed, its ease of spread and presence in new areas are of major concern. In Bhutan, parthenium weed is a relatively new introduction reported first in 1992 (Parker 1992), believed to have arrived from neighbouring India (Dorji and Adkins 2020), which is considered as one of the worst affected countries by parthenium weed in the world (Kumar 2012). Today, parthenium weed is already reported from 19 of Bhutan's 20 Districts (Dorji et al. 2021, 2025), with the weed not being found yet in Bumthang, a very mountainous District with only a very small land area that could support its growth (Dorji et al. 2021, 2025). Nevertheless, parthenium weed has been observed at elevations as high as 2,600 m above sea level in Bhutan (Tshering and Adkins 2012) and 2,627 m above sea level in Ethiopia (McConachie et al. 2011). Despite its presence and rapid spread throughout the country, there is little information concerning its impact on agriculture, public health, or the associated financial burden this weed causes, and this is especially true for the eastern Districts of the country. The remote location of the eastern Districts (Lhuentse, Mongar, Pemagatshel, Samdrup Jongkhar, Trashigang, and Trashiyangtse; Fig. 1), far from the capital and with lower economic development has resulted in most studies being conducted in more convenient and accessible areas (Sharma et al. 2024). As a result, the eastern Districts have been largely overlooked, despite a greater need for research and management of parthenium weed than in other parts of the country.

A previous study on parthenium weed in Bhutan was confined to the west-central, including Tsirang, Punakha, and Wangduephodrang Districts and assessed farmers' perceptions of the weed, which was complemented by modelling (Chhogyel et al. 2021). However, the study did not provide comprehensive information on the impacts caused by parthenium weed. Other studies have conducted national-level modelling studies to predict land

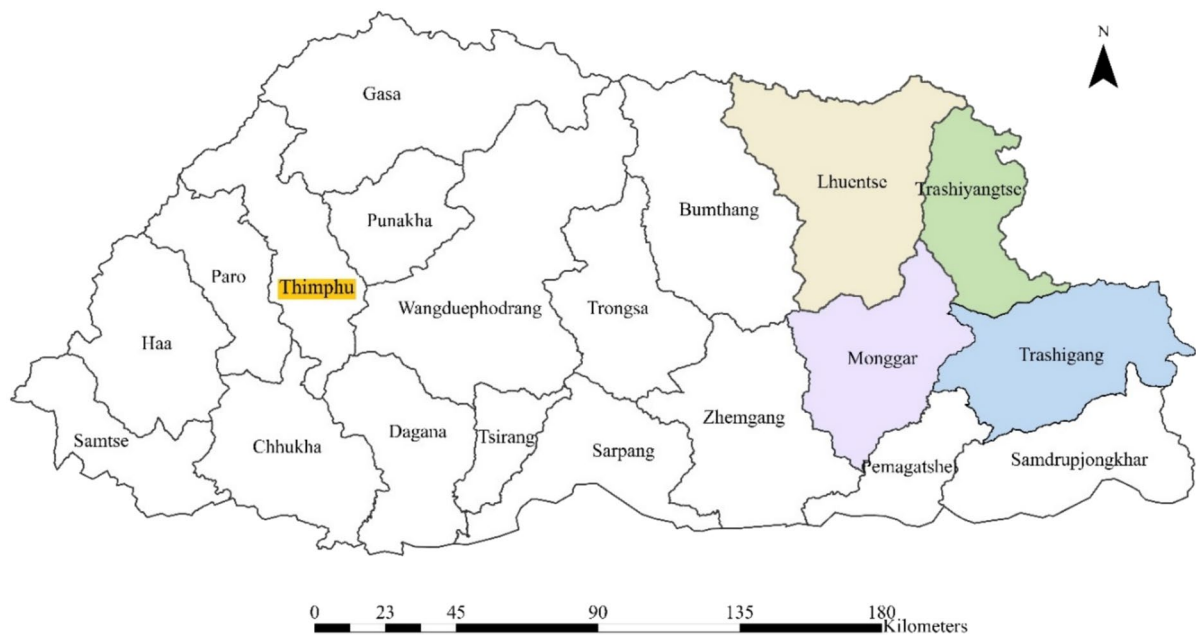


Fig. 1 Map of Bhutan showing the selected four eastern Districts (coloured; Lhuentse, Monggar, Trashigang, and Trashiyangtse) included in the perception assessment about parthenium weed impacts and management, with the capital city highlighted in yellow

suitability under the present and a future climate (Dorji et al. 2021; Thinley et al. 2019). Some further studies included parthenium weed as part of a larger investigation, with farmers in Punakha District not considering it a weed with substantial impact on their livelihood at that time (Dorji et al. 2021). The weed was similarly regarded in south-western Bhutan (Thinley et al. 2019). However, parthenium weed was in an early phase of invasion, mainly present along roadsides with little impact on agriculture, when those studies were undertaken.

The period during the early stages of invasion of any weed presents a crucial time for land managers to take pre-emptive action to mitigate future costs that would otherwise require substantial budgets or human resources. As identifying, determining the impacts of an invasive weed is an essential part to justify management. This study was undertaken to assess the perceptions of farmers of eastern Bhutan about parthenium weed, specifically to: (1) assess farmers' awareness and knowledge on the identification, impacts, and management of parthenium weed, (2) examine the perceived impacts of parthenium weed on agriculture, livestock, and public health, and (3) evaluate farmers' perceptions of the current spread

and distribution of parthenium weed across eastern Bhutan.

Materials and methods

Study area—eastern Bhutan

The perceptions-based assessment was conducted across four Districts in eastern Bhutan, viz. Lhuentse, Monggar, Trashigang, and Trashiyangtse (Fig. 1). These four Districts were selected as they have a more favourable climate for parthenium weed growth than other parts of the country (Dorji et al. 2025), and represented an area of the country not studied before. Climatically, the region experiences higher temperatures and more erratic rainfall distribution, with moist and warm conditions. Agriculturally, dryland farming is predominant in this region with some farmers practicing slash and burn agriculture. The eastern Districts, being remote and less developed, are now seeing an increasing level of economic development, including hydropower projects, road construction, and tourism developments. These activities unintentionally aid

the dispersal of parthenium weed seeds through the movement on vehicles, machinery, and by people (Mao et al. 2021b).

The combined area of these four Districts is *ca.* 9300 km² (24% to total land) and constituted a population of *ca.* 91,000 (12% of total population) in 2023 (National Statistical Bureau 2023). Rice and maize (*Zea mays* L.) are the two main cereal crops while potatoes (*Solanum tuberosum* L.) and chili (*Capsicum* spp.) are the two main cash crops grown by the people in these four Districts. Cattle (*Bos taurus* L.) are the main livestock raised.

Sample size and selection of respondents

Following the approach of Chhogyel et al. (2021) in which 40 farmers from each District in west-central Bhutan were selected for interview, we also selected 40 farmers from each of the four Districts to give a total sample size of 160. To optimize the use of limited time and resources and also considering that parthenium weed is likely in its early phase of invasion in eastern Bhutan, communities/villages with known infestations of parthenium weed were initially identified through consultations with local leaders. Where local leaders were not aware of infestations, agriculture extension agents from the Department of Agriculture were consulted as an alternative. This strategy not only ensured efficient use of resources and time but also helped to screen out non-infested parthenium sites, so that only farmers familiar with parthenium weed were interviewed. Within the identified communities/villages, respondents were approached for interview using purposive sampling, with the inclusion criterion that they had prior knowledge of parthenium weed. While this approach ensured that data collected were relevant to the study objectives, it is acknowledged that purposive sampling introduces the potential for selection bias, as farmers with greater awareness or more experiences of parthenium weed may have been more likely to participate. As such, the findings reflect the perceptions of farmers familiar with parthenium weed rather than a randomly selected or fully representative sample of the broader farming population. Overall, the interviewed farmers were drawn from 56 different communities/villages across the four eastern Districts, with efforts made to include representation from all reported area.

Questionnaire designing and ethical clearance

A semi-structured questionnaire consisting of open- and close-ended questions was used to collect data on farmers' perceptions of impacts and management of parthenium weed under seven themes: (1) demography and socio-economic characteristics (General information and respondent details), (2) farmers awareness and knowledge of parthenium weed, (3) impact on crop production, (4) impact on livestock, (5) impact on public health, (6) control and management, and (7) policy and community management (Supplementary data Table 1). For rating-related questions, such as the perceived invasiveness of the weed, five-point rating scales were employed. The approval to survey human subjects was obtained from the Human Research Ethics Committee, The University of Queensland, Australia (2023/HE001635). The questions related to personal information were kept to a minimum, focusing only on essential details, including name, gender, age, education level, years of residence, and sources of livelihood.

Data collection and training of data collectors

The data were collected by four local data collectors. A comprehensive 2-day training workshop was organized on April 1st and 2nd, 2024, for the data collectors, providing background information, mainly on parthenium weed identification, distribution, and impacts. The in-class training activity was combined with field visits to further reinforce classroom learning. The training also included familiarization with the objectives of the assessment, privacy protection, outcomes, feedback from the study, and obtaining consent from the participants. The data collectors were also handed copies of parthenium weed identification kit developed by the University of Queensland to be distributed to farmers, which contained parthenium weed identification details.

For convenience, speed, and efficiency, data were collected using the “kobotoolbox”, an open-source platform designed for data collection (<https://www.kobotoolbox.org/>). It was developed by the Harvard Humanitarian Initiative in association with Brigham and Women's Hospital, United States Agency for International Development (USAID) for challenging environments (Lakshminarasimhappa 2022). The paper-based questionnaire was transferred into the “kobotoolbox software, which supports offline data

collection on mobile devices, making it ideal for areas with poor or no connectivity. The four data collectors were already experienced with the use of this tool from their past survey work. The assessment was undertaken in April 2024. The data submitted by the data collector were downloaded to the principal investigator's computer in Microsoft Excel format for further analysis.

Statistical analysis

Since the objective of this study was to assess farmers' perceptions about parthenium weed in eastern Bhutan, and not to compare across individual Districts, data collected from each District were combined and the analysis was performed on the combined data set. The open-ended questions were analysed by grouping similar responses into themes, coding, and running statistics in the same manner as closed-ended questions. For multiple response questions, frequency analyses were performed. The data analysis was carried out using the IBM SPSS Statistics Version 29.0.0.0 (New York, United States) and graphs were prepared using R version 4.4.2 (R Core Team 2023).

Results

Demography and socio-economic characteristics of respondents

The perception-based assessment revealed that a total of 160 farmers participated in the interview (Table 1). The largest age class by membership was between 41–50 years (31%), with none under 20. Most farmers (73%) did not have any formal education (Table 1). Majority of farmers (78%) lived in their area for over 20 years, subsisting mainly on crop production (98%) and livestock farming (81%) (Table 1). Among crops, rice and maize were the primary cereals grown by 70 and 76% of farmers, respectively (Supplementary Table 2).

Awareness and knowledge about parthenium weed

Only 2% of farmers called parthenium weed by a local name “Dungman Mento” (*Artemisia* flower) or used various local names, while 91% reported that

Table 1 Socio-demographic profiles of farmers interviewed for the perception of parthenium weed impacts and management in eastern Bhutan (N = 160)

	Farmers (% of total, N = 160)		
	Male	Female	Total
<i>What is your age?</i>			
< 20	0	0	0
21–30	3	3	5
31–40	11	14	24
41–50	12	19	31
51–60	11	10	21
61–70	8	7	14
> 70	3	1	4
<i>What is your education qualification?</i>			
No education	31	42	73
Primary (PP—Class 6)	9	6	14
Secondary (Class 7–10)	3	5	8
Higher Secondary (Class 11–12)	2	1	3
Bachelor and higher	3	0	3
<i>How long have you been living in this place?</i>			
< 5 years	3	3	6
6–10 years	3	1	4
11–15 years	3	4	8
16–20 years	3	1	4
> 20 years	35	43	78
<i>What is your main source of livelihood?</i>			
Crop	46	52	98
Livestock	40	41	81
Business	4	3	7
Remittances	4	11	15

Totals may not sum to exactly 100% due to rounding and multiple responses (e.g., livelihood sources)

there is no local name (Supplementary data Table 3). Majority of farmers (89%) reported parthenium weed is present along roadsides (Fig. 2A). No farmers reported its presence in sewage systems, irrigation channels, or forests (Fig. 2A).

Farmers reported varying abilities to recognize parthenium weed, with 92% perceiving that they can identify it at both the young plant and flowering stages (Fig. 2B). Parthenium weed was most frequently observed in summer (78% of farmers) (Fig. 2C). Regarding the perception when farmers first noticed the weed, 36% recalled sightings 6–10 years ago (Fig. 2D). When asked about the

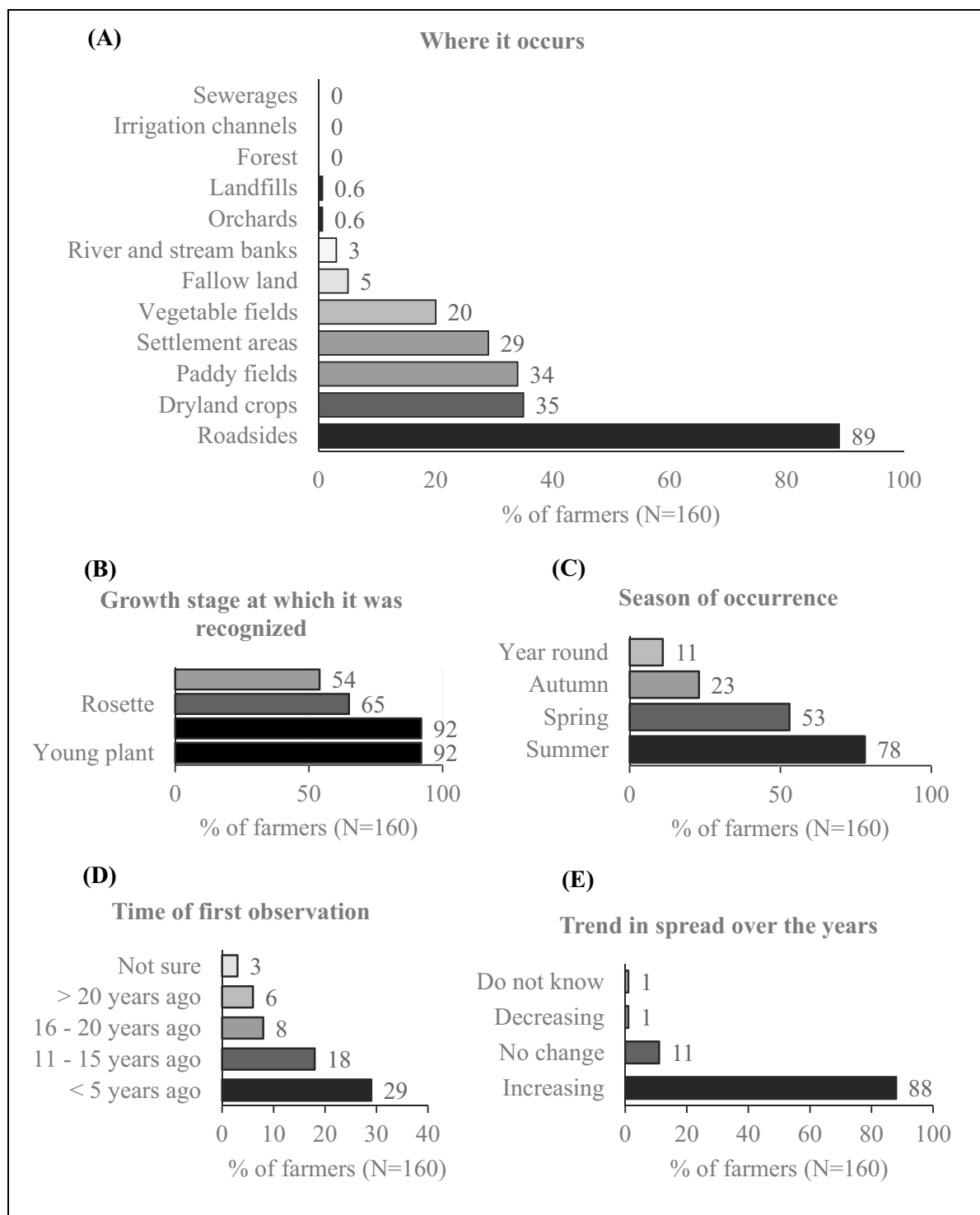


Fig. 2 Farmers' awareness and knowledge about parthenium weed with respect to landscape, where it occurs (A), growth stages as which it was recognized (B), season of occurrence

(C), time of first observation (D), and trends in spread over the years (E). *Note:* Totals may not sum to exactly 100% due to rounding and multiple responses

trend of parthenium weed invasion, 88% of farmers believed its spread was increasing (Fig. 2E).

Majority of farmers (92%) viewed parthenium weed as unwanted (Fig. 3A). Regarding invasiveness, 89% of farmers rated parthenium weed as invasive (Fig. 3B and C). No respondents perceived it as non-invasive. Majority of farmers (55%) acknowledged vehicles as key introduction pathways (Fig. 3D), and others (Supplementary Table 4).

Farmers perception of parthenium weed impacts on crop production, livestock and health

Most farmers (71%) perceived that parthenium weed does not impact crop production (Fig. 4A). Among those perceiving negative effects on crops, the main concerns were reduced crop yield as reported by 76% (Fig. 4B). Farmers perceiving yield losses in crops due to parthenium weed reported its impact on rice, maize, wheat (*Triticum aestivum* L.), vegetables (e.g., cauliflower, cabbage), potatoes, groundnuts (*Arachis hypogaea* L.), and fruit (Supplementary Table 5). The yield losses for major crops, rice and maize ranged from 12–13% (Supplementary Table 5).

About 78% of the farmers interviewed owned livestock, with cattle being the dominant livestock owned by 68% of them (Fig. 4C). About 24% farmers owning livestock believed their animals consume parthenium weed. However, when asked about the impact of feeding on the weed, only one farmer perceived a negative effect on milk production, describing how it gave the milk a bitter taste and reduced production levels. Majority of farmers (59%) perceived the negative health impacts of parthenium weed, causing various symptoms but mainly itching (76%), sneezing (56%), and rashes (53%) (Fig. 4D).

Control, management and policy context

The majority of farmers (89%) controlled parthenium weed, mainly through hand removal as reported by 97% of them (Fig. 5A). The financial costs associated with manual control were estimated by farmers to be approximately 12,500 Ngultrum (BTN) (ca. US \$150) (Supplementary Table 6) per household annually. This financial burden was entirely borne by individual households without external financial support. Despite this, only 2% of farmers reported spending their own funds specifically on parthenium

weed control, while 86% expressed concern about its spread and 89% reported actively managing it (Fig. 5B). Notably, none of the farmers reported being informed by government or other organizations about parthenium weed (Fig. 5B). The absence of community management plans (99%) and awareness of IAS-related policies or programmes (98%) (Fig. 5B) further underscores the gap in institutional outreach. The majority of farmers (89%) felt that a coordinated control and management programme was needed, with 66% specifically proposing awareness programmes as a priority. (Fig. 5C).

Discussion

Awareness and knowledge about parthenium weed

While parthenium weed was present in their locality for ≥ 20 years, only a small proportion of farmers (2%) reported calling the weed by a local name “Dungman Mento” (*Artemesia* flower), indicating that parthenium weed was not considered to be native to their area. Its resemblance to native *Artemesia* species or ragweed (*Ambrosia artemisiifolia* L.) may have led these farmers to associate the weed with this plant. Parthenium weed is known by numerous local names globally (Shabbir et al. 2024), reflecting its widespread distribution and recognition across different regions. Farmers perceived that parthenium weed is present in various habitat types ranging from roadsides, fallow land, river sides, landfills, settlement areas, and agricultural fields, reinforcing its well-documented ability to thrive under diverse environmental conditions (Tanveer et al. 2015). Roads were the primary locations where parthenium weed was perceived, aligning with findings from other studies that identify roads as major conduits through which it is spread (Adhikari et al. 2024; Blackmore and Johnson 2010; Matzrafi et al. 2021; Shrestha et al. 2019). In agricultural settings, farmers perceived that the weed is present in dryland crops (35%), paddy fields (34%), and vegetable fields (20%), highlighting its common association with these environments and its role in causing crop losses. However, unlike the findings of Bajwa et al. (2019) and Etana et al. (2015), no parthenium weed infestations were reported from sewerage or irrigation channels, or from forested areas, likely because it is yet to reach these sites. Parthenium weed is also intolerant to shade (Doley 1977; Kanchan and Jayachandra 1980)

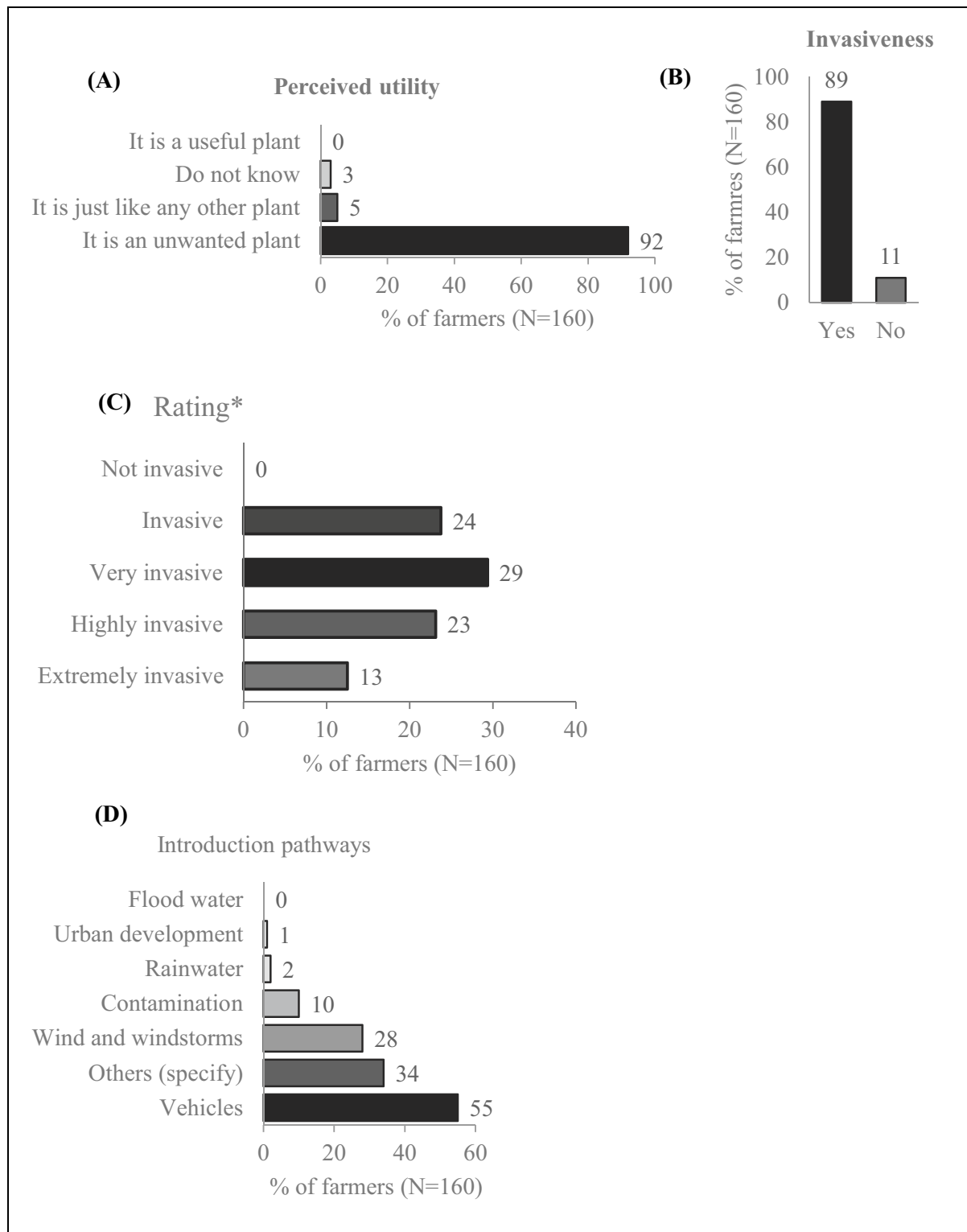


Fig. 3 Farmers' opinions about parthenium weed in eastern Bhutan, including its perceived utility (A), invasiveness (B), rating (C), and introduction pathways (D). *On a scale 1 to 5 (1=Not invasive; 5=Extremely invasive). Note: Totals may not sum to exactly 100% due to rounding and multiple responses

and Bhutan's extensive forest coverage, spanning over more 71% of its land area (Bruggeman et al. 2016) may act as a natural barrier to some aspects of its spread.

Similar to a recent questionnaire-based study in Pakistan, a very high proportion of farmers perceived that they could identify parthenium weed at different growth stages, suggesting their long-term association and familiarity with the weed (Bajwa et al. 2019). Most farmers were able to identify parthenium weed at all stages of growth, likely due to its distinctive characteristics and high visibility during each growth phases. However, dead plants were the least identifiable, as they lose their distinct morphological features and blend with other dried vegetation, making identification more challenging. Summer was the main season during which parthenium weed was most frequently observed, with 11% of the farmers perceiving its presence year-round, indicating that parthenium weed is a warm-season plant with high phenotypic plasticity and adaptability to varying environmental conditions (Adkins and Shabbir 2014). In Kathmandu Valley of Nepal, Shrestha et al. (2015) reported observing parthenium weed throughout the year. Depending upon moisture availability in the soil, parthenium weed is known to complete its life cycle within a short period of time (30 to 90 days) or extend its life over much longer periods to 240 or 300 days, depending upon temperature, soil moisture, and relative humidity (Gnanavel 2013; Tanveer et al. 2015).

Some farmers reported that they have seen parthenium weed ≥ 20 years ago, but most farmers reported seeing the weed for the first time between 6 to 10 years ago, a finding similar to the west-central Bhutan (Chhogyel et al. 2021). Probably this was the period when parthenium weed spread considerably or farmers became more aware and were able to recognize the weed for the first time. The first official report of parthenium weed in the country was in 1992 (Parker 1992). A large majority of farmers (88%) reported increasing infestations over the years, highlighting its continued spread and the growing threat it poses to farmers' livelihoods. Most

farmers considered parthenium weed an unwanted plant (92%), with 34% rating it as highly invasive, highlighting the widespread negative perception and challenges posed by this weed. Notably, no farmers perceived parthenium weed as non-invasive, further reinforcing its global reputation as one of the most aggressive and problematic invasive species (Adkins et al. 2019).

Farmers' perceptions of vehicle movement as the primary dispersal pathway are consistent with other studies (Akter and Zuberi 2009; Bajwa et al. 2018; Bambaradeniya 2002; Khan et al. 2018; Marambe et al. 2001; Mishra 1991; Shrestha et al. 2015). However, in Pakistan, irrigation (Bajwa et al. 2019; Khan et al. 2018) and roads (Shabbir et al. 2011) were identified as the main methods of introduction, highlighting the variation in dispersal mechanisms across different regions. Wind and windstorms (28%) was also perceived to be an important mode of spread in Bhutan. However, a wind tunnel study showed that parthenium weed seed could travel only up to 2 m under a wind velocity of 2 m s^{-1} (Mao et al. 2022), raising uncertainty about the extent to which wind significantly contributes to its dispersal.

Impact of parthenium weed on crop production

Most farmers believed that parthenium weed was not presently impacting crop production, in contrasts to its considerable negative impact on crop production known elsewhere (Shabbir et al. 2024). This is possibly due to the weed still being in its early phase of invasion in the eastern Districts, despite being environmentally and climatically suitable (Dorji et al. 2025). However, 29% of the farmers did perceive the weed's negative impacts, primarily by reducing crop yields (49%). Maize and rice, the two primary cereal crops grown in eastern Bhutan, were reported to suffer 12 and 13% yield loss, respectively (Supplementary data Table 4).

Impact of parthenium weed on livestock

While no significant impact on the livestock production was perceived, about 24% felt livestock consumed parthenium weed, though only one farmer reported milk tasting bitter and quality reduced. Parthenium weed is normally nonpalatable to livestock due to its odour, taste, and the trichome hairs on its

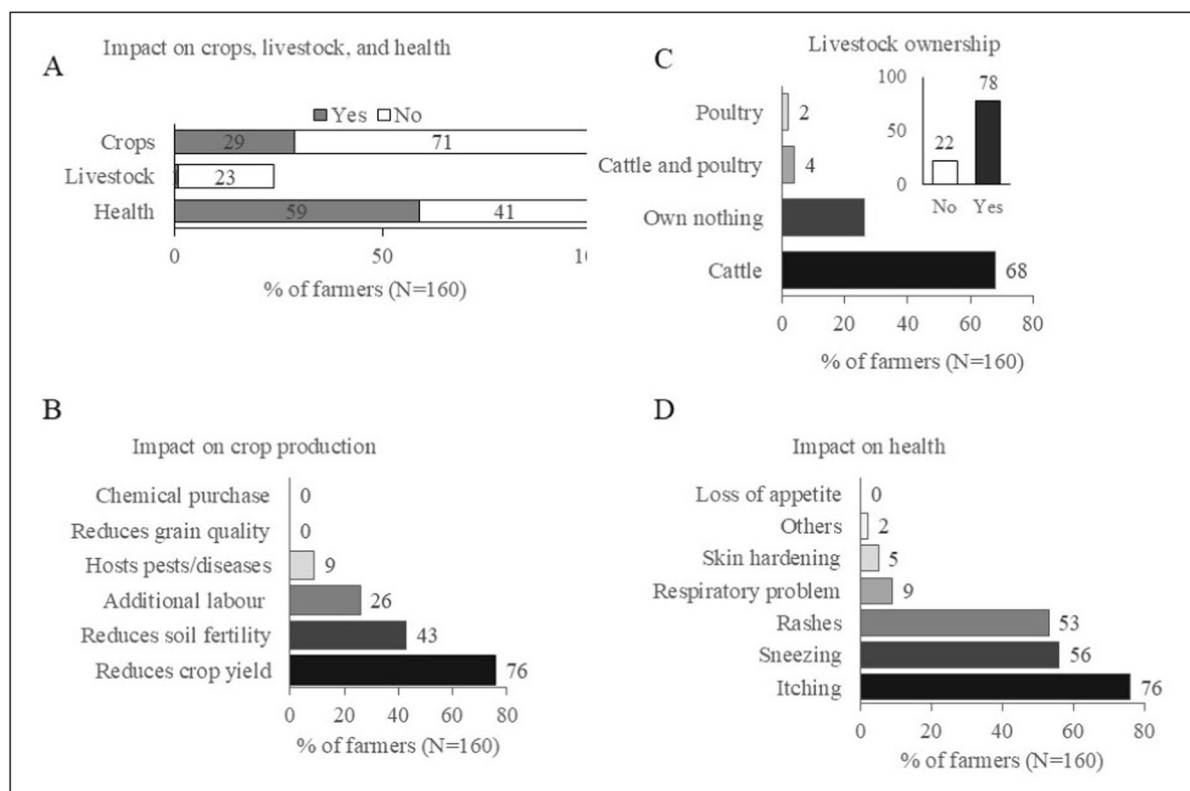


Fig. 4 Farmers' opinions about the impacts of parthenium weed, including different types of impacts (A), impact on crop production (B), impact on livestock (C), and impact on health

(D). Note: Totals may not sum to exactly 100% due to rounding and multiple responses

stems and leaves (Gnanavel 2013), which makes it undesirable for livestock (Khosla and Sobti 1981; Narasimhan et al. 1977). However, when pasture is scarce, livestock may be forced to eat, increasing the risk of potential health effects. Moreover, since parthenium weed is in its initial phase of invasion in Bhutan, it may not yet be abundantly available to cause impact on livestock. Furthermore, the use of improved cattle breeds, and the use of stall-feeding are both increasing in the country (Department of Livestock 2021), which may also be part of the lower impact on cattle. In other countries, impacts on livestock have been reported, including on horses (*Equus ferus caballus* L.) (Dhileepan 2009), goats (*Capra aegagrus hircus* L.) (Ayele 2007; Karki 2008; Narasimhan et al. 1977), sheep (*Ovis aries* L.) (Ayele 2007; Tudor et al. 1982), and chickens (*Gallus gallus domesticus* (L.) (Evans 1997).

Impact of parthenium weed on public health

A majority of farmers (59%) perceived negative impacts of parthenium weed on their health, mainly itching, rashes and sneezing, which are well known health impacts believed to be associated with this weed (Goldsworthy 2005; Karki 2008; Roy and Shaik 2013; Shrestha et al. 2015). While the exact mechanism remains unclear, contact with parthenium weed triggers hypersensitivity reactions in the skin due to airborne pollen and particles, leading to skin rashes, and itching, while inhalation induces sneezing (Sharma and Sethuraman 2007). Parthenium weed produces a large quantity of pollen, estimated at around 624 million pollen grains per plant (Towers and Mitchell 1983), with peak production time occurring in the summer (Jain 1993). As the peak pollen production coincides with the agricultural season, farmers are particularly vulnerable to its effects.

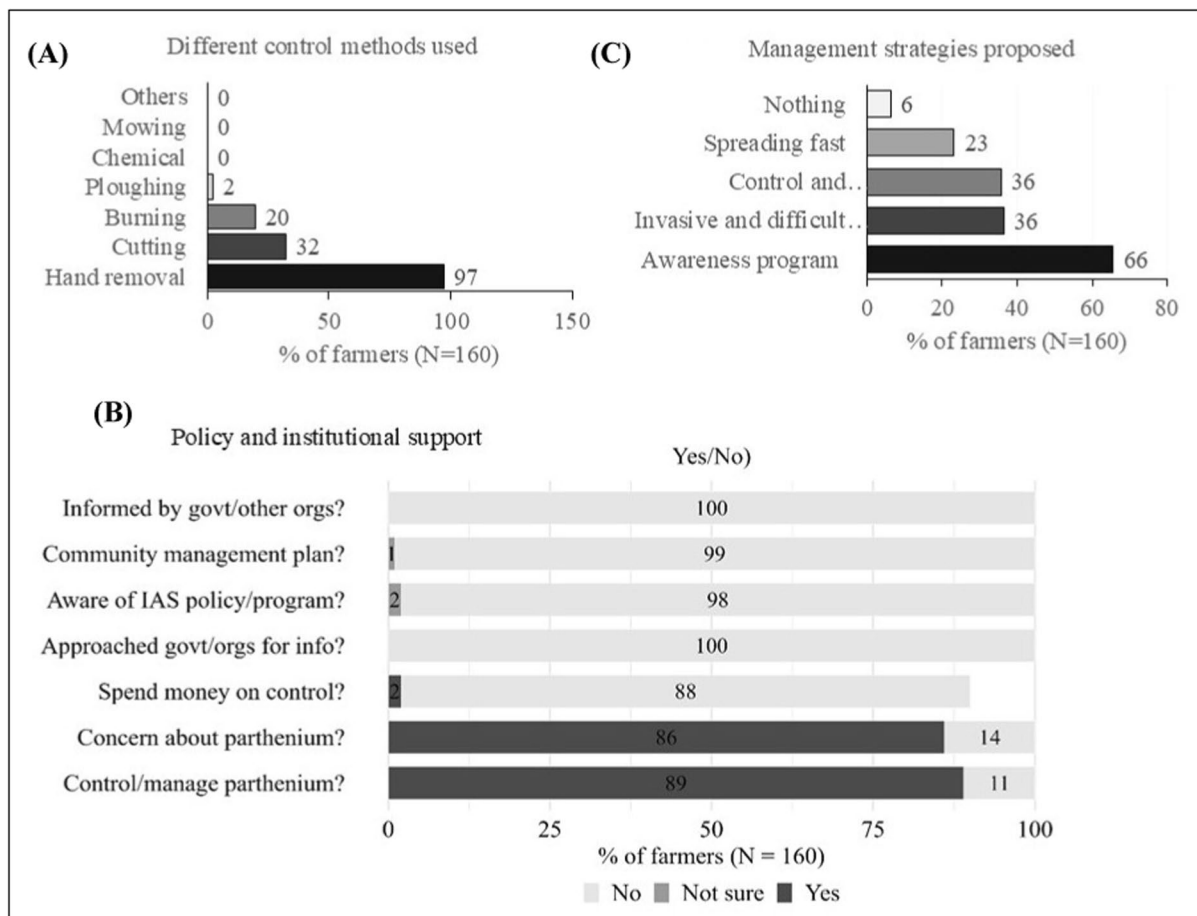


Fig. 5 Farmers' opinion about parthenium weed management in eastern Bhutan, including different control practices used by the farmers (A), policy and institutional support (B), and

management strategies proposed by farmers (C). *Note:* Totals may not sum to exactly 100% due to rounding and multiple responses

Management of parthenium weed

The perception assessment indicated a strong proactive response from farmers in eastern Bhutan toward controlling parthenium weed, with 89% actively implementing management measures, emphasising the extent of their concern about its impact. The primary method of control was the hand removal and burning, utilized by 97% of farmers. However, manual removal is only feasible for small and isolated infestation and is not practical or economical for larger area (Adkins and Shabbir 2014; Campbell et al. 2019). Farmers reported spending *ca.* US \$150 on parthenium weed control, which is a substantial amount given their economic circumstances. However, this figure is based only

on 2% of the farmers who reported spending money on control measures, indicating a need for further assessment through future research and experimental studies. Moreover, parthenium weed being an allergic plant, manual removal would require wearing protective gear like a face mask, long shirt sleeves, and gloves (Goodall et al. 2010), adding cost to the control. No farmer reported using chemical, mowing, or other methods of control, which reflected either a lack of access to such resources or a preference for more traditional, labour-intensive, and inexpensive methods. The reasons why farmers did not adopt other management methods were not explicitly captured in this assessment and future research may be warranted. However, Bhutan has highly regulated and restricted chemical use and only three herbicides

are available, including butachlor and Ethoxysulfuron in transplanted rice and metribuzin in potatoes (<https://www.nppc.gov.bt/>).

Policy and community management of parthenium weed

The findings highlighted considerable farmer concerns regarding parthenium weed, with 86% of respondents perceiving it as a major issue affecting their agricultural activities and livelihoods. Despite this high level of awareness, the absence of a community-level management plan as reported by 99% of farmers and the lack of IAS-related policies as reported by 98% of farmers revealed a critical gap in coordinated control efforts and institutional support. This gap is further emphasized by the fact that none of the surveyed farmers reported seeking information or assistance from the government or any relevant organizations, indicating limited outreach and engagement from extension services or environmental agencies. Farmers consistently perceived parthenium weed as highly invasive, fast spreading, and difficult to control once established, reinforcing the urgent need for comprehensive management strategies. These findings highlight the necessity of developing awareness campaigns, strengthening institutional frameworks, and establishing policies and community-driven action plans to effectively address the perceived spread and socio-economic impacts of parthenium weed in Bhutan.

While the perceptions of farmers provide valuable insights into the presence, spread, and impacts of parthenium weed in eastern Bhutan, this assessment is not without limitations. Perceptions reported in this assessment are inherently subjective and may be influenced by several factors, such as recall bias, agronomic knowledge, and the tendency to associate crop losses, pest problems, or health issues to the most visible or familiar cause rather than to parthenium weed specifically. Without conducting field-based assessments, it is challenging to draw firm conclusions about the magnitude of impacts or to attribute observed changes specifically to parthenium weed. Future study is proposed that combines questionnaire-based assessments with field measurements and ecological surveys to get a more comprehensive understanding of the true extent and impacts of parthenium weed invasion in Bhutan.

Conclusion

This perception-based assessment indicates that parthenium weed poses a considerable and growing threat to agriculture, livestock, and health in eastern Bhutan. Farmers consistently reported that the weed is invasive, expanding its distribution, and causes wide-ranging impacts, highlighting the urgent need for actions. The absence of community-level management plans and policies related to IAS represents a critical gap that requires immediate attention. We recommend the development of targeted awareness programmes, early detection and rapid response mechanisms, and dedicated policy frameworks to prevent further spread and mitigate the impacts of parthenium weed in Bhutan.

Acknowledgements This study is part of the PhD project of Sangay Dorji. He is thankful to The University of Queensland (UQ), Australia for awarding him the Research Training Program scholarship. The authors also thank Professor Ammar Aziz of the School of Agriculture and Food Sustainability, The University of Queensland, for his assistance in obtaining ethical clearance for this study. We also would like to thank Dr Hanwen Wu and Dr Muhammad Nawaz of New South Wales Department of Primary Industries and Regional Development for reviewing the earlier version of this manuscript. Thanks also to data collectors (Pema Rinzin, Sonam Tenzin, Tashi Tshering, Tshering Yangden) in Bhutan. Lastly, we would like to thank the anonymous reviewer/s for the improvement of our paper and the editorial staff for their support.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. The authors have not disclosed any funding.

Availability of data and material Electronic supplementary material.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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References

- Adamson DC (1996) Introducing dynamic considerations when economically evaluating weeds. The University of Queensland, Brisbane
- Adhikari A, Subedi A, Tiwari A, Shrestha B (2024) Impacts of road on plant invasions in the Middle Mountain region of central Nepal. *J Mt Sci* 21:619–632
- Adkins S, Shabbir A (2014) Biology, ecology and management of the invasive parthenium weed (*Parthenium hysterophorus* L.). *Pest Manag Sci* 70:1023–1029
- Adkins S, Asad S, Dhileepan K (2019) An introduction to the ‘demon plant’ parthenium weed. In: Adkins S, Shabbir A, Dhileepan K (eds) *Parthenium weed: biology, ecology and management*. CAB International, Wallingford, pp 1–6
- Akter A, Zuberi M (2009) Invasive alien species in Northern Bangladesh: identification, inventory and impacts. *Int J Biodivers Conserv* 1:129–134
- Angiras NN, Saini JP (1997) Distribution, menace and management of *Parthenium hysterophorus* L. in Himachal Pradesh. In: Mahadevappa M and Patil VC (eds) *First international conference on parthenium management Dharwad (Karnataka)*, pp 13–15
- Ayele S (2007) The impact of parthenium (*Parthenium hysterophorus* L.) on the range ecosystem dynamics of the Jijiga rangeland, Ethiopia. Department of Animal Sciences, School of Graduate Studies. Haramaya University, Ethiopia
- Bajwa AA, Chauhan BS, Farooq M, Shabbir A, Adkins SW (2016) What do we really know about alien plant invasion? A review of the invasion mechanism of one of the world’s worst weeds. *Planta* 244:39–57
- Bajwa AA, Nguyen T, Navie S, O’Donnell C, Adkins S (2018) Weed seed spread and its prevention: the role of roadside wash down. *J Environ Manage* 208:8–14
- Bajwa AA, Farooq M, Nawaz A, Yadav L, Chauhan BS, Adkins S (2019) Impact of invasive plant species on the livelihoods of farming households: evidence from *Parthenium hysterophorus* invasion in rural Punjab, Pakistan. *Biol Invasions* 21:3285–3304
- Bajwa AA, Ullah A, Farooq M, Chauhan BS, Adkins S (2020) Competition dynamics of *Parthenium hysterophorus* in direct-seeded aerobic rice fields. *Exp Agric* 56:196–203
- Bambaradeniya CN (2002) The status and implications of alien invasive species in Sri Lanka. *Zoos’ Print J*. <https://doi.org/10.11609/jott.zpj.17.11.930-5>
- Belgeri A (2013) Assessing the impact of parthenium weed (*Parthenium hysterophorus* L.) invasion and its management upon grassland community composition. The University of Queensland, Brisbane
- Blackmore PJ, Johnson SB (2010) Continuing successful eradication of parthenium weed (*Parthenium hysterophorus*) from New South Wales, Australia. In: Zydenbos SM (ed) *Seventeenth Australasian Weeds Conference*. New Zealand Plant Protection Society, ISBN 978-0-86476-239-9, Christchurch Convention Centre, Christchurch, New Zealand, 26–30 September 2010
- Bruggeman D, Meyfroidt P, Lambin EF (2016) Forest cover changes in Bhutan: revisiting the forest transition. *Appl Geogr* 67:49–66
- Campbell SD, Vogler WD, Tamado Tana TT (2019) Management: physical, cultural, chemical. In: Adkins S, Shabbir A, Dhileepan K (eds) *Parthenium weed: biology, ecology and management*. CAB International, Wallingford, pp 157–176
- Chhogyel N, Kumar L, Bajgai Y (2021) Invasion status and impacts of parthenium weed (*Parthenium hysterophorus*) in West-Central region of Bhutan. *Biol Invasions*. <https://doi.org/10.1007/s10530-021-02534-3>
- Department of Livestock (2021) *Livestock Census 2021*. Department of Livestock, Ministry of Agriculture and Livestock, Thimphu, Bhutan
- Dhileepan K (2009) Managing parthenium weed across diverse landscapes: prospects and limitations. In: Inderjit (ed) *Management of invasive weeds*. Springer, pp 227–260
- Doley D (1977) *Parthenium weed (Parthenium hysterophorus L.): gas exchange characteristics as a basis for prediction of its geographical distribution*. *Aust J Agric Res* 28:449–460
- Dorji S, Lakey L, Wangchen T, Adkins S (2021) Predicting the distribution of parthenium weed (*Parthenium hysterophorus*) under current and future climatic conditions in Bhutan. *J Environ Occup Health* 12:169–181
- Dorji S, Stewart S, Shabbir A, Bajwa A, Aziz A, Adkins S (2025) Comparative analysis of mechanistic and correlative models for global and Bhutan-specific suitability of parthenium weed and vulnerability of agriculture in Bhutan. *Plants* 14:83
- Dorji S, Adkins S (2020) First record of the beetle *Zygothrips bicolorata* and the rust fungus *Puccinia abrupta* var. *partheniicola* on *Parthenium hysterophorus* in Bhutan. *Tropical & Sub-Tropical Weed Research Unit, The University of Queensland, Australia*. In collaboration with IOBC working group on biological control and management of parthenium weed. *International Parthenium News*. Queensland, pp 16
- Etana A, Kelbessa E, Soromessa T (2015) Impact of *Parthenium hysterophorus* L. (Asteraceae) on soil chemical properties and its distribution in a reserve area: a case study in Awash National Park (ANP), Ethiopia. *J Soil Sci Environ Manage* 6:116–124
- Evans HC (1997) *Parthenium hysterophorus*. A review of its weed status and the possibilities for biological control. *Biocontrol News Inf* 18:89N–98N
- Gnanavel I (2013) *Parthenium hysterophorus* L.: a major threat to natural and agro eco-systems in India. *Sci Int* 1:186–193
- Goldsworthy D (2005) Parthenium weed, allergy symptoms and health status in a rural community. *Queensland Health and Medical Scientific Meeting*. Brisbane, November 2005
- Goodall J, Braack M, de Klerk J, Keen C (2010) Study on the early effects of several weed-control methods on *Parthenium hysterophorus* L. *Afr J Range Forage Sci* 27:95–99

- Gupta S, Chanda S (1991) Aerobiology and some chemical parameters of *Parthenium hysterophorus* pollen. *Grana* 30:497–503
- Hulme PE (2006) Beyond control: wider implications for the management of biological invasions. *J Appl Ecol* 43:835–847
- IPBES (2023) Summary for policymakers of the thematic assessment report on invasive alien species and their control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Roy HE, Pauchard A, Stoett P, Renard Truong T, Bacher S, Galil BS, Hulme PE, Ikeda T, Sankaran KV, McGeoch MA, Meyerson LA, Nuñez MA, Ordóñez A, Rahlao SJ, Schwindt E, Seebens H, Sheppard AW and Vandvik V (eds). Bonn, Germany. <https://doi.org/10.5281/zenodo.7430692>
- Jain AK (1993) Allergenic pollen grains of *Parthenium hysterophorus* Linn. In the atmosphere of Gwalior (MP). *Proc. Natl. Acad. Sci. U.S.A., India, Section B* 59, 55–58
- Kanchan SD, Jayachandra (1980) Allelopathic effects of *Parthenium hysterophorus* L.: Part II. Leaching of inhibitors from aerial vegetative parts. *And Soil* 55:61–66
- Karki D (2008) Ecological and socioeconomic impacts of *Parthenium hysterophorus* L. invasion in two urban areas in Nepal. *Science in Botany, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal*
- Khan I, Navie S, George D, O'donnell C, Adkins S (2018) Alien and native plant seed dispersal by vehicles. *Austral Ecol* 43:76–88
- Khosla S, Sobti S (1981) *Parthenium*—a national health hazard, its control and utility—a review. *Pesticides* 13:121–127
- Kull CA, Shackleton CM, Cunningham PJ, Ducatillon C, Dufour-Dror J-M, Esler KJ, Friday JB, Gouveia AC, Griffin AR, Marchante E, Midgley SJ, Pauchard A, Rangan H, Richardson DM, Rinaudo T, Tassin J, Urgenson LS, von Maltitz GP, Zenni RD, Zylstra MJ (2011) Adoption, use and perception of Australian acacias around the world. *Divers Distrib* 17:822–836
- Kumar S (2012) Current spread, impact and management of parthenium weed in India. *International Parthenium News. Tropical and Sub-Tropical Weed Research Unit. The University of Queensland, Australia*
- Lakshmi C, Srinivas C (2012) *Parthenium* the terminator: an update. *Indian Dermatol Online J* 3:89–100
- Lakshminarasimhappa MC (2022) Web-based and smart mobile app for data collection: Kobo Toolbox/Kobo Collect. *J Indian Libr Assoc* 57:8
- Lonkar A, Mitchell JC, Calnan CD (1974) Contact dermatitis from *Parthenium hysterophorus*. *Trans St Johns Hosp Dermatol Soc* 60:43–53
- Mao R, Bajwa AA, Adkins S (2021a) A superweed in the making: adaptations of *Parthenium hysterophorus* to a changing climate. A review. *Agron Sustain Dev* 41:47
- Mao R, Shabbir A, Adkins S (2021b) *Parthenium hysterophorus*: a tale of global invasion over two centuries, spread and prevention measures. *J Environ Manage* 279:111751
- Mao R, Osunkoya OO, Campbell S, Adkins SW (2022) Wind dispersal of seeds of *Parthenium hysterophorus* L. (Asteraceae) contributes to its steady invasion and spread. *Austral Ecol* 47:791–803
- Marambe B, Bambaradeniya C, Kumara DP, Pallewatta N (2001) Human dimensions of invasive alien species in Sri Lanka. In: McNeely J (ed) *The great reshuffling human dimensions of invasive alien species*. IUCN World Conservation Union, pp 135–142
- Marsh AS, Hayes DC, Klein PN, Zimmerman N, Dalsimer A, Burkett DA, Huebner CD, Rabaglia R, Meyerson LA, Harper-Lore BL, Davidson JL, Emery MR, Warziniack T, Flitcroft R, Kerns BK, Lopez VM (2021) Sectoral impacts of invasive species in the United States and approaches to management. In: Poland TM, Patel-Weyand T, Finch DM, Miniati CF, Hayes DC, Lopez VM (eds) *Invasive species in forests and rangelands of the United States: a comprehensive science synthesis for the United States Forest Sector*. Springer International Publishing, Cham, pp 203–229
- Matzrafi M, Raz H, Rubin B, Yaacoby T, Eizenberg H (2021) Distribution and biology of the invasive weed *Parthenium hysterophorus* L. in Israel. *Front Agron* 3:639991
- McConnachie AJ, Strathie LW, Mersie W, Gebrehiwot L, Zewdie K, Abdurehim A, Abrha B, Araya T, Asaregew F, Assefa F, Gebre-Tsadik R, Nigatu L, Tadesse B, Tana T (2011) Current and potential geographical distribution of the invasive plant *Parthenium hysterophorus* (Asteraceae) in eastern and southern Africa. *Weed Res* 51:71–84
- Mishra KK (1991) *Parthenium hysterophorus* Linn: a new record for Nepal. *J Bombay Nat Hist Soc* 88:466–467
- Narasimhan TR, Ananth M, Swamy MN, Babu MR, Mangala A, Rao PV (1977) Toxicity of *Parthenium hysterophorus* L. to cattle and buffaloes. *Experientia* 33:1358–1359
- National Statistical Bureau (2023) *Statistical Yearbook of Bhutan 2023*. National Statistical Bureau, Royal Government of Bhutan, PO Box No 338, Thimphu, Bhutan
- Navie S (2003) The biology of *Parthenium hysterophorus* L. in Australia. *The University of Queensland, Brisbane*
- Nguyen T, Bajwa AA, Navie S, O'donnell C, Adkins S (2017) *Parthenium* weed (*Parthenium hysterophorus* L.) and climate change: the effect of CO₂ concentration, temperature, and water deficit on growth and reproduction of two biotypes. *Environ Sci Pollut Res* 24:10727–10739
- Parker C (1992) *Weeds of Bhutan*. National Plant Protection Center, Ministry of Agriculture, Thimphu
- R Core Team (2023) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, Kidd KA, McCormack TJ, Olden JD, Ormerod SJ, Smol JP, Taylor WW, Tockner K, Vermaire JC, Dudgeon D, Cooke SJ (2019) Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol Rev* 94:849–873
- Roy D, Shaik MM (2013) Toxicology, phytochemistry, bioactive compounds and pharmacology of *Parthenium hysterophorus*. *J Med Plant Stud* 1:126–141
- Shaanker RU, Joseph G, Aravind NA, Kannan R, G KN (2009) 202Chapter 14 Invasive plants in tropical human-dominated landscapes: need for an inclusive management strategy. In: Perrings C, Mooney H, Williamson M (eds)

- Bioinvasions and globalization: ecology, economics, management, and policy. Oxford University Press
- Shabbir A (2014) Ragweed emerging a major host for the cotton mealy bug in Pakistan. *Indian J Weed Sci* 46:291–293
- Shabbir A, Bajwa AA, Mao R, Kezar S, Dorji S, Adkins SW (2024) Biology of invasive plants 6. *Parthenium hysterophorus* L. *Invasive Plant Sci Manag* 17:129–156
- Shabbir A, Dhileepan K, Adkins S (2011) Spread of parthenium weed and its biological control agent in Punjab, Pakistan. In: Proceedings of the 23rd Asia-Pacific weeds science society conference: weed management in a changing world. Cairns, Queensland, Australia, pp 497–503
- Sharma J, Pavlova M, Groot W (2024) Rural–urban inequalities in health care utilization in Bhutan: a decomposition analysis. *Int J Equity Health* 23:69
- Sharma VK, Sethuraman G (2007) Parthenium dermatitis. *Dermatitis* 18:183–190
- Sharman M, Persley DM, Thomas JE (2009) Distribution in Australia and seed transmission of tobacco streak virus in *Parthenium hysterophorus*. *Plant Dis* 93:708–712
- Shrestha BB, Shabbir A, Adkins SW (2015) *Parthenium hysterophorus* in Nepal: a review of its weed status and possibilities for management. *Weed Res* 55:132–144
- Shrestha B, Pokhrel K, Paudel N, Poudel S, Shabbir A, Adkins SW (2019) Distribution of *Parthenium hysterophorus* and one of its biological control agents (Coleoptera: *Zygothema bicolorata*) in Nepal. *Weed Res* 59:467–478
- Sushilkumar, Varshney JG (2010) Parthenium infestation and its estimated cost management in India. *Indian J Weed Sci* 42(73):77
- Tamado T, Schutz W, Milberg P (2002) Germination ecology of the weed *Parthenium hysterophorus* in eastern Ethiopia. *Ann Appl Biol* 140:263–270
- Tanveer A, Khaliq A, Ali HH, Mahajan G, Chauhan BS (2015) Interference and management of parthenium: the world's most important invasive weed. *Crop Prot* 68:49–59
- Thinley U, Banterng P, Gonkhamdee S, Katawatin R (2019) Distributions of alien invasive weeds under climate change scenarios in mountainous Bhutan. *Agronomy* 9:442
- Thomas SM (2023) Invasive alien species: a rising global threat that needs control. *Lancet Planet Health* 7:e875–e876
- Towers GH, Mitchell JC (1983) The current status of the weed *Parthenium hysterophorus* L. as a cause of allergic contact dermatitis. *Contact Dermatitis* 9:465–469
- Tshering C, Adkins S (2012) Parthenium weed in Bhutan. *International Parthenium News. Tropical and Sub-Tropical Weed Research Unit, The University of Queensland, Australia*, p 2
- Tudor G, Ford A, Armstrong T, Bromage E (1982) Taints in meat from sheep grazing *Parthenium hysterophorus*. *Aust J Exp Agric* 22:43–46

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