PRELIMINARY ASSESSMENT OF WEED POPULATION IN FOUR AREAS OF TAIF REGION, SAUDI ARABIA

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Abstract. Weeds are major yield-limiting factors in agricultural areas. This study conducted a comprehensive weed survey in agricultural areas of Taif, Saudi Arabia including Wadi AL-Arje (1200 m), Wadi Afare (1500 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m). The results revealed significantly different weed diversity and density at varying studied altitudes. A total of 13, 10, 23, and 15 weed families were found in Wadi AL-Arje, Wadi Afare, Wadi Kamace, and Wadi Dhi-Kazal, respectively. The weed family Asteraceae was noted to have the highest weed populations of 232 and 89 in Wadi AL-Arje and Wadi Kamace, respectively. Poaceae family demonstrated the highest weed population of 240 in Wadi Afare whereas family Lamiaceae had the highest weed population of 289 in Wadi Dhi-Kazal. Regarding the weed species, a total of 27, 19, 44, and 25 weed species were observed in Wadi AL-Arje, Wadi Afare, Wadi Kamace, and Wadi Dhi-Kazal, respectively. The highest weed populations of 200, 211, 65, and 178 were noted for *Xanthium orientale, Cenchus ciliaris, Portnlaca oleracea,* and *Cynodon dactylon* in Wadi AL-Arje, Wadi Afare, Wadi Kamace, and Wadi Dhi-Kazal, respectively. The rich diversity of weeds necessitates effective management practices for better crop yield.
Keywords: *weed survey, Asteraceae, Poaceae, Lamiaceae*

Introduction

Multiple factors pose tremendous pressure on the crops including weeds, drought, climate change, pollution, pests, diseases, soil deterioration, and reduced availability of freshwater (Singh et al., 2022; Wang et al., 2019). Plants undesirable to a certain place are referred to as weeds, which particularly compete with crops and fruits for nutrients, water, sunlight, and growing space (Holzner and Numata, 2013). This situation enhances the crop susceptibility to diseases and insects leading to significant yield losses. Most importantly weeds consume large amounts of water that hinders its availability to crops resulting in stunted growth. On the other hand, the global population has rapidly grown in the post-industrial revolution era and continues to grow annually by 80 million individuals/year thus putting significant stress on the agriculture sector (Corceiro et al., 2023). The United Nations has projected a global population of 8.1 billion individuals by 2025. It demands a 70% rise in crop production to meet the needs of a rapidly growing population (European Commission, 2020; Tripathi et al., 2019). Weeds could also negatively impact the livestock as they can consume the toxic/poisonous weeds in the pasture (Ekwealor et al., 2019). The poisonous weed plants could contain numerous types of toxins such as nitrates, alkaloids, oxalates, glycosides, resinoids, and saponins. Due to the toxic chemical constituents, certain weeds are unpalatable, which can reduce the proper diet availability for grazing livestock (Zimdahl, 2004). This phenomenon can lead to reduced milk production and poor quality of animal fleece and hide. Weed toxins can impact livestock reproduction as well leading to abortions or mortalities.

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The emergence of invasive weed species has led to reduced biodiversity in several semi-arid and arid ecosystems of the world (Farrell and Gornish, 2019; Bonney et al., 2017). They could impair ecosystem functioning by displacing native species, and result in major habitat alterations by changing microclimates and disturbance regimes. They can also disrupt the ecological interactions among organisms (Farrell and Gornish, 2019). Despite huge investments in arid areas, there is limited information regarding the restoration outcomes of native vegetation, particularly in dryland areas. Weeds are major biotic limitations of crop yield and are associated with the highest losses of 34% in comparison to 16% of pathogens and 18% of insect pests. Majrashi (2020) has indicated that high weed density reduces the crop yield by 50%. The uncontrolled weeds have been reported to cause a yield loss of 52% in soybean and 50% in maize crops in the United States (Soltani et al., 2017, 2016). Weeds are also attributed to yield losses in maize (25%), peanut (36%), wheat (19%), and soybean (31%) in India (Gharde et al., 2018). The weed-related yield losses lead to huge economic losses, which are estimated to be 17.2 billion USD in soybean, and 26.7 billion USD in maize in Canada and the United States. Ten major crops in India also face a yield loss of 11 billion USD whereas losses worth 2.6 billion USD occur in the cereal crops (pulses, sorghum, and canola), and fallow lands in Australia (Gharde et al., 2018; Soltani et al., 2016; Llewellyn et al., 2016). Weeds are also estimated to alleviate vegetable production by 45%–95% (Mennan et al. 2020). Globally, approximately ~200 million metric tons of grain are lost in response to weed competition and pressure on crops, which translates into annual losses worth 100 billion USD (Chauhan, 2020; Appleby et al., 2001).

The uncontrolled growth of weeds can directly increase the irrigation costs by more than 50 USD ha^{-1}, and even the weed population below the economic threshold level can raise the cost by 20 USD ha^{-1}. Moreover, certain factors such as rapid global population growth, climate change, and environmental effects have significantly increased the burden on limited water resources (WRI, 2018). The situation further worsens in the presence of weeds, which compete with the crops for limited water supply. Due to better soil volume and root zone/plant, rapid and extensive development of roots, better tolerance to climate variations than crops, and higher resource affinity, the weeds can consume more moisture content/water than the cultivated crops (Zimdahl, 2018). However, multiple factors contribute to the water/moisture consumption of weeds such as plant architecture, photosynthetic pathway, distribution, root length, management techniques, and environmental aspects (Vaughn et al., 2016; Berger et al., 2015; Pivec and Brant, 2009).

Weed invasion is considered a major threat to vegetated lands (agricultural and forest) after climate change (Haq et al., 2023; Rawat et al., 2020; Tripathi et al., 2019). Invasive weed species could disrupt the natural diversity and balance of existing vegetation and related fauna including insects, which are valuable environmental and agricultural auxiliaries (Panetta and Gooden, 2017). Higher regeneration capability, broad phenotypic plasticity, rapid reproduction, and higher seed-producing ability favor weed expansion along spatial and temporal scales (Richards et al., 2006). They act as energy drains in controlled agroecosystems and thus become a serious threatening factor for horticultural and agricultural crops around the world considerably hindering their yield. The biological stress of weeds on crops could be one of the main reasons for low yield (Weston and Duke, 2003). Moreover, weeds serve as a shelter for several insect pests of crops thus indirectly encouraging the expansion of diseases (Zimdahl, 2018). Weeds-associated losses to crops often exceed the losses caused by insects, fungi, and

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bacteria. Human settings (lawns, orchards, agricultural fields, and parks) are heavily shared by weeds. Weeds have been well-known throughout the human civilization but their particular losses to horticulture and agriculture have been elaborated only a few decades ago (Derpsch et al., 2010). The weeds can invade various types of ecological niches and habitats but their occurrence in horticulture and agricultural fields affects the plant yield by competing with native plants (Zimdahl, 2018). The differences in weed management practices in both fields (horticulture and agriculture) might impact the infestation of selective weeds. This situation provides an opportunity to investigate the phenology of weed invasion in different land use classes for better weed management and control. Weed phenological information and calendars are also crucial for devising an efficient eradication strategy (Kumar et al., 2019; Chmielewski, 2013).

During the last three decades, weed investigations have mainly focused on assessing the weed spreading patterns in various agricultural fields. This understanding is crucial for devising herbicidal management (Blank et al., 2023). Though herbicides facilitate better crop yield, they exert detrimental impacts on human health, groundwater, and biodiversity. Therefore, a site-specific weed management approach (SSWM) has been proposed to counter the negative effects of herbicides. This approach highlights the heterogeneity of weed density in particular areas and discourages the uniform spraying of herbicides in fields containing weed-free patches (Esposito et al., 2021). However, the SSWM approach requires the correct knowledge of weed infestations in certain areas. There are multiple routes of obtaining this information such as field scouting and remote sensing (drones, satellites, proximal sensing, and drones). A significant reduction in herbicide usage (40%–60%) has been noted with the SSWM approach, which helped in mitigating environmental contamination and agricultural costs. However, the heterogeneous dispersal of weeds has slowed down the adoption of the SSWM approach (Fernández-Quintanilla et al., 2018). Agricultural lands particularly have temporal and spatial heterogeneity where different weed species vary in phenology, dispersal, growing time, and geographical presence. Therefore, a better understanding of weed distribution and spatiotemporal dynamics can help address such hurdles for effectively adopting the SSWM approach.

The complex heterogeneous nature of weeds complicates the investigation of various weed species distribution in cropping areas. Several factors could contribute to diverse weed variability in an area on a broad scale, which includes agricultural practices (uprooted plots and crop rotation), climate, weed management in nearby fields, and soil composition (Gafni et al., 2023; Ben-Hamo et al., 2020; Firester et al., 2018). The variations in weed diversity at a local scale might depend on the soil characteristics (moisture, depth), cultural practices, topography, microclimate, and level of farmer's knowledge and experience (Blank et al., 2023; Bagavathiannan et al., 2019). The type of management practices and grown crops also shape weed diversity in an area (Gunton et al., 2011). The weed species are known to spatially cluster in various crops. In addition to management practices (herbicide, tillage, cropping pattern), weed dispersal also depends on weed seeds' spatial pattern. Different types of crops could also affect the weed composition and spatial distribution in the field. The varying canopy structures of crops create different microclimates in the field, which could impact the weed population and emergence (Colbach et al., 2019). The crops with tall and dense canopies (maize) restrict weed growth and thus fewer weed species are found in maize fields as compared to crops with open canopies. Similarly, competitive crops can also suppress the growth of weeds resulting in lower weed density in the field. The role of mechanized farming could also be

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crucial in weed seed distribution. For example, the use of a combine harvesting machine could lead to elongated weed patches toward the row direction. Therefore, cropping systems are also important for studying weeds' spatial distribution and density. Moreover, the weed data should be regularly collected from the fields to obtain a better understanding of weed density and distribution in an area. The weed distribution and density could be inconsistent over time and cropping seasons.

The complexity of the topographical landscape might also play an important role in the richness of weed species. Saudi Arabia has a large area with different types of topographies and soil compositions, which favor the growth of various types of flora and plant communities. The impact of elevation on the population density, spatial distribution, and composition of weed species has been investigated in the Aseer region of Saudi Arabia. The study established a direct correlation between changes in landscape elevation and weed species distribution and concluded that altitude is an important ecological factor impacting the weed vegetation richness of an area (Alwadi and Moustafa, 2016). Weed management is particularly laborious and expensive in vegetable farms, yet the weed tolerance level of crops without yield loss varies in different crops (Madden et al., 2021). Weed management becomes more challenging for organic producers and farmers with small land holdings lacking the financial capacity to invest in labor or necessary weed control equipment (McErlich and Boyston, 2013). The weed-crop competition is the major factor regarding lower profitability of the crops; however, crops might differ in weed competition susceptibility and remedial measures (Brown et al., 2019). Therefore, the varying capabilities of the farmers to acquire weed management options have led to the development of different weed management strategies (Brown and Gallandt, 2018; Jabbour et al., 2014).

Weed documentation and identification in diverse types of fields could provide in-depth knowledge of types of weeds for adopting multiple sustainable management strategies (Haq et al., 2021; Ward et al., 2014; Norsworthy et al., 2013). There is a huge difference in invasion species investigations between developing and developed countries. Invasive species-associated studies in developing countries are far less than in developed countries (Nunez and Pauchard, 2010). Scientific literature is particularly limited regarding invasive species in Asian countries. However, it should not be misinterpreted as lower invasion intensity or risk in developing countries. It rather represents the availability of limited data, which hinders the development of effective management methods. Keeping in view this background, the current study has been carried out to achieve the following objectives (a) documentation of weeds in four agricultural areas of Taif, Saudi Arabia including Wadi AL Arje, Wadi Afare, Wadi Kamace, and Wadi Dhi Kazal, (b) identification of the collected specimens, (c) assessment of weed diversity in these four agricultural areas, and (d) assessment of weed density in the studied areas. The findings of this study will enhance the existing knowledge regarding the presence of invasive weeds in the Taif region of Saudi Arabia. Moreover, the study will help to develop and implement sustainable weed management programs in the area for improved crop yield.

Materials and methods

Study areas

The study was conducted in the surroundings of Taif region, Saudi Arabia. The average altitude of Taif region is 1700 m above sea level and it is situated on the

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Eastern slopes of the Sarwat Mountains. Its altitude further increases towards the west and south and reaches a maximum altitude of 2500 m. The coordinates of the location are represented as N 20-22° and E 40-42°. Taif is a highly populated area with fertile lands for agricultural activities. This region is ranked among the best agricultural areas of the Kingdom of Saudi Arabia. The total agricultural area in the surroundings of Taif is approximately 594,000 ha, which has almost 25,500 established agricultural farms. The weed specimens were collected from different areas of Taif situated at varying altitudes including Wadi AL-Arje (1200 m), Wadi Afare (1500 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m) (*Fig. 1*). The samples were randomly collected from 20 points of each location. The collected samples were appropriately stored and tagged in the field and transferred to the laboratory for further identification.

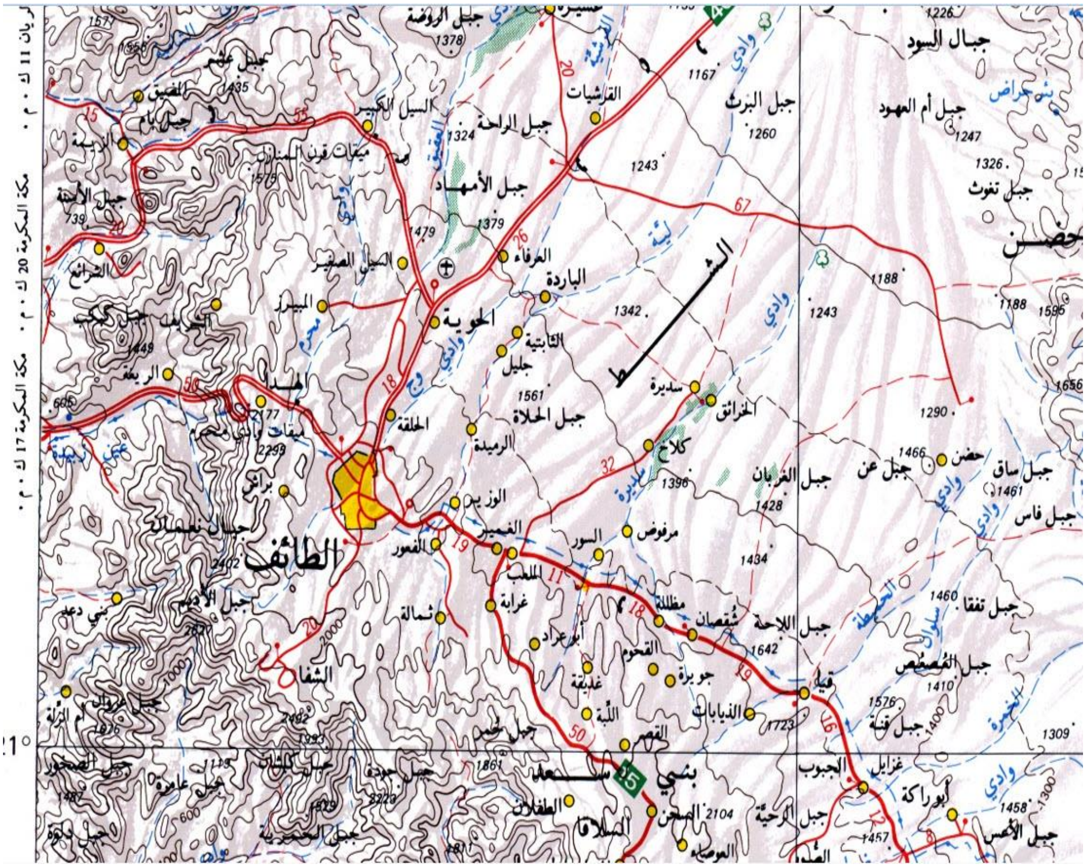

Figure 1. *Map of four studied areas including α: Wadi AL Arje, Area β: Wadi Afare, Area γ: Wadi Kamace, and Area δ: Wadi Dhi kazal of Taif (http://www.athagafy.com/images/montada/camelmap.jpg)*

Weed sample preparation

The preparation of weed samples was carried out as herbarium specimens, which were subjected to identification, and different families and species were recorded. The methodologies of Mandaville (1990) and Al-Yemeny (1989) were used as the reference point for the identification of weeds (families and species). The crop invasion by weeds was estimated based on arbitrary and visual observations. The identified weed samples were counted (families and species) to individually assess the density of each weed

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family and species in all the studied areas [(Wadi AL-Arje (1200 m), Wadi Afare (1500 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m)]. *Figure 2* reveals the weed sampling technique in the fields.

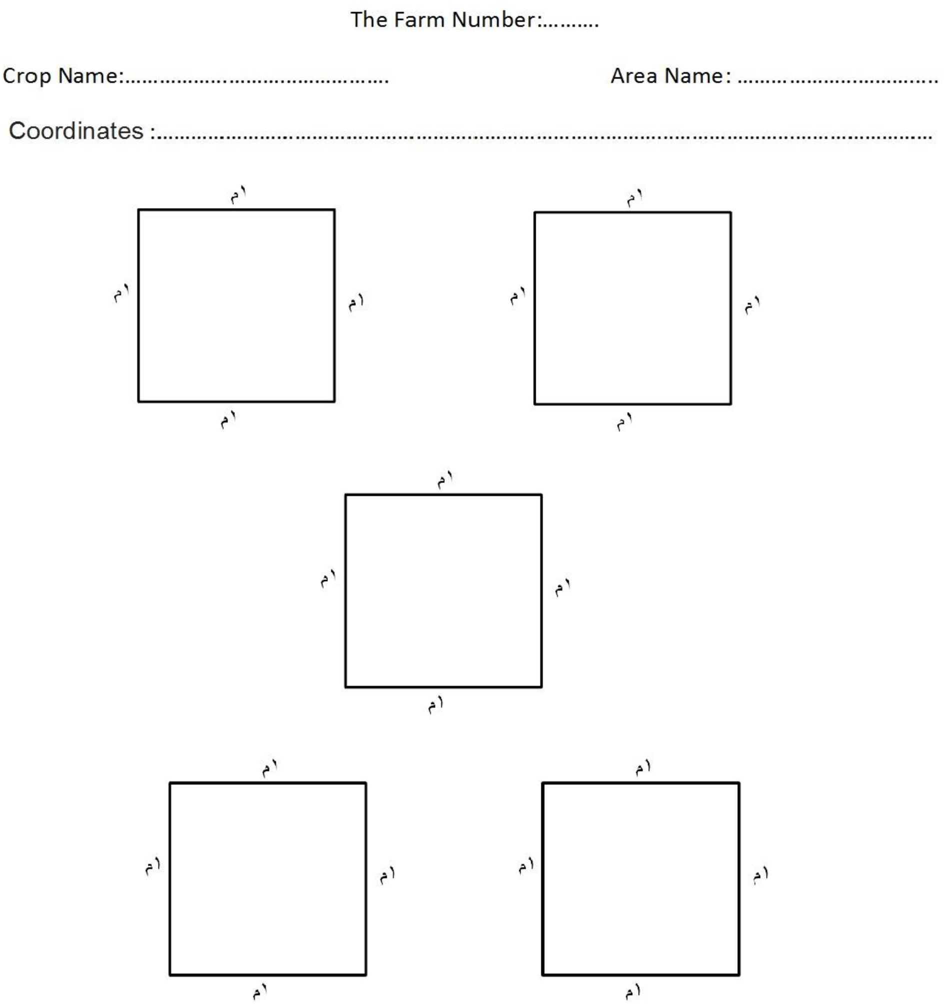

Figure 2. *Experimental design and quadrat arrangements of weeds in the studied areas*

Data analysis

Weed density data were transformed to log^{+1} or log before statistical analysis. Then, data were subjected to one-way ANOVA. Treatment means were differentiated using *t*-tests and the least significant difference (LSD) test. Multiple researchers have followed this analytical approach for similar types of data analysis (Levi et al., 2011; Juan et al., 2010; Zar, 2006).

Results

Weed distribution in Wadi AL-Arje

Wadi AL-Arje, Taif, Saudi Arabia is located at an altitude of 1200 m above sea level. Weed samples of this area revealed a rich diversity of different weed families and species, which are elaborated in the following sections.

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Population density of weed families

The weed sampling demonstrated the presence of 13 weed families in the area including Asteraceae, Plantaginaceae, Lamiaceae, Amaranthaceae, Brassicaceae, Solanaceae, Poaceae, Cyperaceae, Tamaricaceae, Typhaceae, Heliotropiaceae, Cupressaceae, and Zygophyllaceae. The highest weed density was noted for Asteraceae, which demonstrated a weed population of 210 among collected samples. Then, the weed density was followed by the Poaceae family with a representation of 130 weeds in the collected samples. Other major families with comparatively high weed density included Lamiaceae, Brassicaceae, Cyperaceae, Tamaricaceae, and Amaranthaceae, which exhibited a family density of 67, 64, 59, 51, and 49, respectively in the total collected samples. The remaining 6 weed families including Plantaginaceae, Solanaceae, Typhaceae, Zygophyllaceae, Cupressaceae, and Heliotropiaceae comparatively displayed a lower weed density of 21, 14, 12, 4, 2, and 1, respectively (*Table 1*).

Table 1. *Population density of weed families and related weed species in Wadi Al-Arje at an altitude of 1200 m*

Weed family	Density of weed families	Weed species	Density of weed species
Amaranthaceae	49	*Oxybasis glauca*	16
		Amaranthus spinosus	3
		Caroxylon passerinum	6
		Dysphania ambrosioides	6
		Amaranthus viridis	18
Poaceae	130	*Cynodon dactylon*	24
		Panicum dichotomiflorum	1
		Cenchrus clandestinus	101
		Agrostis stolonifera	4
Asteraceae	210	*Xanthium orientale*	200
		Eclipta alba	5
		Eclipta prostrate	5
Solanaceae	14	*Datura wrightii*	5
		Lycium ferocissimum	5
		Datura stramonium	4
Tamaricaceae	51	*Tamarix ramosissima*	42
		Tamarix gallica	9
Plantaginaceae	21	*Bacopa monnieri*	20
		Veronica anagallis-aquatica	1
Cyperaceae	59	*Cyperus laevigatus*	14
		Cyperus esculentus	45
Lamiaceae	67	*Marrubium vulgare*	67
Brassicaceae	64	*Nasturtium officinale*	64
Typhaceae	12	*Typha capensis*	12
Heliotropiaceae	1	*Heliotropium curassavicum*	1
Zygophyllaceae	4	*Peganum harmala*	4
Cupressaceae	2	*Cupressus sempervirens*	2

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Population density of weed species

The weed sampling of the area revealed the presence of 27 weed species in the area including Xanthium orientale, Bacopa monnieri, Marrubium vulgare, Oxybasis glauca, Nasturtium officinale, Datura wrightii, Veronica anagallis-aquatica, Tamarix ramosissima, Amaranthus spinosus, Cynodon dactylon, Cyperus laevigatus, Typha capensis, Panicum dichotomiflorum, Cenchrus clandestinus, Tamarix gallica, Heliotropium curassavicum, Agrostis stolonifera, Cyperus esculentus, Eclipta alba, Eclipta prostrate, Caroxylon passerinum, Lycium ferocissimum, Peganum harmala, Cupressus sempervirens, Datura stramonium, Dysphania ambrosioides, and Amaranthus viridis. The highest weed density was noted for Xanthium orientale, which had a weed population of 200 among the collected samples. Then, the weed density was followed by Cenchrus clandestinus with a representation of 101 weed specimens in the collected samples. Other major species with comparatively high weed density included Marrubium vulgare, Nasturtium officinale, Cyperus esculentus, and Tamarix gallica, which exhibited a weed population of 67, 64, 45, and 42, respectively. The weed density of remaining species was noted as Cynodon dactylon (24), Bacopa monnieri (20), Amaranthus viridis (18), Oxybasis glauca (16), Cyperus laevigatus (14), Typha capensis (12), Tamarix gallica (9), Caroxylon passerinum (6), Dysphania ambrosioides (6), Datura wrightii (5), Eclipta alba (5), Eclipta prostrate (5), Lycium ferocissimum (5), Peganum harmala (4), Datura stramonium (4), Agrostis stolonifera (4), Amaranthus spinosus (3), Cupressus sempervirens (2), Veronica anagallis-aquatica (1), Panicum dichotomiflorum (1), and Heliotropium curassavicum (1) (*Table 1*).

Overall, in the surveyed area of Wadi AL-Arje, five species (Oxybasis glauca, Amaranthus spinosus, Caroxylon passerinum, Dysphania ambrosioides, Amaranthus viridis) belonged to the family Amaranthaceae, four species (Cynodon dactylon, Panicum dichotomiflorum, Cenchrus clandestinus, Agrostis stolonifera) belonged to the family Poaceae, three species (Xanthium orientale, Eclipta alba, Eclipta prostrate) belonged to the family Asteraceae, three species (Datura wrightii, Lycium ferocissimum, Datura stramonium) belonged to family Solanaceae, two species (Tamarix ramosissima, Tamarix gallica) belonged to the family Tamaricaceae, two species (Bacopa monnieri, Veronica anagallis-aquatica) belonged to the family Plantaginaceae, and two species (Cyperus laevigatus, Cyperus esculentus) belonged to the family Cyperaceae. Each of the remaining weed families were represented by only one weed species such as Lamiaceae (Marrubium vulgare), Brassicaceae (Nasturtium officinale), Typhaceae (Typha capensis), Heliotropiaceae (Heliotropium curassavicum), Zygophyllaceae (Peganum harmala), and Cupressaceae (Cupressus sempervirens) (*Table 1*).

Weed distribution in Wadi Afare

Wadi Afare, Taif, Saudi Arabia is situated at an altitude of 1500 m above sea level. A weed survey of this area depicted the presence of various weed families and species, which are further explained in the following sections.

Population density of weed families

The weed sampling revealed the presence of 10 weed families in the area including *Apocynaceae, Cupressaceae, Brassicaceae, Rhamnaceae, Amaranthaceae, Solanaceae, Asteraceae, Lamiaceae,* and *Poaceae*. The highest weed density was noted for *Poaceae,*

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which exhibited a weed population of 240 in the surveyed area. It was followed by the family *Asteraceae* with a representation of 232 weed specimens, and family *Lamiaceae* with a weed density of 131 in the collected samples. *Solanaceae, Amaranthaceae,* and *Brassicaceae* were the other major families, which had the comparative weed density of 63, 37, and 26, respectively in the study area. The remaining 4 weed families including *Cupressaceae, Rhamnaceae* and *Apocynaceae* comparatively displayed a lower weed density of 13, 10, 4, and 4, respectively (*Table 2*).

Table 2. *Population density of weed families and related weed species in Wadi Afare at an altitude of 1500 m*

Weed family	Density of weed families	Weed species	Density of weed species
Asteraceae	232	*Erigeron bonariensis*	114
		Ericameria nauseosa	71
		Erigeron Canadensis	14
		Pulicaria Arabica	12
		Centaurea iberica	11
		Carduus pycnocephalus	10
Poaceae	240	*Cenchus ciliaris*	211
		Aristida purpurea	16
		Cortaderia selloana	13
Amaranthaceae	37	*Aerva javanica*	24
		Amaranthus spinosus	13
Rhamnaceae	10	*Frangula alnus*	5
		Rhamnus lycioides	5
Lamiaceae	131	*Lavandula multifida*	109
		Nepeta cataria	22
Apocynaceae	4	*Carissa bispinosa*	4
Cupressaceae	13	*Pressus sempervirens*	13
Brassicaceae	26	*Nasturtium officinale*	26
Solanaceae	63	*Solanum imcanum*	63

Population density of weed species

The weed survey of Wadi Afare demonstrated the presence of 19 weed species in the area including Aerva javanica, Cenchus ciliaris, Solanum imcanum, Lavandula multifida, Carissa bispinosa, Ericameria nauseosa, Carduus pycnocephalus, pressus sempervirens, Nepeta cataria, Erigeron bonariensis, Pulicaria arabica, Nasturtium officinale, Centaurea iberica, Aristida purpurea, Frangula alnus, Erigeron Canadensis, Amaranthus spinosu, Rhamnus lycioides, and Cortaderia selloana. The highest weed density was noted for Cenchus ciliaris, which had a weed population of 211 among collected specimens. It was followed by the species Erigeron bonariensis with a representation of 114 weed specimens, and the species Lavandula multifida with a weed density of 109 in the collected samples. Other major species with comparatively high weed density were Ericameria nauseosa and Solanum imcanum, which exhibited a weed population of 71 and 63, respectively. The weed density of remaining 14 species Nasturtium officinale, Aerva javanica, Nepeta cataria, Aristida purpurea, Erigeron

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canadensis, Amaranthus spinosus, Cortaderia selloana, Pressus sempervirens, Pulicaria arabica, Centaurea iberica, Carduus pycnocephalus, Frangula alnus, Rhamnus lycioides, and Carissa bispinosa was noted as 26, 24, 22, 16, 14, 13, 13, 13, 12, 11, 10, 5, 5, and 4, respectively (*Table 2*).

Overall, in the surveyed area of Wadi Afare, six species (Erigeron bonariensis, Ericameria nauseosa, Erigeron canadensis, Pulicaria Arabica, Centaurea iberica, Carduus pycnocephalus) belonged to the family Asteraceae, three species (Cenchus ciliaris, Aristida purpurea, Cortaderia selloana) belonged to the family Poaceae, two species (Aerva javanica, Amaranthus spinosus) belonged to the family Amaranthaceae, two species (Frangula alnus, Rhamnus lycioides) belonged to the family Rhamnaceae, two species (Lavandula multifida, Nepeta cataria) belonged to the family Lamiaceae. The other families had a representation of one species such as Apocynaceae (Carissa bispinosa), Cupressaceae (Pressus sempervirens), Brassicaceae (Nasturtium officinale), and Solanaceae (Solanum imcanum) (*Table 2*).

Weed distribution in Wadi Kamace

The altitude of Wadi Kamace, Taif, Saudi Arabia is 2000 m above sea level. The weed survey of Wadi Kamace demonstrated the highest richness and diversity of weed population and density among all studied areas. The following sections present the details of weed families and species density in this area.

Population density of weed families

The weed survey of this area revealed the presence of 23 weed families in this area including Apocynaceae, Asphodelaceae, Asteraceae, Amaranthaceae, Cactaceae, Cheropuiaceae, Convolvulaceae, Cupressaceae, Euphorbiaceae, Fabaceae, Lamiaceae, Malvaceae, Moraceae, Orobanchaceae, Papaveraceae, Poaceae, Portulaceae, Resedaceae, Rhamnaceae, Sapindaceae, Solanaceae, and Urticaceae. The highest weed density was noted for Asteraceae, which demonstrated a weed population of 89 in the collected samples that was followed by Lamiaceae with a population density of 84. Other major families with comparatively high weed density included Portulaceae, Cactaceae, Asphodelaceae, Euphorbiaceae, and Urticaceae, which exhibited a family density of 65, 44, 44, 34, and 29, respectively in the total collected samples. The remaining fourteen weed families including Poaceae, Solanaceae, Sapindaceae, Apocynaceae, Convolvulaceae, Papaveraceae, Orobanchaceae, Malvaceae, Rhamnaceae, Fabaceae, Cupressaceae, Moraceae, Amaranthaceae, Resedaceae, and Cheropuiaceae comparatively displayed a lower weed density of 16, 13, 11, 10, 10, 9, 8, 7, 5, 5, 5, 4, 4, 3 and 2 respectively (*Table 3*).

Population density of weed species

The weed survey of Wadi Kamace depicted the presence of 44 weed species in the area including Argemone mexicana, Asphodelus fistulosus, Argemone ochroleuca, Carduus pycnocephalus, Caryopteris mongholica, Centaurea calcitrapa, Centaurea iberica, Cheropouim volvorio, Amaranthus spinosus, Cylindropuntia leptocaulis, Cynodon dactylon, Datura innoxia, Dodonaea viscosa, Echinops spinosissimus, Eclipla alba, Ericameria nauseosa, Erigeron bonariensis, Euphorbia dendroides, Ficus carica, Flavaria trnervia, Frangula alnus, Gomphocarpus fruticosus, Gymnosperma glutinosum, Juniperus communis, Lavandula dentata, Lavandula multifida, Ipomea

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sp., Malva parviflora, Marrubium vulgare, Oligomeris linifolia, Onopordum acanthium, Orobanche sp., Peucephyllum schottii, Phagnalon saxatile, Portnlaca oleracea, Prosopis glandulosa, Rhamnus lycioides, Solanum incanum, Stipagrrostis bemralri, Teucrium capitatum, Teucrium polium, Urtica dioica, Urtica urens, and Vachellia karroo. The highest weed density was noted for Portulaca oleracea, which had a weed population of 65 among collected specimens. It was followed by the species Cylindropuntia leptocaulis and Asphodelus fistulosus with a representation of 44 and 44 weed specimens, respectively. Euphorbia dendroides, Lavandula multifida, Marrubium vulgare, and Eclipla alba were the following major weed species with a population density of 34, 31, 23, and 21, respectively. The population density of other species was significantly low such as Urtica dioica (19), Phagnalon saxatile (14), Cynodon dactylon (13), Gymnosperma glutinosum (12), Lavandula dentata (12), Ericameria nauseosa (12), Dodonaea viscosa (11), Teucrium polium (11), Gomphocarpus fruticosus (10), Solanum incanum (10), Ipomea sp. (10), Urtica urens (9), Orobanche sp. (8), Echinops spinosissimus (8), Centaurea iberica (8), Malva parviflora (7), Teucrium capitatum (6), Erigeron bonariensis (5), Argemone ochroleuca (5), Juniperus communis (5), Ficus carica (4), Prosopis glandulosa (4), Argemone Mexicana (4), Amaranthus spinosus (4), Frangula alnus (4), Stipagrrostis bemralri (3), Oligomeris linifolia (3), Datura innoxia (3), Carduus pycnocephalus (2), Centaurea calcitrapa (2), Cheropouim volvorio (2), Peucephyllum schottii (2), Flavaria trnervia (1), Onopordum acanthium (1), Rhamnus lycioides (1), Caryopteris mongholica (1), and Vachellia karroo (1) (*Table 3*).

Collectively, among all the specimens of Wadi Kamace, twelve species (Carduus pycnocephalus, Centaurea calcitrapa, Centaurea iberica, Echinops spinosissimus, Eclipla alba, Ericameria nauseosa, Erigeron bonariensis, Flavaria trnervia, Gymnosperma glutinosum, Onopordum acanthium, Peucephyllum schottii, and Phagnalon saxatile) belonged to the family Asteraceae, six species (Caryopteris mongholica, Lavandula dentata, Lavandula multifida, Marrubium vulgare, Teucrium polium, and Teucrium capitatum) belonged to the family Lamiaceae, three species (Urtica dioica, Urtica urens, Vachellia karroo) belonged to the family Urticaceae, two species (Argemone mexicana, Argemone ochroleuca) belonged to the family Papaveraceae, two species (Cynodon dactylon, Stipagrrostis bemralri) belonged to the family Poaceae, two species (Frangula alnus, Rhamnus lycioides) belonged to the family Rhamnaceae, and two species (Datura innoxia, Solanum incanum) belonged to the family Solanaceae. The remaining weed families were represented by the presence of only one species such as Apocynaceae (Gomphocarpus fruticosus), Asphodelaceae (Asphodelus fistulosus), Amaranthaceae (Amaranthus spinosus), Cactaceae (Cylindropuntia leptocaulis), Cheropuiaceae (Cheropouim volvorio), Convolvulaceae (Ipomea sp), Cupressaceae, (Juniperus communis), Euphorbiaceae (Euphorbia dendroides), Fabaceae (Prosopis glandulosa), Malvaceae (Malva parviflora), Moraceae (Ficus carica), Orobanchaceae (Orobanche sp), Portulaceae (Portnlaca oleracea), Resedaceae (Oligomeris linifolia), and Sapindaceae (Dodonaea viscosa) (*Table 3*).

Weed distribution in Wadi Dhi-Kazal

Wadi Dhi-Kazal, Taif, Saudi Arabia is situated at an altitude of 2200 m above sea level. A weed survey of this area depicted the presence of various weed families and species in this area, which are further explained in the following sections.

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Table 3. *Population density of weed families and related weed species in Wadi Kamace at an altitude of 2000 m*

Weed family	Density of weed families	Weed species	Density of weed species
Asteraceae	89	*Carduus pycnocephalus*	2
		Centaurea calcitrapa	2
		Centaurea iberica	8
		Echinops spinosissimus	8
		Eclipla alba	21
		Ericameria nauseosa	12
		Erigeron bonariensis	5
		Flavaria trnervia	2
		Gymnosperma glutinosum	12
		Onopordum acanthium	1
		Peucephyllum schottii	2
		Phagnalon saxatile	14
Lamiaceae	84	*Caryopteris mongholica*	1
		Lavandula dentate	12
		Lavandula multifida	31
		Marrubium vulgare	23
		Teucrium polium	11
		Teucrium capitatum	6
Urticaceae	29	*Urtica dioica*	19
		Urtica urens	9
		Vachellia karroo	1
Papaveraceae	9	*Argemone mexicana*	4
		Argemone ochroleuca	5
Poaceae	16	*Cynodon dactylon*	13
		Stipagrrostis bemralri	3
Rhamnaceae	5	*Frangula alnus*	4
		Rhamnus lycioides	1
Solanaceae	13	*Datura innoxia*	3
		Solanum incanum	10
Apocynaceae	10	*Gomphocarpus fruticosus*	10
Asphodelaceae	44	*Asphodelus fistulosus*	44
Amaranthaceae	4	*Amaranthus spinosus*	4
Cactaceae	44	*Cylindropuntia leptocaulis*	44
Cheropuiaceae	2	*Cheropouim volvorio*	2
Convolvulaceae	10	*Ipomea sp*	10
Cupressaceae,	5	*Juniperus communis*	5
Euphorbiaceae	34	*Euphorbia dendroides*	34
Fabaceae	5	*Prosopis glandulosa*	4
Malvaceae	7	*Malva parviflora*	7
Moraceae	4	*Ficus carica*	4
Orobanchaceae	8	*Orobanche sp.*	8
Portulaceae	65	*Portnlaca oleracea*	65
Resedaceae	3	*Oligomeris linifolia*	3
Sapindaceae	11	*Dodonaea viscosa*	11

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Population density of weed families

The weed survey of this area revealed the presence of 15 weed families in this area including Lamiaceae, Poaceae, Heliotropiaceae, Solanaceae, Asteraceae, Urticaceae, Aizoaceae, Montiaceae, Crossosomataceae, Fabaceae, Amaranthaceae, Zygophyllaceae, Crassulaceae, and Euphorbiaceae. The highest weed density was noted for Lamiaceae, which demonstrated a weed population of 289 in the collected samples that was followed by Asteraceae with a population density of 226, and Poaceae with a population density of 207. Other major families with comparatively high weed density included Crossosomataceae, Montiaceae, Amaranthaceae, Zygophyllaceae, Aizoaceae, Solanaceae, Urticaceae, Heliotropiaceae, and Fabaceae, which exhibited a family density of 94, 89, 63, 60, 59, 56, 46, 41, 38, and 36, respectively. The remaining two weed families Euphorbiaceae, and Crassulaceae comparatively exhibited a lower weed density of 32 and 25, respectively (*Table 4*).

Population density of weed species

The weed survey of Wadi Dhi-Kazal demonstrated the presence of 25 weed species in the area including Pelargonium graveolens, Lavandula multifida, Cynodon dactylon, Cenchrus longisetus, Salpichroa origanifolia, Ditaxis lanceolata, Heliotropium curassavicum, Urtica dioica, Marrubium vulgare, Clinopodium nepeta, Baileya multiradiata, Scutellaria indica, Chrysanthemum morifolium, Cynodon dactylon, Brickellia californica, Aizoon canariense, Aerva javanica, Montia Fontana, Crossosoma bigelovii, Artemisia schmidtiana, Peganum harmala, Crassula perforata, Oncosiphon piluliferum, Euphorbia cyparissias, and Prosopis glandulosa. The highest weed density was noted for Cynodon dactylon, which had a weed population of 178 among collected specimens. It was followed by the species Marrubium vulgare and Crossosoma bigelovii with a representation of 116 and 94 weed specimens, respectively. Montia Fontana, Brickellia californica, Chrysanthemum morifolium, Clinopodium nepeta, Scutellaria indica, Aerva javanica, Pelargonium graveolens, Peganum harmala, Aizoon canariense, and Cynodon dactylon were the following major weed species with a population density of 89, 82, 73, 71, 69, 63, 60, 59, 56, and 54, respectively. The population density of other species was comparatively lower such as Salpichroa origanifolia (46), Urtica dioica (41), Heliotropium curassavicum (38), Artemisia schmidtiana (37), Prosopis glandulosa (36), Lavandula multifida (33), Cenchrus longisetus (29), Baileya multiradiata (26), Ditaxis lanceolata (25), Crassula perforata (25), Oncosiphon piluliferum (8), and Euphorbia cyparissias (7) (*Table 4*).

Collectively, among all the specimens of Wadi Dhi-Kazal, five species (Baileya multiradiata, Chrysanthemum morifolium, Brickellia californica, Artemisia schmidtiana, Oncosiphon piluliferum) belonged to the family Asteraceae, four species (Lavandula multifida, Marrubium vulgare, Clinopodium nepeta, Scutellaria indica) belonged to the family Lamiaceae, three species (Cynodon dactylon, Cenchrus longisetus, Cynodon dactylon) belonged to the family Poaceae, and two species (Ditaxis lanceolata, Euphorbia cyparissias) belonged to the family Euphorbiaceae. Other weed families were represented by the presence of only one species such as Heliotropiaceae (Heliotropium curassavicum), Solanaceae, (Salpichroa origanifolia), Urticaceae (Urtica dioica), Aizoaceae (Aizoon canariense), Montiaceae (Montia Fontana), Crossosomataceae, (Crossosoma bigelovii), Fabaceae (Prosopis glandulosa), Amaranthaceae (Aerva javanica), Zygophyllaceae (Peganum harmala), and Crassulaceae (Crassula perforate) (*Table 4*).

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Table 4. *Population density of weed families and related weed species in Wadi Dhi-Kazal at an altitude of 2200 m*

Weed family	Density of weed families	Weed species	Density of weed species
Asteraceae	226	*Baileya multiradiata*	26
		Chrysanthemum morifolium	73
		Brickellia californica	82
		Artemisia schmidtiana	37
		Oncosiphon piluliferum	8
Lamiaceae	289	*Lavandula multifida*	33
		Marrubium vulgare	116
		Clinopodium nepeta	71
		Scutellaria indica	69
Poaceae	207	*Cenchrus longisetus*	29
		Cynodon dactylon	178
Euphorbiaceae	32	*Ditaxis lanceolata*	25
		Euphorbia cyparissias	7
Geraniceae	60	*Pelargonium graveolens*	60
Heliotropiaceae	38	*Heliotropium curassavicum*	38
Solanaceae	46	*Salpichroa origanifolia*	46
Urticaceae	41	*Urtica dioica*	41
Aizoaceae	56	*Aizoon canariense*	56
Montiaceae	89	*Montia Fontana*	89
Crossosomataceae	94	*Crossosoma bigelovii*	94
Fabaceae	36	*Prosopis glandulosa*	36
Amaranthaceae	63	*Aerva javanica*	63
Zygophyllaceae	59	*Peganum harmala*	59
Crassulaceae	25	*Crassula perforate*	25

Comparative weed densities at varying altitudes

The survey in four areas at different altitudes Wadi AL-Arje (1200 m), Wadi Afare (1500 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2250 m) revealed interesting information about weed distribution and density, which considerably varied in these areas.

Comparative density of weed families

The number of weed families varied at all the studied altitudes. The highest number of weed families (23) were found in Wadi Kamace at an altitude of 2000 m whereas the number of weed families decreased to 15 at a more high altitude of 2200 m in Wadi Dhi-Kazal. Contrarily, the lowest number of weed families (10) were noted in Wadi Afare at an altitude of 1500 m whereas the number of weed families slightly increased to 13 at a further lower altitude of 1200 m in Wadi AL-Arje. *Asteraceae* had the highest weed populations in Wadi AL-Arje (232) and Wadi Kamace (89) at altitudes of 1200 m and 2000 m, respectively. The weed family *Poaceae* had the highest weed population of 240 in Wadi Afare at an altitude of 1500 m whereas the population of family *Lamiaceae*

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was the highest (289) in Wadi Dhi-Kazal at an altitude of 2200 m. The lowest weed population was noted for the family *Heliotropiaceae* in Wadi AL-Arje (1) at 1200 m, family *Apocynaceae* in Wadi Afare (4) at an altitude of 1500 m, family *Cheropuiaceae* in Wadi Kamace (2) at an altitude of 2000 m, and family *Crassulaceae* in Wadi Dhi-Kazal (25) at an altitude of 2200 m. The population also varied for the other weed families in all the studied areas at various altitudes.

Family *Amaranthaceae* was found to have the highest variation of species in Wadi AL-Arje at 1200 m where the weed population of its five species (*Oxybasis glauca, Amaranthus spinosus, Caroxylon passerinum, Dysphania ambrosioides, Amaranthus viridis*) was noted. In Wadi Afare at an altitude of 1500 m, the family *Asteraceae* had the representation of the highest number of six weed species (*Erigeron bonariensis, Ericameria nauseosa, Erigeron canadensis, Pulicaria Arabica, Centaurea iberica, Carduus pycnocephalus*). The highest species variation among all the studied areas was noted for family *Asteraceae* in Wadi Kamace at an altitude of 2000 m as twelve weed species belonging to this family were noted (*Carduus pycnocephalus, Centaurea calcitrapa, Centaurea iberica, Echinops spinosissimus, Eclipla alba, Ericameria nauseosa, Erigeron bonariensis, Flavaria trnervia, Gymnosperma glutinosum, Onopordum acanthium, Peucephyllum schottii,* and *Phagnalon saxatile*). In Wadi Dhi-Kazal, the family *Asteraceae* had the highest species variation among identified families, and five weed species belonging to this family were noted (*Baileya multiradiata, Chrysanthemum morifolium, Brickellia californica, Artemisia schmidtiana,* and *Oncosiphon piluliferum*). The weeds belonging to the family *Asteraceae* were able to survive at all altitudes and their population dominated the other families except Wadi AL-Arje at 1200 where it ranked third after *Amaranthaceae* and *Poaceae* (*Tables 1–4*). The statistical analysis (One Way ANOVA) depicted that the weed family density of Wadi AL-Arje (1200 m) did not significantly vary from other studied areas [Wadi Afare (1500 m) (0.920), Wadi Kamace (2000 m) (0.456), and Wadi Dhi-Kazal (2250 m) (0.620)]. The weed family density of Wadi Kamace (2000 m) significantly varied from the weed family density of Wadi Dhi-Kazal (2250 m) (0.021) whereas it remained non-significant to other areas [Wadi AL-Arje (1200 m) (0.456) and Wadi Afare (1500 m) (0.173)]. Similarly, the weed family density of Wadi Dhi-Kazal (2250 m) only significantly differed from Wadi Kamace (2000 m) (0.021) whereas the differences were non-significant with other areas [Wadi AL-Arje (1200 m) (0.620) and Wadi Afare (1500 m) (0.965)]. The weed family density of Wadi Afare (1500 m) remained non-significantly different from other studied areas [Wadi AL-Arje (1200 m) (0.920), Wadi Kamace (2000 m) (0.173), and Wadi Dhi-Kazal (2250 m) (0.965)]. F-value of the analysis was noted as 4.037 at $P < 0.05$.

Comparative density of weed species

The density of weed species significantly varied at all the studied altitudes. The highest number of weed species (44) were noted in Wadi Kamace at an altitude of 2000 m. The number of weed species decreased to 25 in Wadi Dhi-Kazal at a higher altitude of 2200 m. The number of weed species (27) in Wadi AL-Arje at the lowest altitude of 1200 m was also comparable to the Wadi Dhi-Kazal at an altitude of 2200 m where 25 weed species were noted. The lowest number of weed species was noted in Wadi Afare (1500 m) where the number of weed species was noted as 19. The highest weed densities of 200, 211, 65, and 178 were noted for *Xanthium orientale, Cenchus ciliaris, Portnlaca oleracea,* and *Cynodon dactylon* in Wadi AL-Arje (1200 m), Wadi

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Afare (1500 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m), respectively. *Cenchus ciliaris* exhibited the highest individual weed population of 211 in Wadi Afare among all the studied altitudes. Interestingly, this species was absent in the weed specimens of Wadi AL-Arje (1200 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m).

The weed species *Xanthium orientale*, which presented the second-highest weed population among all the studied areas with a weed density of 200 in Wadi AL-Arje (1200 m) was not found in the samples of other studied areas. The weed species *Portulaca oleracea* had the highest density of 65 in Wadi Kamace (2000 m) and remained absent in the weed samples of other altitudes (1200 m, 1500 m, and 2200 m). Similarly, the weed species *Cynodon dactylon* with the highest weed density in Wadi Dhi-Kazal (2200 m) was not observed in the samples of other altitudes (1200 m, 1500 m, and 2200 m). Multiple species presented the lowest weed population of 1 in Wadi AL-Arje (1200 m) and Wadi Kamace (2000 m). However, the lowest weed population of a species in Wadi Afare was noted as 4 whereas it remained at 7 in the Wadi Dhi-Kazal (2200 m). Thus, the results of this study revealed varying weed richness at different altitudes (*Tables 1–4*). The statistical analysis (One Way ANOVA) demonstrated that the weed species density of Wadi AL-Arje (1200 m) significantly varied (0.028) from Wadi Dhi-Kazal (2250 m) whereas the differences of weed species density were non-significant from Wadi Kamace (2000 m) (0.424) and Wadi Afare (1500 m) (0.573). The weed species density of Wadi Kamace (2000 m) significantly varied from Wadi Dhi-Kazal (2250 m) (0.0) and Wadi Afare (1500 m) (0.03) but it remained non-signficantly different from the weed species density of Wadi AL-Arje (1200 m) (0.424). The weed species density of Wadi Dhi-Kazal significantly differed from Wadi Kamace (2000 m) (0.0) and Wadi AL-Arje (1200 m) (0.028). However, it remained non-significantly different from Wadi Afare (1500 m) (0.576). Wadi Afare (1500 m) had only significantly different weed species density from Wadi Kamace (2000 m) (0.03) whereas it was noted to be non-significantly different from Wadi AL-Arje (1200 m) (0.573) and Wadi Dhi-Kazal (2250 m) (0.576). F-value of the analysis was noted as 9.310 at $P < 0.05$.

Discussion

Global agricultural settings are tremendously crippled by the weeds, which drain moisture and nutrients from the soil. They hinder sunlight to affect optimal crop growth leading to significantly reduced crop yield (Monaco et al., 2002). Weeds are serious competitors of agricultural crops and become better adapted to the farm environments than grown crops because of rapid growth and spreading, dormancy capabilities under undesirable conditions, and ability to yield large quantities of seeds. Moreover, deeper root system and early flowering and fruiting than cultivated crops also facilitate their monopoly in the agricultural fields and help in expanding their generations rapidly (Pankaj et al. 2017). Therefore, understanding the weed diversity and distribution patterns in various cropping systems is crucial for effective weed management to attain sustainable yield (Zimdahl, 2018). The weed identification and documentation in the cropping systems of a specific area is the preliminary step towards their management.

Weeds exert multidimensional impacts on crop growth (nutrients, space, and light). Weeds' competition for rainwater and field moisture becomes particularly significant under arid climates with limited water availability. Agricultural fields with unattended

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weed populations could face a complete disaster for the cultivated crops. Their role as a pathogen and pest niche further complicates the situation and they could gradually become a serious threat to crops and grazing animals. However, yield-limiting impacts of weeds vary with the weed species, cultivated crop, weed emergence time, and weed density in the field. Weed countermeasures lead to a significant financial burden on the growers. The USA growers spend about 33 billion USD during the cropping season to alleviate the effects of weeds on the yield (Pimentel et al. 2005). In this regard, the knowledge of weed biology, ecology, and aligned environmental factors can assist in the timely implementation of management measures leading to suppression and gradual elimination of weeds from agricultural farms (Chauhan and Johnson, 2010).

This study was conducted in the Taif region of Saudi Arabia and it covered the major agricultural areas located at different altitudes including Wadi AL-Arje (1200 m), Wadi Afare (1500 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m). The findings of this study revealed that the number of weed families varied in all the studied areas. The highest number of weed families (23) was found in Wadi Kamace at an altitude of 2000 m whereas the number of weed families decreased to 15 in Wadi Dhi-Kazal at a higher altitude of 2200 m. The numbers of weed families were detected as 13 and 10 in Wadi AL-Arje at 1200 m and Wadi Afare at 1500 m, respectively. The results revealed an important role of altitude in weed distribution and density. Alwadi and Moustafa (2016) conducted a study of weed flora in five locations of Abha City, Aseer region, Saudi Arabia, which were situated at varying elevations and reported differential weed diversity and density at different elevations. They noted 24 weed families at an elevation of 2250 m above sea level, which slightly decreased with the rising elevation, and 22 weed families were found at an elevation of 2293 m. At a further higher elevation of 2550 m, they identified 22 weed families. The density of the weed family further decreased to 19 at an elevation of 2862 m. The lowest weed diversity was noted at the highest elevation of 2935 m where 15 weed families were detected. Their findings slightly contradict the results of the current study as they noticed 24 weed families at an elevation of 2250 m whereas in the current study, 15 weed families were detected at almost similar elevation of 2200 m. This could be due to different climatic conditions in both areas.

The weed species diversity and density also significantly varied in all the studied areas at different altitudes. Wadi Kamace at an altitude of 2000 m presented the highest number of weed species (44), which significantly decreased with the further rise in elevation and only 25 species were noted in the farms of Wadi Dhi-Kazal at an altitude of 2200 m. Contrarily, Wadi AL-Arje at the lowest altitude of 1200 m also had almost similar weed diversity, and 27 weed species were noted in this area. The lowest number of weed species were noted in Wadi Afare at an altitude of 1500 m where only 19 weed species were identified. In contradiction to the results of the current study, Alwadi and Moustafa (2016) noted a gradual decrease in the prevalence of weed species with the rise in elevation. They noted the presence of 63 weed species at an elevation of 2250 m followed by 54 weed species at an elevation of 2293 m and 50 weed species at an altitude of 2550 m. The weed diversity and density further decreased to 40 weed species at an elevation of 2862 m and they noted the lowest prevalence of 30 weed species at the highest elevation of 2935. The difference in weed diversity and density in both studies could be attributed to different soil fertility levels, climatic conditions, nutrient availability, and weed management practices in both areas.

Three weed families were noted to be the most prominent in all the studied areas including *Asteraceae, Lamiaceae,* and *Poaceae*. The presence of the weed family

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Asteraceae was the most dominant among all the identified families. The weed density of family *Asteraceae* was the highest among Wadi AL-Arje (1200 m) and Wadi Kamace (2000 m) samples with a population of 232 and 89, respectively. In the other two areas [Wadi Afare (1500 m) and Wadi Dhi-Kazal (2200 m)], *Asteraceae* was found to be the second-highest weed family among all the collected samples and had a population of 232 and 226, respectively. *Asteraceae* family was presented by four species in Wadi AL-Arje (1200 m), six species in Wadi Afare (1500 m), 12 species in Wadi Kamace (2000 m), and five species in Wadi Dhi-Kazal (2200 m). *Asteraceae* family demonstrated the highest species variation among all the studied areas as twelve weed species belonging to this family were noted in Wadi Kamace at an altitude of 2000 m. *Asteraceae* family contributes approximately 43% of the global weed burden to agricultural areas. This family contains almost 1000 genera and 25,000 flowering plant species (Bessada et al. 2015). *Asteraceae* is the largest global family of flowering plants with cosmopolitan distribution across all continents at varying elevation levels, except Antarctica. Many species of the *Asteraceae* family can employ allelopathy function to impact the development of other plant species. The *Asteraceae* family is also known to exert secondary metabolites-based phytotoxic potential. The secondary metabolites of this family (flavonoids, terpenes, saponins, polyacetylenes, phenolic acids, and sesquiterpene lactones) facilitate its dominant growth by restricting the development of crops and other plant species (Araújo et al., 2021).

The weed density of family *Lamiaceae* remained highest (289) among the samples of the highest altitude sampling area of Wadi Dhi-Kazal (2200 m) whereas its density was second highest (84) in the samples of Wadi Kamace (2000 m). The weeds belonging to the family *Lamiaceae* also demonstrated considerable presence in Wadi AL-Arje (1200 m) and Wadi Afare (1500 m) with a population of 67 and 131, respectively. The weeds of the *Lamiaceae* family are known for diverse toxicological and pharmacological properties and allelopathic potential (Islam et al., 2022). Most species of this family are herbaceous or shrubby in nature. The *Lamiaceae* family is comprised of 250 genera and 7000 species and its 45 genera and 175 species are considered weed plants in various regions of the world (Stankovic, 2020). The weed density of family *Poaceae* was noted to be the highest (240) among the samples of Afare (1500 m) whereas its density was second-highest (130) among the samples of Wadi AL-Arje (1200 m). The *Poaceae* family also had significant weed density in Wadi Dhi-Kazal (2200 m) where its weed population was noted as 207. Contrarily, the weed population of the *Poaceae* family was quite low in Wadi Kamace (2000 m) where only 16 weed plants were observed among all collected samples. *Poaceae* is an important global family of plants and weeds that is comprised of 793 genera and 8000-9000 species. The weeds of the *Poaceae* family are known to tolerate diverse types of environments and weather conditions, which justifies their considerable presence in the weed samples of all the studied areas during the current study. The ability of *Poaceae* family weeds to reproduce from any plant part (roots, rhizome, stems, seeds, and node) highlights the importance of developing novel weed management practices (Majrshi and Khandaker, 2016). The weeds of the *Poaceae* family can release allelochemicals to inhibit the growth of other plants to better utilize the available resources for their growth. These plants are also known to release essential oils, which are rich in monoterpenes and sesquiterpenes (Scrivanti, 2010).

The data revealed the highest species population of 200, 211, 65, and 178 for *Xanthium orientale*, *Cenchus ciliaris*, *Portnlaca oleracea*, and *Cynodon dactylon* in Wadi AL-Arje (1200 m), Wadi Afare (1500 m), Wadi Kamace (2000 m), and Wadi

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Dhi-Kazal (2200 m), respectively. Overall, *Cenchus ciliaris* had the highest individual weed population (211) in Wadi Afare among all the studied altitudes. However, this species was absent in all the other studied areas including Wadi AL-Arje (1200 m), Wadi Kamace (2000 m), and Wadi Dhi-Kazal (2200 m). *Cenchrus ciliaris* is an invasive plant that has adapted to drought conditions and has emerged as a serious weed in several semi-arid and arid environments. This weed species can chemically suppress native species via allelochemical leaching through soils (Wright et al., 2021). *Xanthium orientale* with the highest population in Wadi AL-Arje (1200 m) samples and the second-highest individual weed population (200) among all the studied samples was not found in the samples of other studied areas. The species is known to contain various bioactive phytochemicals mainly including sesquiterpene lactones, saponins, and sesquiterpenes. The *Xanthium* genus belonging to the family *Asteraceae* is widely distributed across Europe, Asia, Africa, and America (Olivaro et al., 2016). The weed species *Portulaca oleracea* with the highest density of 65 in Wadi Kamace (2000 m) was not found in other studied areas. It is an annual grass plant with known distribution in various regions, particularly in subtropical and tropical areas (Rahimi et al., 2019). *Cynodon dactylon* with the highest weed density in Wadi Dhi-Kazal (2200 m) remained absent in the weed samples of other altitudes. The weed species of the genus *Puccinellia* are generally referred to as “alkali grasses” due to their frequent presence and high tolerance to alkaline soils (Ievinsh, 2023). In addition to these dominant weed species, the study also revealed several other prominent weed species at all four studied altitudes. Therefore, a broad-spectrum approach should be devised to mitigate the harmful impacts of these weeds on agricultural produce and lands of studied areas.

Conclusion

In-depth knowledge of weed distribution and density is crucial to devise novel management strategies according to the conditions of the particular area. Therefore, a detailed survey was carried out during this study, which elaborated on the weed population in the main agricultural areas (Wadi AL-Arje, Wadi Afare, Wadi Kamace, and Wadi Dhi-Kazal) of Taif, Saudi Arabia. The studied areas were located at different altitudes (1200 m, 1500 m, 2000 m, and 2200 m), which revealed the prevalence of weed populations in relation to varying altitudes. The study revealed the presence of a wide range of weed families and relevant species with varying diversity and populations at these altitudes. Thus, the data of this study will facilitate the development of broad-spectrum and site-specific weed management programs for an improved agricultural yield in the area.

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