

Research Article

Ecological Diversity of Summer Maize Weed Species in the Western Mid-Hills of Nepal

Dinesh Marasini , Shrawan Kumar Sah , Santosh Marahatta ,
and Madhav Prasad Neupane 

Department of Agronomy, Agriculture and Forestry University, Bharatpur, Nepal

Correspondence should be addressed to Dinesh Marasini; dmarasini@afu.edu.np

Received 11 September 2025; Revised 19 December 2025; Accepted 20 December 2025

Academic Editor: Flavio Boccia

Copyright © 2026 Dinesh Marasini et al. International Journal of Agronomy published by John Wiley & Sons Ltd. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

Maize (*Zea mays* L.) cultivation in the mid-hills of Nepal is vital for food security but faces significant yield losses due to weed competition. The two-year (2023–2024) phytosociological study on summer maize was conducted to assess weed diversity and dynamics in randomly selected 40 farmers' fields of Puranchaur, Dhikidada, Gharmi, and Lamachaur at Pokhara Metropolitan City of Nepal. During both years, a total of 21 weed species were documented, predominantly from the Asteraceae and Poaceae families, and the majorities were annual broadleaf weeds. *Persicaria nepalensis* (Meisner) H. Gross emerged as the most ecologically significant species, exhibiting the highest Importance Value Index (49.06) due to its widespread distribution, higher density, and abundance. *Cyperus* spp. (34.74), *Galinsoga parviflora* Cav. (31.86), and *Ageratum conyzoides* L. (26.96) were also dominant, reflecting resilience in a rainfed disturbed environment. Spatial-temporal analysis revealed declining weed diversity in Dhikidada (Shannon index: 2.23 to 2.04) but increased in Gharmi (1.97 to 2.09). The study underscores the need for integrated weed management that targets the dominant weed species and actively monitors shifts in community diversity to reduce yield losses and enhance maize production for smallholders in the region.

Keywords: mid-hill; Nepal; phytosociological parameters of weed; summer maize; weed diversity

1. Introduction

Maize (*Zea mays* L.) is a valuable and versatile cereal that can be grown in diverse environments and geographical regions for food, feed, fodder, and raw materials for industrial products. In Nepal maize is grown in 0.94 million-ha, of which 67% of area, and 61% of the production is accompanied by the mid-hills region [1]. The majority of maize in mid-hills is grown on upland as a rainfed crop during the rainy season and it is a way of life for most of the hill farmers [2]. Maize-based cropping systems are dominant in upland, i.e., Bari land of mid-hills [3]. Due to large spacing, high fertilizer use [4], and adequate moisture content accompanied with high rainfall [5], rainy season maize is greatly infested by a wide range of weed flora [6]. Weeds lower photosynthetic efficiency, dry matter production, and distribution of photosynthate to

reproductive parts, which lowers the crop's sink capacity and results in low grain yield [7]. Yield losses in maize due to weeds ranges from 28% to 100% [8], 35%–83% [9], 7%–62% [10], and 8%–60% [11]. Weed removal in smaller farms in hills is done manually [12]. Due to labor migration and urbanization, manual weeding is getting more expensive, which raises the cost of production [13]. Thus, specific and effective weed management practices for small hill farmers could save the cost of cultivation and maximize their profit.

For the development of a specific weed control strategy, the first step involves the identification of problematic and dominant weed species in an area since the weed population extremely varies over the location and within the location as well [14]. A phytosociological survey is a method used to study plant communities, focusing on the types and distribution of plants in an area [15]. In agriculture, these surveys are useful for

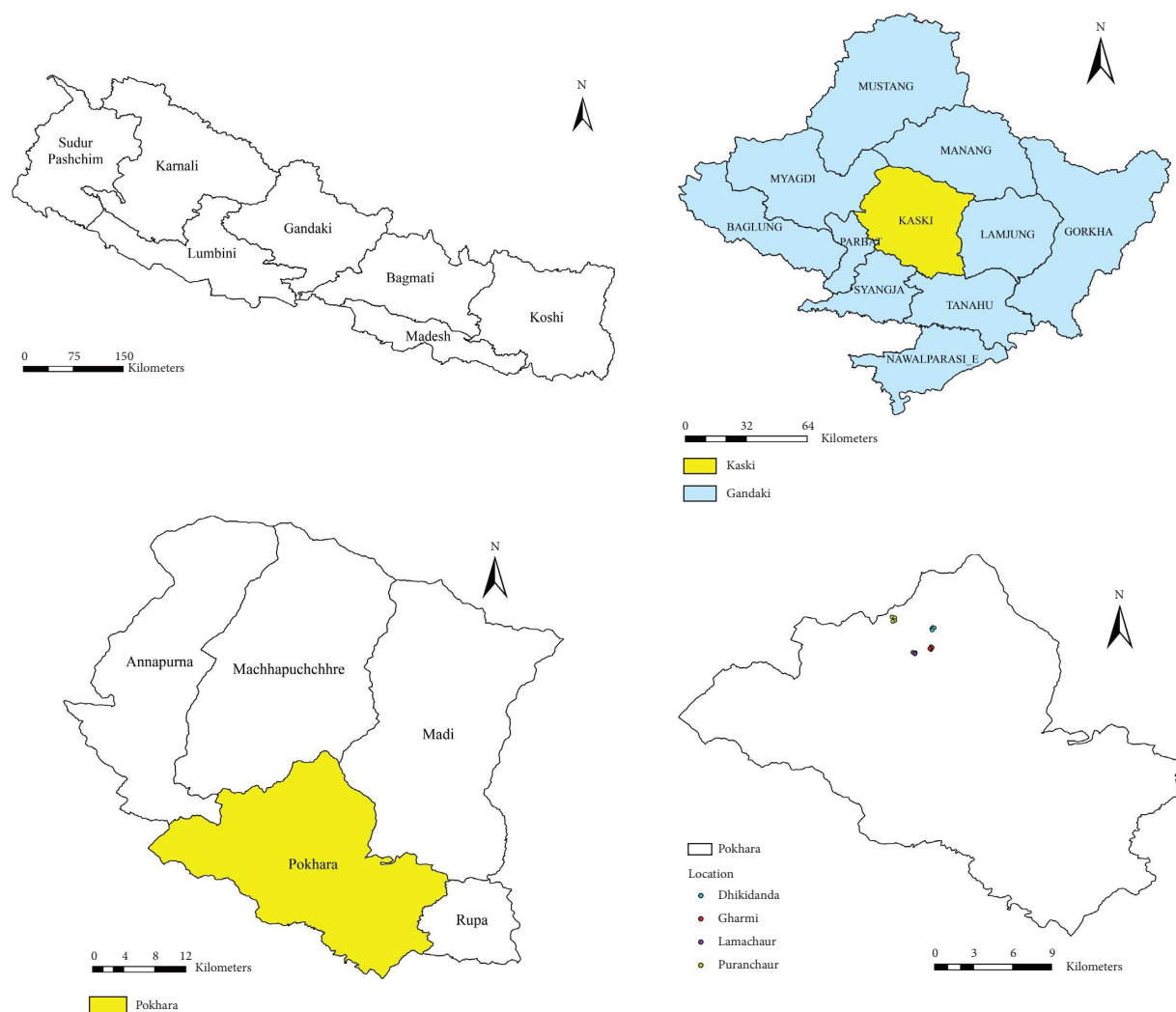


FIGURE 1: Map showing the study location (Source: ArcGIS, 2024).

understanding weed dynamics in crop fields. This helps to identify changes in weeds within crops, and how these changes relate to farming practices, and can guide the development of site-specific weed management strategies [16]. Phytosociological study is the starting point for the development of appropriate, effective, and affordable weed management technology. Thus, this study was undertaken to determine the phytosociological characters of weeds in summer maize in the western mid-hill of Nepal with the view to identify the most important weeds associated with maize that can be the entry point for an effective weed management strategy.

2. Materials and Methods

2.1. Study Site. The phytosociological survey was carried out during the rainy season of 2023 and 2024 at Pokhara Metropolitan City-Ward 16 and 19 (viz., Lamachaur, Dhikidada, Gharmi, and Puranchaur). The study area extends from 28°17'52"N/83°56'45"E to 28°16'21"N/83°57'42"E from East to West and 28°17'52"N/83°56'45"E to 28°16'21"N/83°56'41"E from North to South (Figure 1).

The elevation of the study area ranges from 1038 to 1227 msal.

2.2. Climate. The region has a moderate subtropical climate [17], with annual rainfall of about 3900 mm [18]. The weather condition of the study site during rainy season is presented in Figure 2.

2.3. Weed Survey Methodology. The weed survey was conducted in the rainy season of 2023 and 2024. Each year, 40 farmers from Pokhara Metropolitan City Ward Nos. 16 and 19 (10 from each location, viz., Lamachaur, Gharmi, Dhikidada, and Puranchaur), growing maize in succession to wheat or mustard, were randomly selected, having a farm size of at least 0.25 ha. Weed sampling was done from a quadrant of 1 m² (1 × 1 m) from each farmer between 60 and 70 days after sowing of maize, a period coinciding with the critical period of crop weed competition. All weeds within the quadrant were carefully uprooted.

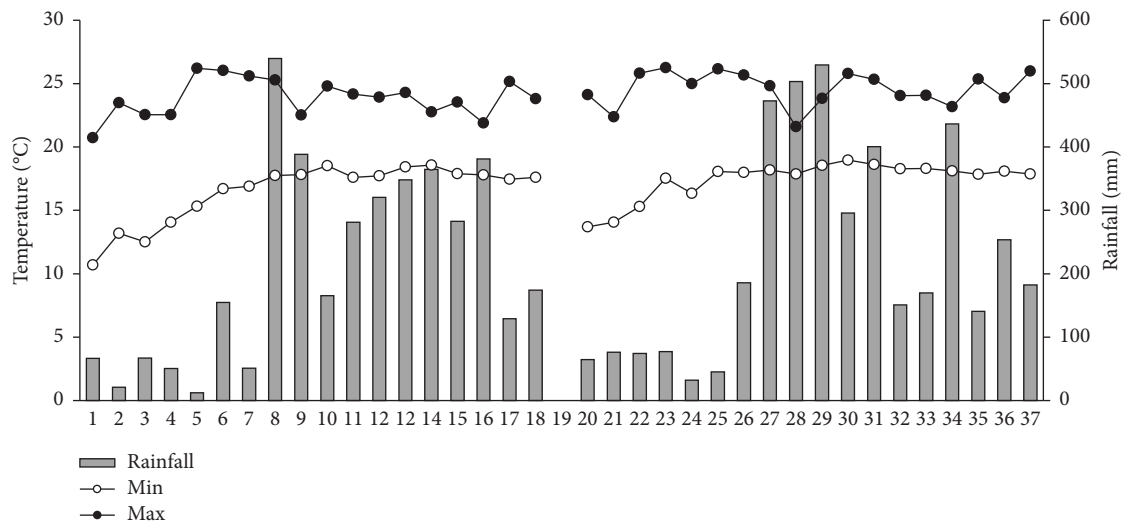


FIGURE 2: Weather conditions of the study site during the rainy seasons of 2023 and 2024. Note: 1–18 = weather condition in 2023; 20–37 = weather condition in 2024; 19 = blank (gap between years); 1 = May 1st Week; 2 = May 2nd Week; each number represents one-week interval; in the next year, 20, 21, and so on are the same as 1 and 2 of the first year (Source: Directorate of Agricultural Research, Gandaki Province, Lumle).

2.4. Weed Identification Protocol. In the field, weed specimens were initially sorted and counted by species. For species that could be confidently identified on-site using standard morphological keys, data were recorded directly. For specimens that could not be readily identified in the field, representative samples were collected, tagged, and prepared as herbarium. This preparation involved pressing the plants between absorbent paper and drying them using a standard plant press for subsequent detailed analysis. All specimens, both those identified in the field and those collected as herbarium, were then subjected to formal botanical identification. This process was conducted with the expert assistance and the reference herbarium at the National Herbarium and Plant Laboratories in Godawari,

Kathmandu, Nepal. There, specimens were cross-verified, identified to the level of family, genus, and species, and confirmed against the herbarium's reference collections [19].

2.5. Data Analysis. The following phytosociological parameters were calculated for each species.

Frequency refers to the proportion of sampling units (e.g., quadrats) in which a particular species is found relative to the total number of sampling units surveyed (i.e., 80). This is the likelihood of finding a species in a specific quadrant or sample area [20]. A high frequency indicates that the species is widely distributed across the sampled area. It is calculated using the formula given by [21].

$$\text{Frequency} = \frac{\text{Number of quadrants in which particular species occurred}}{\text{Total number of quadrants}} \quad (1)$$

A species' relative frequency, expressed as a percentage using [20] formula, indicates how common it is in a given area. A high relative frequency indicates that the species is dominant or extremely common because it is found in a higher number of sampling units than the majority of others.

$$\text{Relative frequency} = \frac{\text{Frequency of particular species}}{\text{Total frequency of all species}} \times 100. \quad (2)$$

Density refers to the average number of individuals of a particular species per sampling unit (e.g., quadrant). A high density indicates that the species is abundant in the sampled area. It is calculated using the formula given by [21].

$$\text{Density} = \frac{\text{Total number of particular species in all quadrants}}{\text{Total number of quadrants}} \quad (3)$$

Relative density is a measure of how abundant a species is compared to all other species in the study area. A high relative density means that the species is dominant or highly abundant compared to other species. It is expressed as a percent and is calculated using the formula suggested by [20].

$$\text{Relative density} = \frac{\text{Density of particular species}}{\text{Total density of all species}} \times 100. \quad (4)$$

Abundance is the average number of individuals of a particular species per quadrant in which the species actually occurs. A high abundance means that the species is

densely populated in the quadrants where it is present. It is calculated using the formula suggested by [22].

$$\text{Abundance} = \frac{\text{Total number of particular species in all quadrants}}{\text{Number of quadrant in which targeted species occurred}} \quad (5)$$

Relative abundance is the measure of abundance of a particular species in relation to all other species within the study area. A high relative abundance means a species is dominant or more abundant compared to other species. It is expressed as a percentage and is calculated using the formula suggested by [22].

$$\text{Relative abundance} = \frac{\text{Abundance of a particular species}}{\text{Total abundance of all species}} \times 100. \quad (6)$$

The Importance Value Index (IVI) is the integrated measure to determine the overall importance of a species in a community. The IVI gives an overall understanding of the species' ecological role in an area. A high IVI indicates that the species has higher ecological importance or dominance in the community; it is calculated using the formula suggested by [22].

$$\text{Important value index} = \text{Relative frequency} + \text{relative density} + \text{relative abundance}. \quad (7)$$

2.6. Simpson's Diversity Index. Simpson's Diversity Index is calculated using the following formula given by [23] and represents the probability that two individuals randomly selected from a community belong to different species.

$$D = 1 - \frac{\sum n_i(n_i - 1)}{N(N - 1)}, \quad (8)$$

where n_i is the total number of each species and N is the total number of all the species.

2.6.1. Shannon and Weiner Index (H'). The Shannon-Wiener index is a measure of species diversity in a community that quantifies the uncertainty in predicting the species identity of a randomly chosen individual and is calculated using the formula given by [24].

$$H' = - \sum (p_i \times \ln p_i). \quad (9)$$

H' is Shannon's Diversity Index, p_i is the proportion of individuals of species i in the total sample, and $\ln$ is the natural logarithm.

3. Results and Discussion

3.1. Weed Flora. During the study, 21 weed species were collected from different locations and categorized with order, family, growth habit and plant morphology (Table 1). A total of 11 families were recognized. Among them, the largest number of weed species belongs to Asteraceae and Poaceae families. The predominance of the Asteraceae and Poaceae weeds in agroecosystems is a direct consequence of their exceptional ecological adaptability to the disturbed, resource-rich, and highly competitive conditions created by

farming practices [25, 26]. Both families exhibit rapid life cycles and prolific seed production, enabling them to exploit temporary gaps, colonize bare soil quickly, and maintain persistent seed banks [27]. Diverse growth forms and competitive nature, including rosettes that concentrate ground-level light, dense root systems that insensitively capture nutrients and water, and C4 photosynthesis make many grass weeds common [28]. Most of the weeds were broadleaf followed by grassy weeds which were categorized as annual and occasionally as perennial in nature. The upland attributed to maize cultivation in Nepal is under conventional agriculture practices, leading to high soil disturbance, increasing the dominance of annual weeds [29].

The higher abundance of annual broadleaf weeds, compared to perennial weeds, reflects their evolutionary adaptation to frequent agricultural disturbances [30], which favor species with short life cycles and transient seed banks [31]. The greater number of tillage operations are performed in the cultivation of summer maize in the mid-hills of Nepal [32], leading to the abundance of annual weeds. *Euphorbia hirta* and *Oxalis latifolia* were the weeds observed only in the second year.

3.2. Phytosociological Values. The observed IVI among weed species in this study underscores the ecological heterogeneity and competitive dynamics within the plant community. The most dominant species is *Persicaria nepalensis*, with the highest IVI of 49.06, which is attributed to its high frequency (9.52%), high density (22.70%), and high abundance (16.84%) (Table 2). The success of *Persicaria nepalensis* is associated to its efficient resource acquisition, ability to produce many seeds and grow from vegetative parts, commonness in May Polygonaceae species [33, 34]. The

TABLE 1: Weeds in the rainy season maize in western mid-hills, at Pokhara, Nepal.

Scientific name	Order	Family	Growth habit	Plant morphology	2023	2024
<i>Ageratum conyzoides</i> L.	Asterales	Asteraceae	A	D-B	Pl	Pl
<i>Bidens pilosa</i> L.	Asterales	Asteraceae	A	D-B	Pl	Pl
<i>Crassocephalum crepidioides</i> (Benth.) S. Moore	Asterales	Asteraceae	A	D-B	Pl	Pl
<i>Galinsoga parviflora</i> Cav.	Asterales	Asteraceae	A	D-B	Pl	Pl
<i>Synedrella nodiflora</i> (L.) Gaertn.	Asterales	Asteraceae	A	D-B	Pl	Pl
<i>Amaranthus viridis</i> L.	Caryophyllales	Amaranthaceae	A	D-B	Pl	Pl
<i>Drymaria cordata</i> (L.) Willd ex Roem. and Schult.	Caryophyllales	Caryophyllaceae	A	D-B	Pl	Pl
<i>Commelina benghalensis</i> L.	Commelinales	Commelinaceae	A	M-B	Pl	Pl
<i>Cynodon dactylon</i> (L.) Pers.	Cyperales	Poaceae	P	M-G	Pl	Pl
<i>Digitaria ciliaris</i> (Retz.) Koeler	Cyperales	Poaceae	A	M-G	Pl	Pl
<i>Echinochloa crus-galli</i> (L.) P. Beauv.	Cyperales	Poaceae	A	M-G	Pl	Pl
<i>Eleusine indica</i> (L.) Gaertner	Cyperales	Poaceae	A	M-G	Pl	Pl
<i>Eragrostis pilosa</i> (L.) P. Beauv.	Cyperales	Poaceae	A	M-G	Pl	Pl
<i>Cyperus</i> spp.	Cyperales	Cyperaceae	Pl	M-S	Pl	Pl
<i>Fimbristylis littoralis</i> Gaud.	Cyperales	Cyperaceae	A/Pl	M-S	Pl	Pl
<i>Euphorbia hirta</i> L.	Euphorbiales	Euphorbiaceae	A	D-B	AB	Pl
<i>Borreria latifolia</i> (Aubl.) K. Schum.	Gentianales	Rubiaceae	A	D-B	Pl	Pl
<i>Oxalis latifolia</i> Kunth	Geraniales	Oxalidaceae	Pl	D-B	AB	Pl
<i>Phyllanthus niruri</i> L.	Malpighiales	Phyllanthaceae	A	D-B	Pl	Pl
<i>Persicaria nepalensis</i> (Meisner) H. Gross	Polygonales	Polygonaceae	A	D-B	Pl	Pl
<i>Polygonum plebeium</i>	Polygonales	Polygonaceae	A/Pl	D-B	Pl	Pl

Note: A, annual; P, perennial; D, dicot; M, monocot; B, broad leaf; G, grass; S, sedge; Pl, present; AB, absent.

TABLE 2: Phytosociological values of the weed species in the rainy season maize in western mid-hills, at Pokhara, Nepal.

Weeds	TOI	TNI	F	D	A	RF (%)	RD (%)	RA (%)	IVI
<i>Persicaria nepalensis</i>	61	1766	0.76	22.08	28.95	9.52	22.70	16.84	49.06
<i>Cyperus</i> sp.	66	1128	0.83	14.10	17.09	10.30	14.50	9.94	34.74
<i>Galinsoga parviflora</i>	57	996	0.71	12.45	17.47	8.89	12.80	10.16	31.86
<i>Ageratum conyzoides</i>	66	769	0.83	9.61	11.65	10.30	9.89	6.78	26.96
<i>Digitaria ciliaris</i>	59	712	0.74	8.90	12.07	9.20	9.15	7.02	25.38
<i>Eleusine indica</i>	55	575	0.69	7.19	10.45	8.58	7.39	6.08	22.05
<i>Cynodon dactylon</i>	35	411	0.44	5.14	11.74	5.46	5.28	6.83	17.57
<i>Eragrostis pilosa</i>	40	349	0.50	4.36	8.73	6.24	4.49	5.08	15.80
<i>Drymaria cordata</i>	40	276	0.50	3.45	6.90	6.24	3.55	4.01	13.80
<i>Echinochloa crus-galli</i>	43	243	0.54	3.04	5.65	6.71	3.12	3.29	13.12
<i>Synedrella nodiflora</i>	31	207	0.39	2.59	6.68	4.84	2.66	3.88	11.38
<i>Fimbristylis littoralis</i>	17	124	0.21	1.55	7.29	2.65	1.59	4.24	8.49
<i>Borreria latifolia</i>	3	27	0.04	0.34	9.00	0.47	0.35	5.24	6.05
<i>Phyllanthus niruri</i>	19	70	0.24	0.88	3.68	2.96	0.90	2.14	6.01
<i>Commelina benghalensis</i>	14	44	0.18	0.55	3.14	2.18	0.57	1.83	4.58
<i>Bidens pilosa</i>	10	26	0.13	0.33	2.60	1.56	0.33	1.51	3.41
<i>Polygonum plebeium</i>	8	24	0.10	0.30	3.00	1.25	0.31	1.75	3.30
<i>Amaranthus viridis</i>	9	23	0.11	0.29	2.56	1.40	0.30	1.49	3.19
<i>Crassocephalum crepidioides</i>	4	5	0.05	0.06	1.25	0.62	0.06	0.73	1.42
<i>Euphorbia hirta</i>	3	3	0.04	0.04	1.00	0.47	0.04	0.58	1.09
<i>Oxalis latifolia</i>	1	1	0.01	0.01	1.00	0.16	0.01	0.58	0.75

Note: F, frequency; D, density; A, abundance.

Abbreviations: IVI, Importance Value Index; RA, relative abundance; RD, relative density; RF, relative frequency; TNI, total number of individuals; TOI, Total Occurrence Index.

shallow and fibrous root system of *Persicaria* rapidly captures soil nutrients and moisture, enabling aggressive growth in disturbed, nutrient-rich agroecosystems. Concurrently, a single plant of *Persicaria* can produce thousands of small seeds that form a persistent seed bank [35]. *Cyperus* sp. ranked second in dominance with an IVI of 34.74, indicating a substantial presence in the community because of their resilience attributed to their propagation through tubers and

C4 photosynthesis [36]. *Galinsoga parviflora* (31.86) and *Ageratum conyzoides* (26.96), both from the Asteraceae family, are moderately dominant due to their short life cycles, which allow them to regenerate and spread quickly [37, 38]. *Digitaria ciliaris* (25.38) and *Eleusine indica* (22.05) were moderately dominant species, playing a significant role in the weed flora. On the other hand, *Cynodon dactylon* (17.57), *Eragrostis pilosa* (15.80), and *Drymaria cordata*

TABLE 3: Diversity indices of weeds in rainy season maize in the western mid-hills at Pokhara, Nepal.

Location	Shannon–Weiner Index (H')		Simpson's Diversity Index (D)	
	Year		Year	
	2023	2024	2023	2024
Puranchaur	2.27	2.26	0.86	0.88
Lamachaur	2.36	2.29	0.87	0.87
Dhikidada	2.23	2.04	0.86	0.82
Gharmpi	1.97	2.09	0.80	0.81
Overall	2.39	2.30	0.88	0.86

(13.80) were less dominant but still ecologically relevant. Competitive pressure from vegetatively propagating species and management practices limits the growth of grass and keeps grass populations under control [39]. Rare species, like *Borreria latifolia* (6.05), *Commelina benghalensis* (4.58), and *Crassocephalum crepidioides* (1.42), had negligible ecological importance in the current study.

3.3. Diversity Indices. The Shannon–Weiner Index reveals changes in species richness, while the Simpson's Index shows how prevalent species are. The data reveal changes in weed diversity across four locations between 2023 and 2024, with mixed trends in the Shannon–Weiner and Simpson's Diversity Indices (Table 3). In Puranchaur, weed diversity remained relatively stable, with a slight increase in dominance by common weed species indicating that management practices adopted in Puranchaur are favoring certain weeds [40]. Lamachaur experienced a mild decline in weed species richness, but the dominant weed species remained unchanged. In Dhikidada, there has been a significant reduction in weed diversity, which is likely due to intensified land use or ineffective weed management, which has allowed certain weeds to dominate at the expense of others [41]. In contrast, weed diversity in Gharmpi has been increasing over the years, suggesting that current management practices have reduced the dominance of a few species and promoted a more balanced weed community, which can be further enhanced through integrated weed management [42]. Despite Gharmpi, overall weed diversity in the region declined, with fewer rare weed species and more dominance by a few species.

Spatial variation is more important than temporal variation in understanding weed diversity [43]. The study shows that differences between locations (spatial variation) were more pronounced and significant than changes between years (temporal variation). There were slight changes in overall diversity indices for the entire study area from 2023 to 2024 (Shannon Index: 2.39 to 2.30; Simpson's Index: 0.88 to 0.86), which indicated that the weed community structure was relatively stable over time. In contrast, the diversity indices differed substantially between the four locations (Puranchaur, Lamachaur, Dhikidada, and Gharmpi) within the same year. Furthermore, the trends over time were not uniform across location; diversity declined in Dhikidada, increased in Gharmpi, and remained relatively stable in Puranchaur and Lamachaur. Differences in the weed management practices across the locations [44],

microenvironments, or unique soil conditions to each site had a stronger influence on the weed community and its diversity than temporal variation [45].

4. Conclusions

The study identified *Persicaria nepalensis* as the most ecologically dominant weed in rainy season maize fields of western mid-hills in Nepal, due to its widespread distribution and adaptability. *Cyperus* spp., *Galinsoga parviflora*, and *Ageratum conyzoides* followed as competitors, reflecting their resilience in rainfed and disturbed environments. *Euphorbia hirta* and *Oxalis latifolia* were emerging weed species in the regions. Differences in the management practices and microclimate resulted in the differences in the weed dominance across the location but remained more stable across time. To address these challenges, integrated weed management strategies based on phytosociological insights prioritizing high-IVI and emerging weed species are critical to minimize the yield losses and enhance maize productivity in smallholder farming. As such, it requires a two-fold approach, where scientific research could advance ecological understanding related to dominant and emerging weed species, and policy intervention should be made to develop spatial maps and locally adapted management packages for small-scale farmers.

Data Availability Statement

The data regarding this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

This research was funded by the University Grant Commission, Nepal (Grant number: PhD-80/81-Ag&F-03).

References

- [1] MoALD, "Statistical Information on Nepalese Agriculture: 2079/80 (2022/23). Ministry of Agriculture and Livestock Development, Planning and Development Cooperation Coordination Division, Statistics and Analysis Section" (2024).
- [2] K. R. Paudyal, J. K. Ransom, N. P. Rajbhandari, K. Adhikari, R. V. Gerpacio, and P. L. Pingali, "Maize in Nepal: Production

- Systems, Constraints, and Priorities for Research,” *NARC and CIMMYT* (2001).
- [3] S. Dhakal, S. K. Sah, L. P. Amgain, and K. H. Dhakal, “Maize Cultivation: Present Status, Major Constraints and Farmer’s Perception at Madichaur, Rolpa,” *Journal of Agriculture and Forestry University* 5 (2022): 125–132, <https://doi.org/10.3126/jafu.v5i1.48454>.
 - [4] R. K. Bhattarai, B. Chaulagain, P. Gaywaly, et al., “Integrated Weed Management in Summer Maize in Mid-Hills of Nepal,” *Agronomy Journal of Nepal* 6, no. 4 (2022): 145–152, <https://doi.org/10.3126/aj.n.v6i1.47957>.
 - [5] P. K. Yadav, P. K. Sah, P. Bhujel, and A. Ojha, “Characterizing Maize Hybrid Varieties in Lamjung, Nepal: A Study on Varietal Traits,” *International Journal of Agronomy* 2025, no. 1 (2025): 1–13, <https://doi.org/10.1155/ija/9038500>.
 - [6] D. Tuesca, E. Puricelli, and J. C. Papa, “A Long-Term Study of Weed Flora Shifts in Different Tillage Systems,” *Weed Research* 41, no. 4 (2001): 369–382, <https://doi.org/10.1046/j.1365-3180.2001.00245.x>.
 - [7] A. Devkota, K. Karki, S. Kafle, and M. Sunar, “Review on Weed Control in Glyphosate Tolerant Maize,” *Reviews in Food and Agriculture* 2, no. 1 (2021): 24–26, <https://doi.org/10.26480/rfna.01.2021.24.26>.
 - [8] S. Dass, A. Kumar, S. L. Jat, et al., “Maize Holds Potential for Diversification and Livelihood Security,” *Indian Journal of Agronomy* 57, no. 3s (2012): 32–37.
 - [9] A. Usman, K. A. Elemo, A. Bala, and A. Umar, “Effect of Weed Interference and Nitrogen on Yields of a Maize/Rice Intercrop,” *International Journal of Pest Management* 47, no. 4 (2001): 241–246, <https://doi.org/10.1080/09670870110044625>.
 - [10] P. Gurung, S. Dhakal, S. Marahatta, and J. Adhikary, “Effects of Spacing and Weed Management Practices in Winter Maize in Rampur, Chitwan,” *Journal of Agriculture and Forestry University* 3 (2019): 77–84.
 - [11] B. Shrestha, S. K. Sah, D. Marasini, K. R. Kafle, and H. B. Bista, “Effect of Weed Management Practices on Weed Dynamics, Yield and Economics of Spring Maize at Dhading Besi, Nepal,” *Journal of Nepal Agricultural Research Council* 7, no. 1 (2021): 45–52.
 - [12] R. Acharya, T. B. Karki, and B. Adhikari, “Effect of Various Weed Management Practices on Weed Dynamics and Crop Yields Under Maize-Wheat Cropping System of Western Hills,” *Agronomy Journal of Nepal* 6, no. 1 (2022): 153–161, <https://doi.org/10.3126/aj.n.v6i1.47965>.
 - [13] B. S. Chauhan, “Grand Challenges in Weed Management,” *Frontiers in Agronomy* 1 (2020): 3, <https://doi.org/10.3389/fagro.2019.00003>.
 - [14] S. Christensen, H. T. Sogaard, P. Kudsk, et al., “Site-Specific Weed Control Technologies,” *Weed Research* 49, no. 3 (2009): 233–241, <https://doi.org/10.1111/j.1365-3180.2009.00696.x>.
 - [15] R. Pott, “Phytosociology: A Modern Geobotanical Method,” *Plant Biosystems* 145, no. sup1 (2011): 9–18, <https://doi.org/10.1080/11263504.2011.602740>.
 - [16] F. D. Menalled, K. L. Gross, and M. Hammond, “Weed Aboveground and Seedbank Community Responses to Agricultural Management Systems,” *Ecological Applications* 11, no. 6 (2001): 1586–1601, [https://doi.org/10.1890/1051-0761\(2001\)011\[1586:waascr\]2.0.co;2](https://doi.org/10.1890/1051-0761(2001)011[1586:waascr]2.0.co;2).
 - [17] U. Paudel, “Trends of Temperature and Rainfall in Pokhara,” *Prithvi Academic Journal* 3 (2020): 22–32, <https://doi.org/10.3126/paj.v3i0.29556>.
 - [18] S. Kharel and K. Basnet, “Analysis of Spatial and Temporal Rainfall Variation in Pokhara Metropolitan City, Nepal,” *Proceedings of the 9th IOE Graduate Conference* 9 (2021): 208–216.
 - [19] National Herbarium and Plant Laboratories (Nhpl), “Plant Database,” (2024), <http://plantdatabase.kath.gov.np/plants/search>.
 - [20] M. Kent, *Vegetation Description and Data Analysis: A Practical Approach* (John Wiley & Sons, 2011).
 - [21] C. D. Bonham, *Measurements for Terrestrial Vegetation* (John Wiley & Sons, 2013).
 - [22] S. Kumar, J. S. Mishra, and S. Shivani, “Phytosociological Studies on Weeds of Wheat (*Triticum aestivum*) in the Middle Indo-Gangetic Plains,” *Indian Journal of Agricultural Sciences* 90, no. 3 (2020): 477–482, <https://doi.org/10.56093/ijas.v90i3.101452>.
 - [23] T. I. Chernov, A. K. Tkachakhova, and O. V. Kutovaya, “Assessment of Diversity Indices for the Characterization of the Soil Prokaryotic Community by Metagenomic Analysis,” *Eurasian Soil Science* 48, no. 4 (2015): 410–415, <https://doi.org/10.1134/s1064229315040031>.
 - [24] R. Baliton, L. Landicho, R. E. Cabahug, et al., “Ecological Services of Agroforestry Systems in Selected Upland Farming Communities in the Philippines,” *Biodiversitas Journal of Biological Diversity* 21, no. 2 (2020): <https://doi.org/10.13057/biodiv/d210237>.
 - [25] H. Hani, R. Lebazda, and M. Fenni, “Variations of Weeds Seeds of Species Belonging to Poaceae on the Basis of Germination, Production and Morphological Characteristics,” *Advances in Research* 10, no. 3 (2017): 1–8, <https://doi.org/10.9734/air/2017/33747>.
 - [26] B. Usharani and A. J. Raju, “Reproductive Ecology of the Globally Invasive Whitetop Weed, *Parthenium Hysterophorus* (Asteraceae),” *Phytologia Balcanica* 24, no. 2 (2018): 225–238.
 - [27] S. S. Rana and M. C. Rana, *Principles and Practices of Weed management* (Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishwavidyalaya, 2016).
 - [28] E. A. Kellogg, “Flowering Plants,” *Monocots: Poaceae*, 13 (Berlin, Germany: Springer, 2015).
 - [29] K. R. Tiwari, B. K. Sitaula, R. M. Bajracharya, and T. Borresen, “Effects of Soil and Crop Management Practices on Yields, Income and Nutrients Losses From Upland Farming Systems in the Middle Mountains Region of Nepal,” *Nutrient Cycling in Agroecosystems* 86, no. 2 (2010): 241–253, <https://doi.org/10.1007/s10705-009-9289-0>.
 - [30] C. E. Murphy and D. Lemerle, “Continuous Cropping Systems and Weed Selection,” *Euphytica* 148, no. 1-2 (2006): 61–73, <https://doi.org/10.1007/s10681-006-5941-9>.
 - [31] S. Ramesh, P. Sudhakar, and S. Elankavi, “Effect of Organic Foliar Nutrition on Growth and Yield of Maize (*Zea mays* L.),” *International Journal of Research and Analytical Reviews* 5, no. 3 (2018): 64–67.
 - [32] K. Atreya, S. Sharma, R. M. Bajracharya, and N. P. Rajbhandari, “Applications of Reduced Tillage in Hills of Central Nepal,” *Soil and Tillage Research* 88, no. 1-2 (2006): 16–29, <https://doi.org/10.1016/j.still.2005.04.003>.
 - [33] T. Kowalczyk, A. Pliszko, and S. M. Drobnik, “*Persicaria nepalensis* (Polygonaceae), A New Potentially Invasive Anthropophyte in the Polish Flora,” *Polish Botanical Journal* 59, no. 2 (2014): 255–261, <https://doi.org/10.2478/pbj-2014-0031>.
 - [34] S. Araki and I. Washitani, “Seed Dormancy/Germination Traits of Seven *Persicaria* Species and Their Implication in Soil Seed-Bank Strategy,” *Ecological Research* 15, no. 1 (2000): 33–46, <https://doi.org/10.1046/j.1440-1703.2000.00323.x>.

- [35] K. B. Bhandari, D. Kotal, R. M. Kunwar, H. A. Jan, R. W. Bussmann, and N. Y. Paniagua-Zambrana, "*Persicaria amphibia* (L.) Delarbre *persicaria barbata* (L.) H. Hara *Persicaria capitata* (Buch.-Ham. Ex D. Don) H. Gross *Persicaria hydropiper* (L.) Spach *Persicaria nepalensis* (Meisn.) H. Gross Polygonaceae," in *Ethnobotany of the Himalayas* (Cham, Switzerland: Springer International Publishing, 2021), 1477–1489.
- [36] M. P. Anwar, A. M. Islam, S. Yeasmin, et al., "Weeds and Their Responses to Management Efforts in a Changing Climate," *Agronomy* 11, no. 10 (2021): 19–21, <https://doi.org/10.3390/agronomy11101921>.
- [37] R. K. Kohli, D. R. Batish, H. P. Singh, and K. S. Dogra, "Status, Invasiveness and Environmental Threats of Three Tropical American Invasive Weeds (*Parthenium hysterophorus* L., *Ageratum conyzoides* L., *Lantana camara* L.) in India," *Biological Invasions* 8, no. 7 (2006): 1501–1510, <https://doi.org/10.1007/s10530-005-5842-1>.
- [38] U. Shankar, A. S. Yadav, J. P. N. Rai, and R. S. Tripathi, "Status of Alien Plant Invasions in the North-Eastern Region of India," *Invasive Alien Plants an Ecological Appraisal for the Indian Subcontinent* 1 (2011): 174–188, <https://doi.org/10.1079/9781845939076.0174>.
- [39] V. Sardana, G. Mahajan, K. Jabran, and B. S. Chauhan, "Role of Competition in Managing Weeds: An Introduction to the Special Issue," *Crop Protection* 95 (2017): 1–7, <https://doi.org/10.1016/j.cropro.2016.09.011>.
- [40] D. R. Clements, S. F. Weise, and C. J. Swanton, "Integrated Weed Management and Weed Species Diversity," *Phytoprotection* 75, no. 1 (1994): 1–18, <https://doi.org/10.7202/706048ar>.
- [41] B. S. Chauhan, R. G. Singh, and G. Mahajan, "Ecology and Management of Weeds Under Conservation Agriculture: A Review," *Crop Protection* 38 (2012): 57–65, <https://doi.org/10.1016/j.cropro.2012.03.010>.
- [42] J. Storkey and P. Neve, "What Good is Weed Diversity?" *Weed Research* 58, no. 4 (2018): 239–243, <https://doi.org/10.1111/wre.12310>.
- [43] A. Alignier and S. Petit, "Factors Shaping the Spatial Variation of Weed Communities Across a Landscape Mosaic," *Weed Research* 52, no. 5 (2012): 402–410, <https://doi.org/10.1111/j.1365-3180.2012.00934.x>.
- [44] S. V. Garibay, W. Richner, P. Stamp, et al., "Extent and Implications of Weed Spatial Variability in Arable Crop Fields," *Plant Production Science* 4, no. 4 (2001): 259–269, <https://doi.org/10.1626/pps.4.259>.
- [45] E. A. Stockdale, B. S. Griffiths, P. R. Hargreaves, A. Bhogal, F. V. Crotty, and C. A. Watson, "Conceptual Framework Underpinning Management of Soil Health—Supporting Site-Specific Delivery of Sustainable Agro-Ecosystems," *Food and Energy Security* 8, no. 2 (2019): e00158, <https://doi.org/10.1002/fes3.158>.