POWER BI-BASED ANALYSIS AND VISUALIZATION OF WEED PLANT DATASETS OF TAIF, SAUDI ARABIA

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Abstract. The integration of biological data with intelligence tools could yield exciting outputs for better visualization, understanding, and decision-making. This study integrated the distribution and density data of weeds with the Power BI platform for an accurate analysis of the current weed population scenario in the Taif region of Saudi Arabia. A total of 15,213 samples were collected from 64 different altitudes of 12 studied agricultural pockets. The collected samples belonged to 98 species and 33 families. The Al-Qayam area presented the highest density of weeds (3161, 20.87%) whereas the lowest density was observed in the Bani-Saad area (266, 1.75%). The altitude of 1562 m had the highest weed population (2005, 13.18%) whereas the lowest weed population was noted at 1509 m (15, 0.1%). Overall, the *Portulacaceae* family had the highest representation (2627) in all the studied areas followed by *Poaceae* (2222), and *Asteraceae* (2024). The species *Portulaca oleracea* belonging to the *Portulacaceae* family had the highest overall density. The presence of diverse weed families and species in the study area urges the development of novel management approaches that can be facilitated by the Power BI-based accurate data analysis and visualization.
Keywords: *weed diversity, weed distribution, weed density, altitude, portulacaceae, poaceae*

Introduction

The weed invasion of vegetative lands is a major challenge for cropping systems (Haq et al., 2023; Tripathi et al., 2019). The expansion of invasive weed species exerts severe pressure on the local fauna and vegetation in addition to protecting and facilitating pathogen and pest growth (Panetta and Gooden, 2017). They drain a considerable share of agroecosystem resources, which hinders plantation growth leading to alleviated yield. Swift reproduction, high regeneration, wide phenotypic plasticity, and high seed production facilitate rapid and sustained weed growth and expansion. Know-how of farmers, topography, cultural practices, and microclimate determine local weed diversity (Blank et al., 2023; Bagavathiannan et al., 2019). Agricultural losses of weeds often exceed the collective damage of insects and pathogens. Weeds have traveled with the human civilization over centuries and they significantly occupy various human settings such as parks, orchards, lawns, and agricultural fields. Different

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types of habitats and ecological niches face weed invasion threats but their presence in agricultural fields becomes particularly detrimental for the crops and native plants leading to significant economic losses (Zimdahl, 2018).

An understanding of weed-spreading patterns is necessary for devising and implementing management programs (Rawat et al., 2020). It could assist in exploring weed invasion phenology across various land use classes for better management. Moreover, weed calendars and phonological information could help in designing effective weed eradication programs (Kumar et al., 2019). However, the complexity of weed nature hinders their distribution assessment across plantation fields. Factors such as crop rotation, weeding in neighboring plots, soil composition, and empty fields determine weed diversity and density in an area (Gafni et al., 2023; Ben-Hamo et al., 2020; Firester et al., 2018). Cropping patterns and management practices also contribute to shaping weed composition, diversity, and distribution. The canopy structures of various crops form different microclimates, which also determine the level of weed presence in that particular field (Colbach et al., 2019). Therefore, intercropping systems and cover crops have emerged as effective weed control options with the additional benefits of erosion control and enhanced soil fertility. The cover crops could considerably mitigate weed density (51%), and herbicidal applications (37%) (Soule et al., 2024; Scavo et al., 2022). However, weed tolerance can vary among crops and their management specifically poses a higher economic burden on organic producers with frequent involvement of labor. It leads to the acquisition of different weed management options depending on the capacity of farmers, which could have an impact on the overall weed management of an area (Madden et al., 2021).

The landscape is another known aspect that affects weed population and distribution as the soil composition and topography vary at various altitudes (Alwadi and Moustafa, 2016). Taif is a major agricultural region in Saudi Arabia that grows various types of agricultural produce. This region faces a serious threat of weeds similar to other fertile areas worldwide. The topography of this area is characterized by varying altitudes, which favors the flourishing of diverse types of weeds in different agricultural pockets. In this regard, site-specific weed management could be an effective approach to handling weed diversity in regions with varying altitudes without over-judicious applications of herbicides (Esposito et al., 2021). The effective implementation of this approach requires thorough and sound information on weed infestation in the particular target area. Field visits/scouting and advanced tools (satellites, drones, proximal sensing) can be adopted to gather this information. Weed heterogeneity in a particular site could limit the efficacy of this approach, which can be overcome by up-to-date information on spatiotemporal dynamics of weed diversity and distribution (Fernández-Quintanilla et al., 2018). Moreover, weed density and distribution can be inconsistent in various cropping seasons. Therefore, regular monitoring of weed data is a prerequisite for effective countermeasures.

Microsoft Power BI is a rapidly emerging business intelligence tool that can convert simple data into exciting reports and elegant representations. The features of this tool maximize the data value to facilitate data-driven decisions in the current competitive world (Metre et al., 2024). Microsoft developed Power BI as a novel data visualization and business intelligence platform, which enables individuals and organizations to transform raw data into compelling reports, dashboards, and valuable insights (Patil et al., 2022). Powerful data connectivity of Power BI assists its users in connecting with diverse data sources such as spreadsheets, databases, on-premises

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settings, and cloud-based services (Metre et al., 2024). Power BI users can employ various functions for data manipulation (modeling, cleaning, and transforming) to ensure its swift availability for analysis. Data visualization options are the crown of Power BI, which helps users generate dynamic and interactive tables, charts, maps, and graphs. It offers multidimensional angles for data exploration to conveniently identify various patterns, outliers, and trends. Data Analysis Expressions (DAX) language of Power BI assists in performing complex calculations with seamless ease of dashboard and report sharing across team members and organizations (Shoaib and Nandi, 2022).

The real-time data access among stakeholders provides up-to-date insights and facilitates collaborative data-driven decisions. The users can also anytime access the dashboards and reports through the Power BI mobile app to stay connected and informed about critical data and report metrics (Heang, 2017). The capability of Power BI to analyze diverse data types and correspondingly devise strategies is a main attraction for individuals and organizations (Singh and Jadhav, 2022). Input data is commonly grouped as unstructured, semi-structured, and structured where computers can more conveniently interpret structured data with standardized information. This platform utilizes the information to provide conclusive insights through data processing and result extraction within a particular domain (Saabith et al., 2022). On the other hand, knowledge-based information includes experience-oriented domain-specific expertise that is employed for decision-making regarding complicated issues (Krishnan, 2017). Multiple factors such as human resources, technology, and analytics are crucial for the successful implication of Power BI tools (Heang, 2017). Software and hardware technologies collectively facilitate the designing of BI systems for complex organizations. These technologies offer to utilize their advanced enhancement models and inductive learning techniques within short processing times (Widjaja and Mauritsius, 2019). Moreover, Power BI tools present the processed data through state-of-the-art graphical visualizations with real-time animations, and cost-effective mass storage capacity permits the storage of vast datasets as well.

The main objective of this study was to perform a weed survey of 65 altitudes in 12 agricultural areas (Al-Sayl, Wadi-Kamace, Liyah, Al-Arje, Wadi-Afare, Al-Qayam, Al-Hada Road, Al-Wahat and Al-Whit, Al-Shifa Road, Bani Saad, Wadi Dhi-Khazal, and Saiysad) of Taif region. The collected samples were identified and documented respectively to their collection sites followed by the estimation of weed diversity and density in the studied areas. Moreover, this enormous data was integrated with the advanced Power BI platform for analysis and better visualization. The study provides a comprehensive overview of varying weed situations in agricultural pockets of the Taif region whereas the data integration offers an appealing and quick understanding for rapid and timely decision-making.

Material and methods

Study areas

The study was carried out in the spring semester of 2017-2022. The study area comprised of surroundings of the Taif region (1245-2150 m above sea level), Saudi Arabia, which is located on the Eastern side of the Sarwat Mountains (N 20-22° and E 40-42°). The area is characterized by a high population and fertile agricultural lands (594,000 ha) and contains 25,500 agricultural farms. The weed sampling was carried

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out in AL-Arje, Wadi Afare, Wadi Kamace, Wadi Dhi-Kazal, Al-Hada Road, Al-Qayam, Al-Sayl, Al-Shifa Road, Al-Wahat and Al-Whit, Bani Saad, Liyah, and Saiysad areas of Taif region (*Fig. 1*). The collection points were determined by the coordinates presented in the general table at https://n9.cl/rznab. The weed plant samples were labeled and transferred to the laboratory for further identification and analysis.

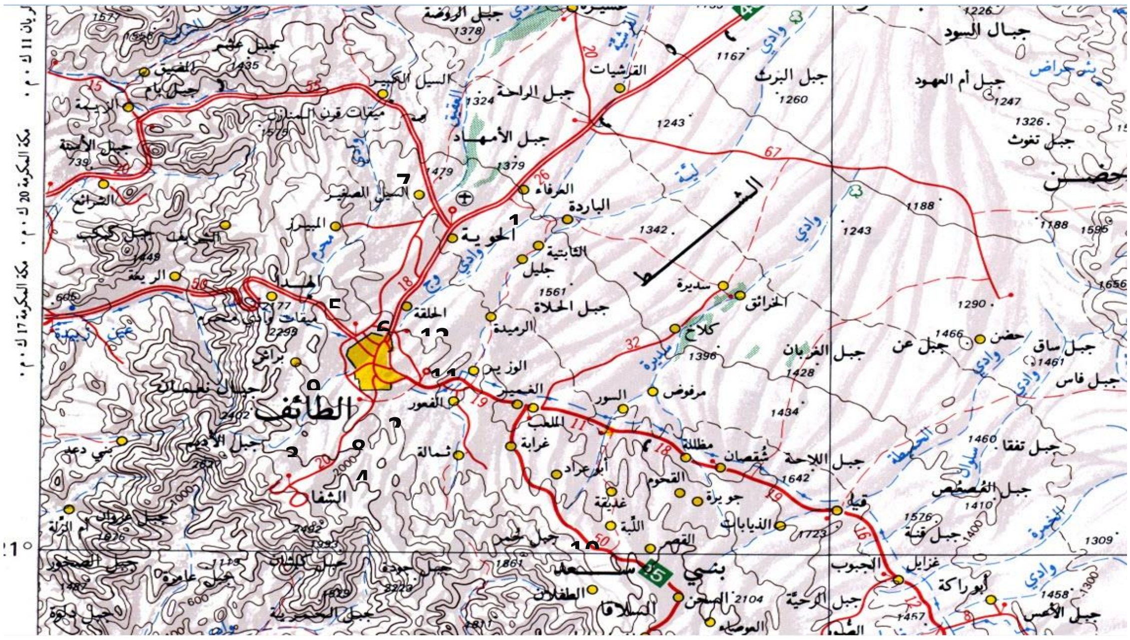

Figure 1. *Map of studied areas. 1: AL-Arje, 2: Wadi Afare, 3: Wadi Kamace, 4: Wadi Dhi-Kazal, 5: Al Hada Road, 6: Al Qayam, 7: Al Sayl, 8: Al Shifa Road, 9: Al Wahat and Al Whit, 10: Bani Saad, 11: Liyah, 12: Saiysad of Taif (http://www.athagafy.com/images/montada/camelmap.jpg) (https://n9.cl/rznab)*

Weed sample preparation

Herbarium specimens of collected weed samples were prepared and weed families and species were identified by adopting the techniques of Mandaville (1990). The visual and arbitrary observations revealed crop invasion by weed plants in studied pockets. Generally, the Taif region is an agricultural area with fertile lands in different terrains (mountains, valleys, flat lands). The identified weed samples were counted to individually estimate the density and diversity of each weed family and species in the studied areas [AL-Arje, Wadi Afare, Wadi Kamace, Wadi Dhi-Kazal, Al Hada Road, Al Qayam, Al Sayl, Al Shifa Road, Al Wahat and Al Whit, Bani Saad, Liyah and Saiysad]. *Figures 2* and *3* depict the weed sampling strategy in the fields. The general size of each area is different, but 20 random sites were identified and each site had an area of 100 m^2.

Data analysis

The data of weed density were transformed to log^{+1} or log and subjected to statistical analysis (one-way ANOVA). LSD (least significant difference) test and *t*-test were applied to differentiate treatment means by following the approach of previous studies (Besaw et al., 2011; Oliet et al., 2010).

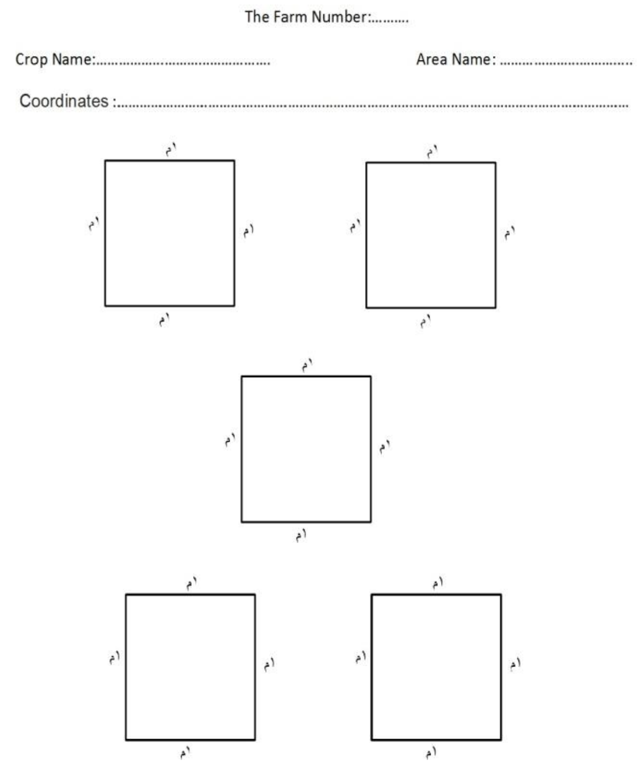

Figure 2. *Experimental design and quadrat arrangements in the studied areas*

Figure 3. *Pictures of some sampling sites in the studied areas*

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Data visualization with Power BI

Power BI is a convenient platform for dashboard or report preparation, which can be subjected to Power BI-based cloud publishing. During this study, Excel sheet data was linked to the Power BI through the “Get Data” option on the “Home tab”. Data rows and columns were modified according to the requirement of this study and data was uploaded to the Power BI platform. During the next step, data was transformed, and columns were renamed using data visualization components, which clarified the relationship among variables and eliminated the duplicates. The “Transform Data” option on the Home tab of the Editing Panel was used to apply the alterations in the graphical interface. The “Custom Columns” option in the “Add Columns” menu further allowed column customization and changes were saved by clicking “OK”, and “Close & Apply”. After data transformation, data visualizations were generated in the form of tables, and charts. The “Visualizations” panel was used to perform this task, which also allowed to change various settings such as fonts and colors. Then, the dashboards were generated by pinning the analysis charts in the Power BI service. It was carried out by selecting the “Publish Report button” on the Home tab. Then, in the online version, the “pin symbol” was selected from our graphs visualization (upper right corner) to enter a title and pin the display to a new dashboard.

The pinned display could be modified for the dashboard or a mobile view. We selected the key display options on the first page of the report. Then, interactive features (filters and segmenters) were added to the dashboard to make it more user-friendly and dynamic. These filters allow the selection and display of a particular data subset whereas segmenters help to filter multiple simultaneous visualizations. Drill-downs facilitated the creation of data hierarchies, which can be navigated through interactive buttons. More interactivity can be added to the dashboard via the “Visualizations” panel. Finally, the dashboard data update rate was configured in the control panel, which is set for weekly, daily, hourly, or real-time updates. The refresh rate was adjusted as Settings > Options > Data Load > Update options. The live dashboard was ready to use upon completion of these steps and could be shared with others by selecting the “Workspace” from the “Navigation pane”. It requires entering the name and email addresses of the individuals followed by access permission and pressing the “Share button” to share the dashboard. Moreover, the dashboard can be published to the Power BI service, which allows access to other users through embedding on a SharePoint site or web page.

Results

The study involved the weed survey of 12 agricultural areas (AL-Arje, Wadi Afare, Wadi Kamace, Wadi Dhi-Kazal, Al Hada Road, Al Qayam, Al Sayl, Al Shifa Road, Al Wahat and Al Whit, Bani Saad, Liyah and Saiysad) around Taif city, Saudi Arabia. A total of 15,213 weed samples were collected during the survey from 64 different altitudes of studied sites. Collectively, the results revealed the presence of 98 weed species belonging to 33 weed families in all the studied sites. The weed diversity and density considerably varied among all the sites, which are individually elaborated in the following sections (*Fig. 4*).

Weed distribution in the Al-Arje area

A total of 772 weed samples were collected from 11 different altitudes (1410 to 1570 m) of the Al-Arje area where the weed distribution ranged from 5 to 215 specimens at different altitudes. The data revealed the presence of 22 weed species belonging to 12

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weed families. The maximum number of weed plants were found at the highest altitude of 1570 m (215) followed by 1562 m (120). The weed density at other altitudes remained at 1422 (90), 1527 (86), 1565 (81), 1530 (62), 1532 (50), 1410 (40), 1454 (15), 1509 (8) and 1509 (8) whereas the least weed distribution was noted at 1510 m (5). *Asteraceae* family had the highest representation in this area with a plant density of 209 followed by *Poaceae* (170). Other significant families included *Brassicaceae* (77), *Amaranthaceae* (75), and *Montinaceae* (67). The families *Cyperaceae* (59), *Tamaricaceae* (56), *Plantaginaceae* (24), *Solanaceae* (14), *Zygophyllaceae* (12) and *Boraginaceae* (7), whereas the *Cupressaceae* family presented the lowest weed density of only 2. The species *Xanthium Orientale* had the highest density of 198 followed by *Cenchrus clandestinus (119)*, *Nasturtium officinale* (77), and *Montia Fontana* (67). The densities of other species were noted as *Cyperus laevigatus* (59), *Tamarix ramosissima* (56), *Cynodon dactylon* (36), *Amaranthus vindi* (30), *Oxybasis glauca* (30), *Bacopa monnieri* (24), *Tribulus terrestris* (12), *Panicum dichotomiflorum* (11), *Eclipta prostrate* (10), *Datura wrightii* (9), *Heliotropium curassavicum* (7), *Caroxylon passerinum* (6), *Dysphania ambrosioides* (6), *Lycium ferocissimum* (5), *Agrostis stolonifera* (4), *Amaranthus hybridus* (3), and *Pressus sempervirens* (2), and whereas *Verbesina encelioides* had the lowest density of 1 (*Fig. 5*). One-way ANOVA analysis revealed an F-value of 1.899 and P-value of 0.061 depicting non-significant variations among weed species at various altitudes of the Al-Arje area.

Centaurea iberica

Cynodon dactylon

Malva parviflora

Figure 4. *Pictures of some weed plants in the studied areas*

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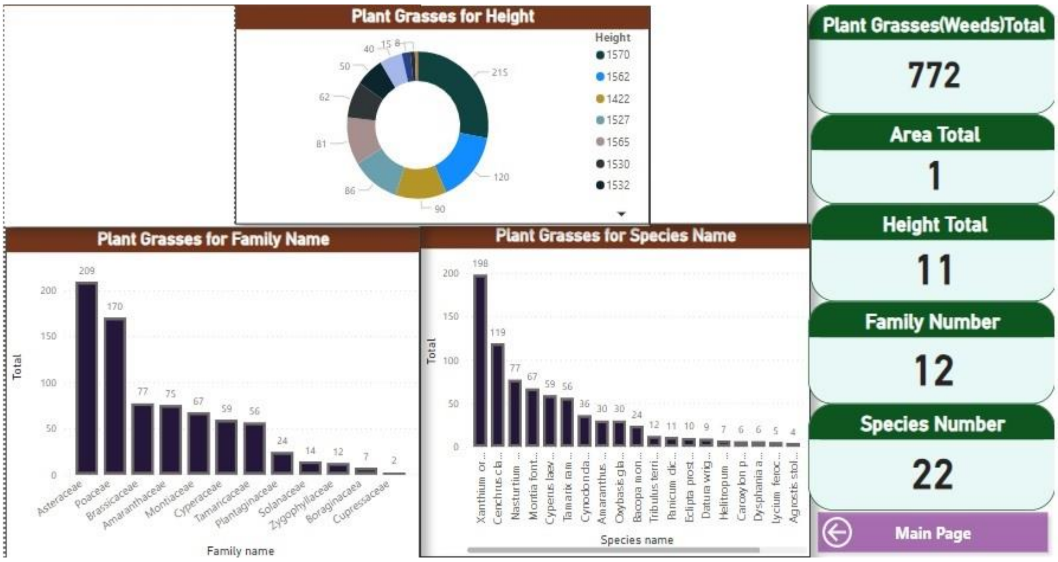

Figure 5. *Weed diversity and density at various altitudes of the Al-Arje area (https://n9.cl/rznab)*

Weed distribution in the Al-Hada Road area

A total of 2104 weed samples were collected from 9 different altitudes (1546 to 1620 m) of the Al-Hada Road area where the weed distribution ranged from 42 to 858 specimens at different altitudes. The data revealed the presence of 18 weed species belonging to 16 weed families. The maximum number of weed plants were found at the highest altitude of 1620 m (858) followed by 1558 m (445). The weed density at other altitudes remained at 1561 (401), 1555 (112), 1550 (91), 1576 (64), 1546 (46), and 1551 (45) whereas the least weed distribution was noted at 1554 m (42). *Urticaceae* family had the highest representation in this area with a plant density of 455 followed by *Chenopodioideae* (421). Other significant families included *Malvaceae* (323), *Portulacaceae* (193), and *Amaranthaceae* (165). The families *Poaceae* (137), *Zygophyllaceae* (97), *Convolvulaceae* (81), *Boraginaceae* (77), *Asteraceae* (33), *Brassicaceae* (30), *Solanaceae* (6), *Boaceae* (5), and *Aizoaceae* (4), comparatively had a lower presence whereas the *Montiaceae* family presented the lowest weed density of only 4. The species *Urtica dioica* had the highest density of 455 followed by *Chenopodium murale (421)*, *Malva parviflora* (323), *Portulaca oleracea* (193), and *Amaranthus vindi* (165). The densities of other species were noted as *Cynodon dactylon* (132), *Tribulus terrestris* (97), *Ipomoea sp.* (81), *Heliotropium curassavicum* (77), *Convolvulus arvensis* (73), *Echinops spinosissimus* (30), *Brassica tournefortii* (30), *Withania somnifera* (6), *Eleusine indica* (5), *Stipagrrostis bemralri* (5), *Aizoon canariense* (4), and *Montia fontana* (4) whereas *Sonchus oleraceus* had the lowest density of 3 (*Fig. 6*). One-way ANOVA analysis demonstrated highly significant variations among weed species at various altitudes of Al-Hada Road area with an F-value of 9.961 and P-value of 0.00.

Weed distribution in the Al-Qayam area

A total of 3161 weed samples were collected from 4 different altitudes (1545 to 1562 m) of the Al-Qayam area where the weed distribution ranged from 74 to 1872 specimens at different altitudes. The data revealed the presence of 33 weed species

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belonging to 15 weed families. The maximum numbers of weed plants were found at the highest altitude of 1562 m (1872) followed by 1545 m (794), and 1560 (421) whereas the least weed distribution was noted at 1548 m (74). *Portulacaceae* family had the highest representation in this area with a plant density of 833 followed by *Chenopodioideae* (653). Other significant families included *Brassicaceae* (610), *Asteraceae* (343), and *Malvaceae* (238). The families *Poaceae* (183), *Crassulaceae* (103), *Boraginaceae* (96), *Amaranthaceae* (35), *Solanaceae* (22), *Cupressaceae* (15), *Urticaceae* (14), Apiaceae (8), and *Lamiaceae* (6), whereas the *Resedaceae* family presented the lowest weed density of only 2. *The species Portulaca oleracea* had the highest density of 833 followed by *Chenopodium murale* (653), *Descurainia Sophia (486), Malva parviflora* (238), and *Oncos iphon pilulifer* (128). The densities of other species were recorded as *Heliotropium curassavicum* (96), *Agropyron repens* (90), *Matthiola incana* (85), *Emilia sonchifolia (66), Stipagrrostis bemralri* (57), *Sedum lineare (56), Crassula perforata* (47), *Saussurea japonica* (41), *Brassica tournefortii* (39), *Cirsium arvense* (35*), Polypogon monspeliensis (34), Amaranthus vindi* (27), *Sonchus oleraceus* (22), *Solanum incanum* (21), *Coreopsis drummondii* (20), *Pressus sempervirens* (15), *Sonchus oleraceus* (15), *Aster subulatus* (14), *Urtica dioica (14), Dysphania ambrosioides* (8), *Hydrocotyle nepalensis* (6), *Teucrium polium* (6), *Foeniculum vulgare* (2), *Reseda Arabica* (2), *Setaria viridus* (2), *Echinops spinosissimus* (1), and *Pleurocoronis pluriseta* (1). whereas *Salpichroa origanifolia* had the lowest density of 1 (*Fig. 7*). One-way ANOVA analysis revealed an F-value of 0.178 and P-value of 0.911 depicting non-significant variations among weed species at different altitudes of the Al-Qayam area.

Weed distribution in the Al-Sayl area

A total of 2346 weed samples were collected from 8 different altitudes (1245 to 1565 m) of the Al-Sayl area where the weed distribution ranged from 11 to 800 specimens at different altitudes. The data revealed the presence of 26 weed species belonging to 17 weed families. The maximum number of weed plants were found at an altitude of 1490 m (800) followed by 1245 m (335). The weed density at other altitudes was observed at 1555 (298), 1260 (292), 1440 (279), 1270 (182), and 1265 (149) whereas the least weed distribution was noted at 1565 m (11). *Portulacaceae* family had the highest representation in this area with a plant density of 657 followed by *Poaceae* (586). Other significant families included *Boraginaceae* (448), *Chenopodioideae* (317), *Crassulaceae* (89), and *Malvaceae* (62). The families *Asteraceae* (51), *Amaranthaceae* (35), *Urticaceae* (29), *Fabaceae* (18), *Convolvulaceae* (15), *Solanaceae* (15), *Brassicaceae* (12), *Resedaceae* (5), and *Tamaricaceae* (4), whereas the *Apiaceae* family presented the lowest weed density of only 3. *The species Portulaca oleracea* had the highest density of 657 followed by *Heliotropium curassavicum* (448), *Cynodon dactylon* (378), *Chenopodium murale* (263), and *Setaria viridus* (182). The densities of other species were recorded as *Sedum lineare (89), Malva parviflora* (62), *Atriplex leucoclada* (54), *Sonchus oleraceus (30), Urtica dioica (29), Amaranthus hybridus* (28), *Eleusine indica* (26), *Astragalus nutallianus* (18), *Convolvulus arvensis (15), Descurainia sophia* (12), *Datura wrightii (8), Eclipta prostrate (7), Lycium ferocissimum* (7), *Pleurocoronis pluriseta* (6), *Coleogyne ramosissima* (5), *Flaveria trinervia* (4), *Lactuca sativa* (4), *Oxybasis glauca* (4), *Tamarix ramosissima* (4), and *Aerva javanica* (13), whereas *Hydrocotyle nepalensis* had the lowest density of 3 (*Fig. 8*). One-way ANOVA analysis demonstrated non-significant variations among weed species at various altitudes of Al-Sayl area with an F-value of 1.789 and P-value of 0.102.

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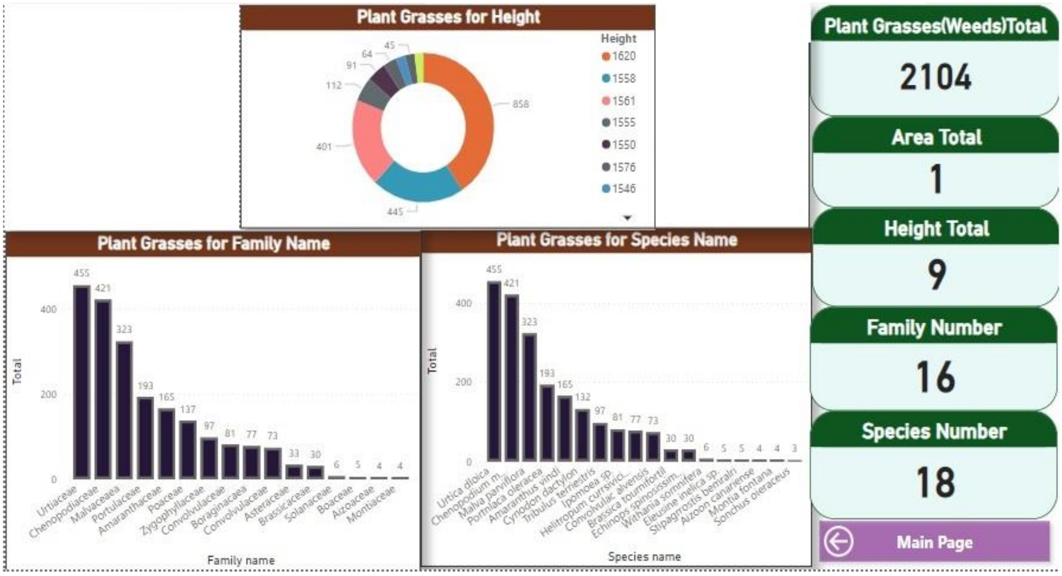

Figure 6. *Weed diversity and density at various altitudes of the Al-Hada Road area (https://n9.cl/rznab)*

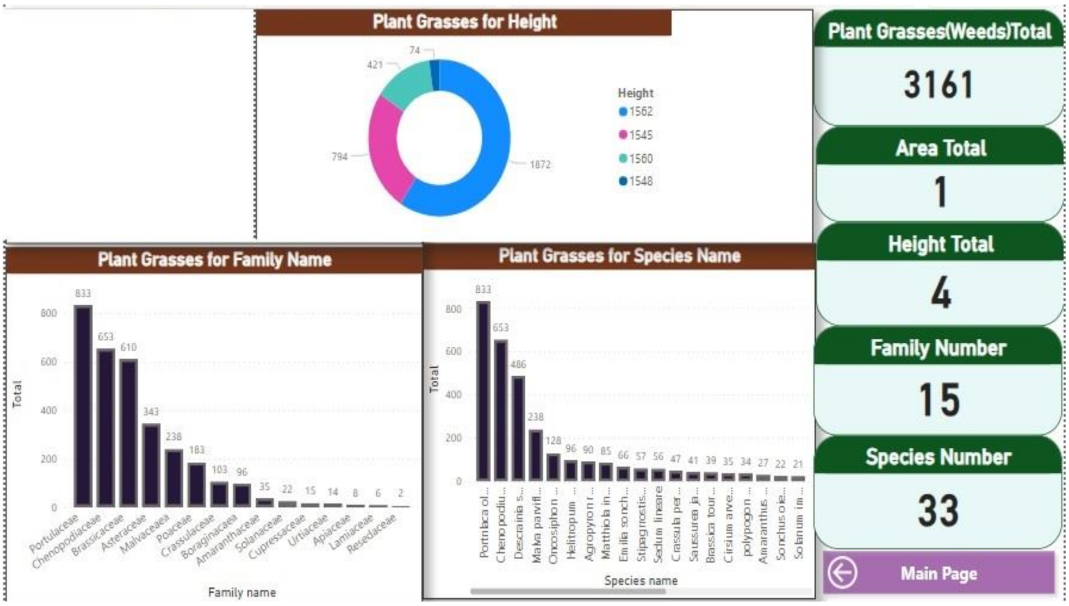

Figure 7. *Weed diversity and density at various altitudes of the Al-Qayam area (https://n9.cl/rznab)*

Weed distribution in the Al-Shifa Road area

A total of 545 weed samples were collected from 9 different altitudes (1745 to 1830 m) of the Al-Shifa Road area where the weed distribution ranged from 14 to 233 specimens at different altitudes. The data revealed the presence of 34 weed species belonging to 17 weed families. The maximum number of weed plants were found at an altitude of 1790 m (233) followed by 1800 m (68). The weed density at other altitudes was observed at 1815 (55), 1805 (50), 1745 (45), 1820 (36), 1795 (22), and 1830 (22) whereas the least weed

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distribution was noted at 1810 m (14). *Asteraceae* family had the highest representation in this area with a plant density of 134 followed by *Poaceae* (72). Other significant families included *Amaranthaceae* (57), *Apiaceae* (45), *Solanaceae* (43), *Lamiaceae* (39), *Apocynaceae* (36), *Fabaceae* (31), *Zygophyllaceae* (25), *Sapindaceae* (17), *Boraginaceae* (13), *Cyperaceae* (11), *Capparaceae* (8), *Malvaceae* (5), *Resedaceae* (4), and *Montiaceae* (3), whereas the *Cupressaceae* family presented the lowest weed density of only 2. *The species Cenchrus clandestinus* had the highest density of 57 followed by *Verbesina encelioides* (47), *Cornulaca monacantha* (45), and *Phagnalon saxatile* (45). The data revealed the densities of other species as *Lavandula multifida* (39), *Carissa bispinosa* (36), *Hydrocotyle nepalensis* (30), *Astragalus nutallianus* (29), *Lycium ferocissimum* (29), *Tribulus terrestris* (25), *Gymnosperma glutinosum* (18), *Dodonaea viscosa* (17), *Foeniculum vulgare* (15), *Bothriochloa ischaemum* (13), *Cyperus laevigatus* (11), *Heliotropium curassavicum* (11), *Bebbia juncea* (10), *Dysphania ambrosioides* (10), *Solanum incanum* (10), *Capparis spinosa* (8), *Echinops spinosissimus* (6), *Kleinia neriifolia* (5), *Malva parviflora* (5), *Coleogyne ramosissima (4)*, *Montia Fontana* (3), *Alhagi sparsifolia (2)*, *Amsinckia tessellata* (2), *Juniperus communis* (2), *Oxybasis glauca* (2), *Pleurocoronis pluriseta* (2), *Salpichroa origanifolia* (41), *Scleropogon brevifolius* (2), and *Withania somnifera* (2), whereas *Lactuca sativa* had the lowest density of 1 (*Fig. 9*). One-way ANOVA analysis revealed an F-value of 1.402 and P-value of 0.228 representing non-significant variations among weed species at different altitudes of the Al-Shifa Road area.

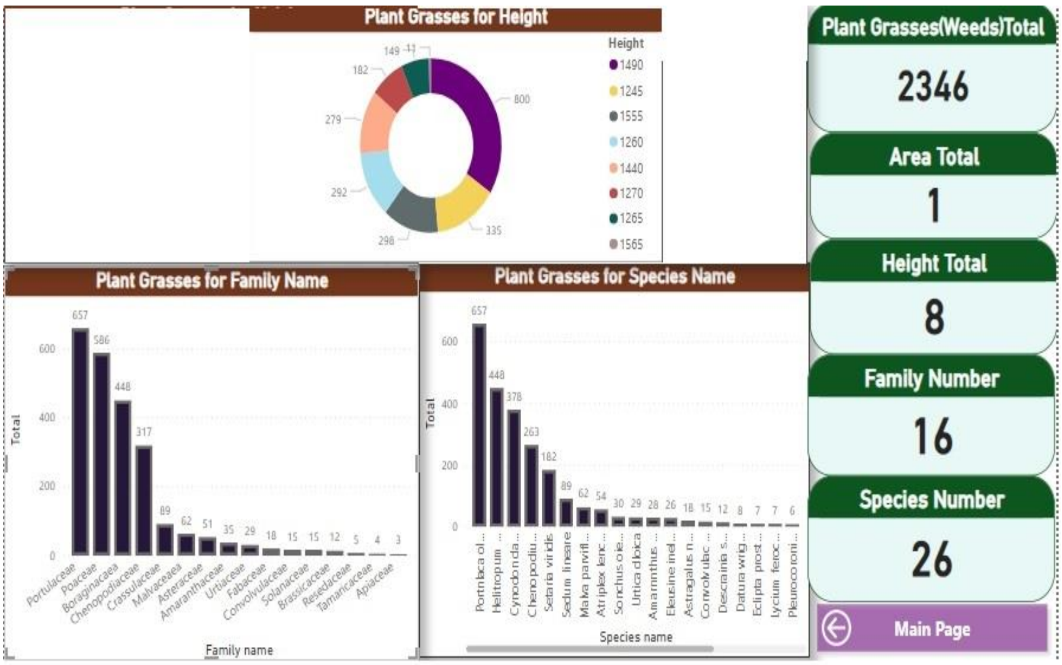

Figure 8. *Weed diversity and density at various altitudes of the Al-Sayl area (https://n9.cl/rznab)*

Weed distribution in Al-Wahat and Al-Whit Road area

A total of 2074 weed samples were collected from 7 different altitudes (1739 to 1797 m) of the Al-Wahat and Al-Whit Road area where the weed distribution ranged from 66 to 525 specimens at different altitudes. The data revealed the presence of 27

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weed species belonging to 13 weed families. The maximum number of weed plants were found at the lowest altitude of 1739 m (525) followed by 1741 m (492). The weed density at other altitudes was observed at 1794 (335), 1797 (269), 1742 (213), and 1793 (174) whereas the least weed distribution was noted at 1787 m (66). *Protulaceae* family had the highest representation in this area with a plant density of 796 followed by *Asteraceae* 308. Other significant families included *Poaceae* (299), *Chenopodioideae* (160), *Amaranthaceae* (120), *Solanaceae* (91), *Convolvulaceae* (81), *Urticaceae* (43), *Malvaceae* (39), Aizoaceae (10), and *Zygophyllaceae* (7) whereas the *Papaveraceae* family presented the lowest weed density of only 2. *The species Portulaca oleracea* had the highest density of 796 followed by *Astrebla pectinata* (145), *Launaea capitata* (131), *Chenopodium murale (130)*, and *Ipomoea sp.* (118). The densities of other species were noted as *Echinops spinosissimus* (115), *Solanum incanum* (82), *Convolvulus arvensis* (81), *Amaranthus hybridus* (70), *Polypogon monspeliensis (70)*, *Stipagrrostis bemralri* (46), *Urtica dioica* (43), *Malva parviflora* (39), *Cynodon dactylon* (38), *Amaranthus vindi* (32), *Atriplex leucoclada* (30), *Phagnalon saxatile (27)*, *Oxybasis glauca* (18), *Eclipta prostrate* (17), *Aizoon canariense* (10), *Datura wrightii* (9), *Sonchus oleraceus* (8), *Tribulus terrestris* (7), *Lactuca sativa* (6), *Verbesina encelioides* (3), and *Argemone ochroleuca* (2), whereas *Erigeron bonariensis* had the lowest density of 1 (*Fig. 10*). One-way ANOVA analysis demonstrated highly significant variations among weed species at various altitudes of Al-Wahat and Al-Whit Road area with an F-value of 3.831 and P-value of 0.02.

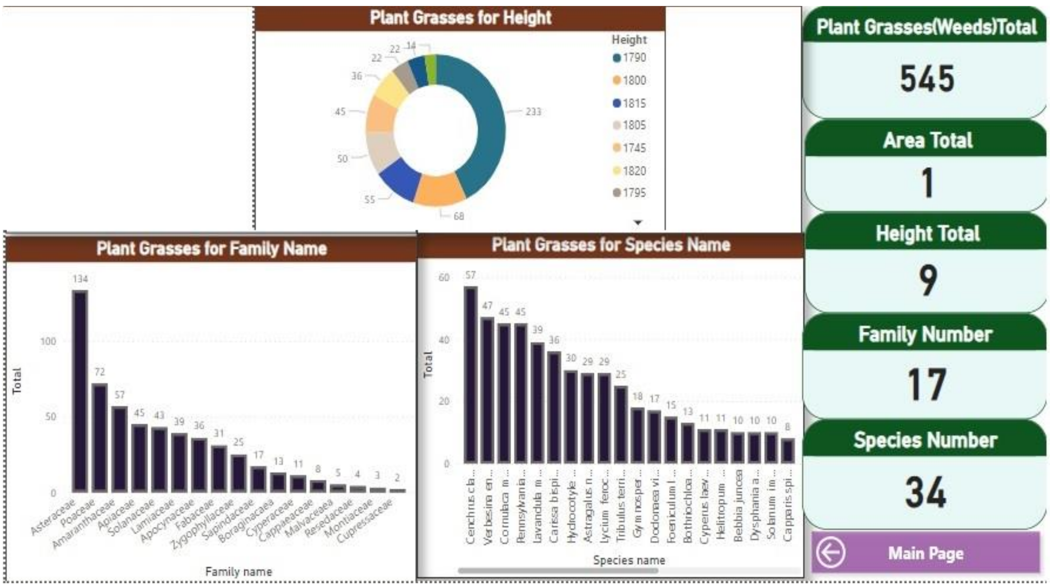

Figure 9. *Weed diversity and density at various altitudes of the Al-Shifa Road area (https://n9.cl/rznab)*

Weed distribution in the Bani Saad area

A total of 266 weed samples were collected from 2 different altitudes (1755 to 1915 m) of the Bani Saad area where the weed distribution ranged from 111 to 155 specimens at different altitudes. The data revealed the presence of 8 weed species belonging to 8 weed families. The maximum number of weed plants were found at the lower altitude of 1755 m (155) followed by 1915 m (111). *Protulaceae* family had the

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highest representation in this area with a plant density of 71 followed by *Aizoaceae* 51. Other significant families included *Chenopodioideae* (51), *Asteraceae* (37), *Solanaceae* (25), *Brassicaceae* (19), *Poaceae* (9) whereas the *Capparaceae* family presented the lowest weed density of only 3. *The species Portulaca oleracea* had the highest density of 71 followed by *Aizoon canariense (51)*. The densities of other species were observed as *Chenopodium murale* (51), *Echinops spinosissimus* (37), *Withania somnifera* (25), *Brassica tournefortii* (19), *and Setaria viridus* (9) whereas *Caparis spinosa* had the lowest density of 3 (*Fig. 11*). One-way ANOVA analysis depicted non-significant variations among weed species at various altitudes of Bani Saad area with an F-value of 0.100 and P-value of 0.757.

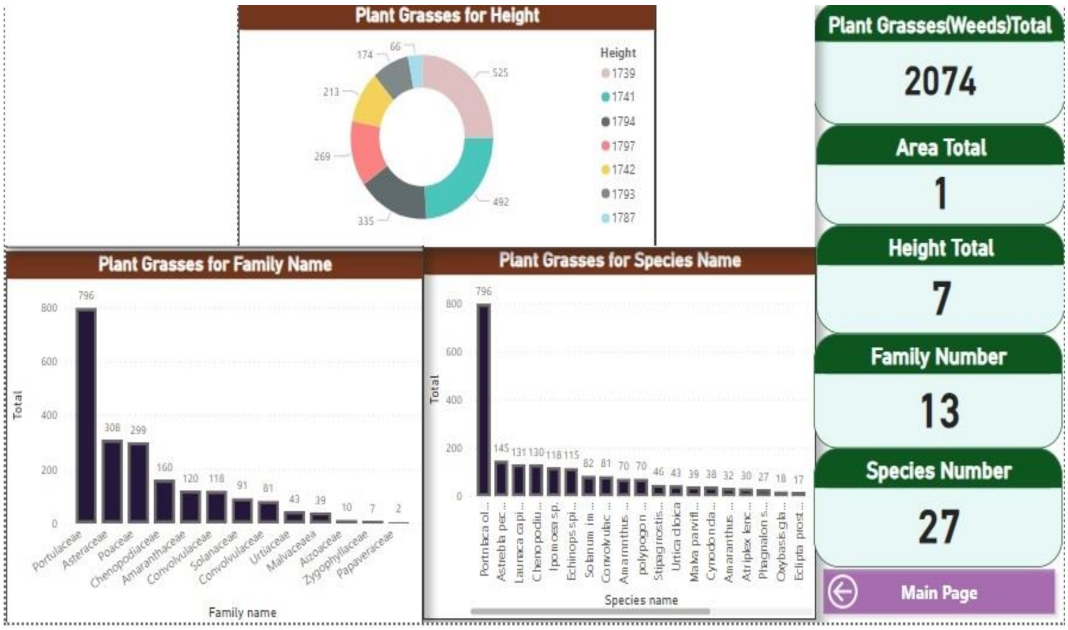

Figure 10. *Weed diversity and density at various altitudes of Al-Wahat and Al-Whit Road area (https://n9.cl/rznab)*

Weed distribution in the Liyah area

A total of 720 weed samples were collected from 11 different altitudes (1391 to 1570 m) of the Liyah area where the weed distribution ranged from 7 to 253 specimens at different altitudes. The data revealed the presence of 22 weed species belonging to 12 weed families. The maximum number of weed plants were found at the highest altitude of 1570 m (253) followed by 1565 m (131). The weed density at other altitudes was observed as 1422 (90), 1527 (86), 1530 (48), 1532 (37), 1391 (31), 1454 (15), 1562 (13), and 1510 (9) whereas the lowest weed distribution was noted at 1509 m (7). *Asteraceae* family had the highest representation in this area with a plant density of 209 followed by *Poaceae* (140), and *Amaranthaceae* (75). The other families included *Brassicaceae* (68), *Montiaceae* (67), *Cyperaceae* (59), *Tamaricaceae* (49), *Plantaginaceae* (24), *Solanaceae* (14), *Zygophyllaceae* (12), and *Cupressaceae* (2) whereas the *Boraginaceae* family presented the lowest weed density of only 1. *The species Xanthium Orientale* had the highest density of 198 followed by *Cenchrus clandestinus (101)*, *Nasturtium officinale* (68), *Montia Fontana* (67), and *Cyperus laevigatus* (59). The densities of other species were recorded as *Tamarix ramosissima*

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(49), *Amaranthus vindi* (30), *Oxybasis glauca* (30), *Bacopa monnieri* (24), *Cynodon dactylon* (24), *Tribulus terrestris* (12), *Panicum dichotomiflorum* (11), *Eclipta prostrate* (10), *Datura wrightii* (9), *Caroxylon passerinum* (6), *Dysphania ambrosioides* (6), *Lycium ferocissimum* (5), *Agrostis stolonifera* (4), *Amaranthus hybridus* (3), *Pressus sempervire* (2), and *Heliotropium curassavicum* (1) whereas *Verbesina encelioides* had the lowest density of 1 (*Fig. 12*). One-way ANOVA analysis demonstrated an F-value of 1.642 and P-value of 0.114 revealing non-significant variations among weed species at different altitudes of Liyah area.

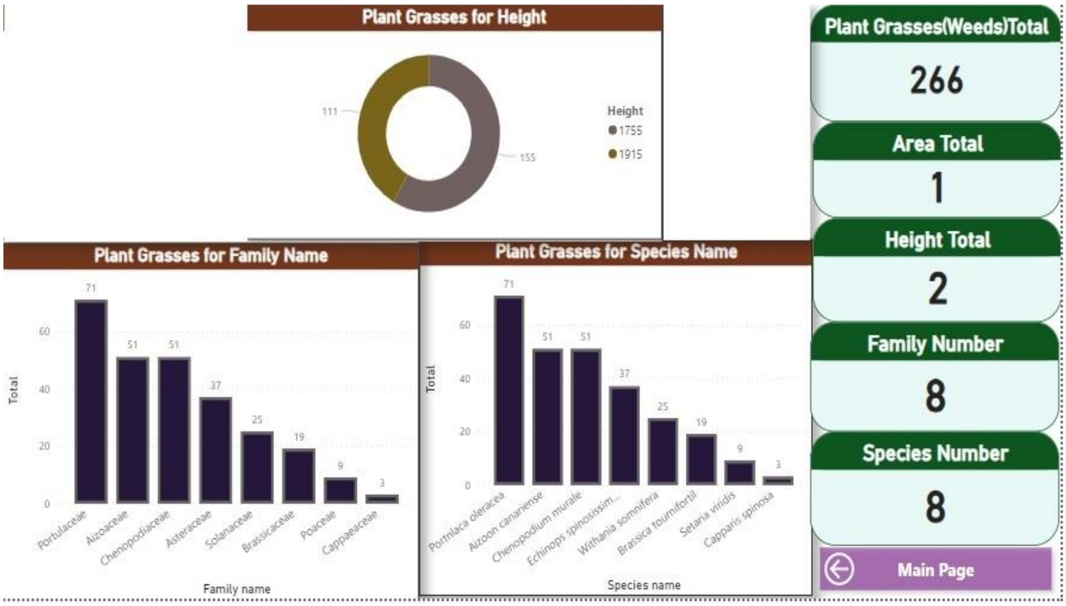

Figure 11. *Weed diversity and density at various altitudes of the Bani Saad area (https://n9.cl/rznab)*

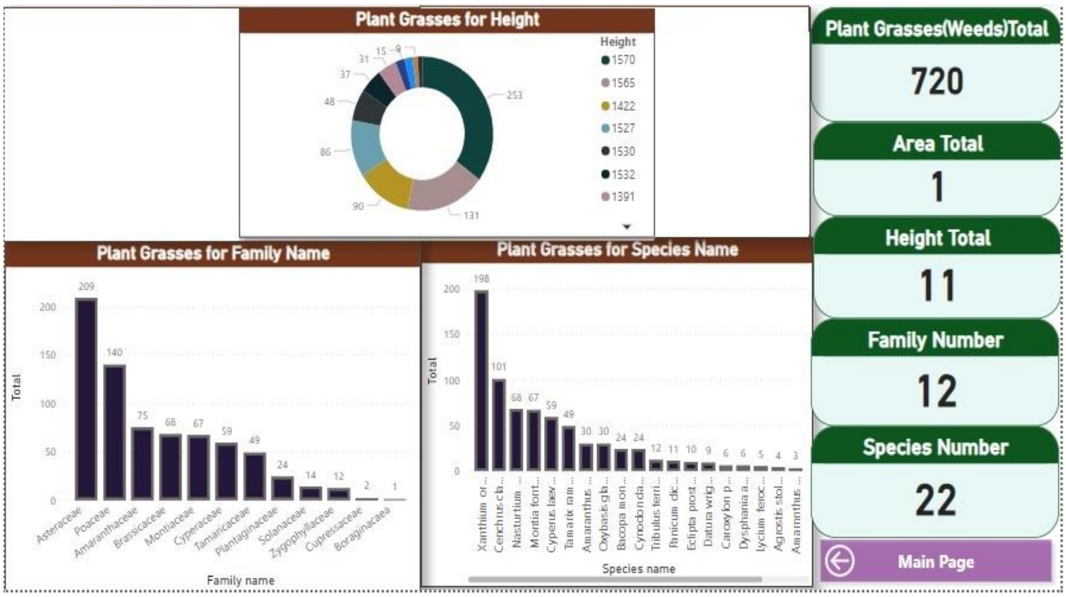

Figure 12. *Weed diversity and density at various altitudes of the Liyah area (https://n9.cl/rznab)*

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Weed distribution in the Saiysad area

A total of 635 weed samples were collected from 6 different altitudes (1578 to 1663 m) of the Saiysad area where the weed distribution ranged from 57 to 168 specimens at different altitudes. The data revealed the presence of 13 weed species belonging to 10 weed families. The maximum number of weed plants were found at the highest altitude of 1645 m (168) followed by 1578 m (115). The weed density at other altitudes was observed as 1640 (113), 1642 (97), and 1663 (85) whereas the lowest weed distribution was noted at 1580 m (57). *Asteraceae* family had the highest representation in this area with a plant density of 135 followed by *Prassicaceae* (97), and *Campanulaceae* (89). The other families included *Amaranthaceae* (79), *Chenopodioideae* (76), *Malvaceae* (56), *Poaceae* (49), *Urticaceae* (32), and *Fabaceae* (19) whereas the *Portulaceae* family presented the lowest weed density of only 3. *The species Sisymbrium irio* had the highest density of 97 followed by *Lobelia erinus* (89), *Chenopodium murale (76)*, and *Echinops spinosissimus* (69). The densities of other species were noted as *Sonchus oleraceus* (66), *Amaranthus hybridus* (58), *Malva parviflora* (56), *Urtica dioica (32)*, *Cynodon dactylon* (30), *Amaranthus vindi* (21), *Astragalus sesameus* (19), and *Polypogon monspeliensis (19)* whereas Portulaca oleracea had the lowest density of 3 (*Fig. 13*). One-way ANOVA analysis depicted non-significant variations among weed species at various altitudes of Saiysad area with an F-value of 1.778 and P-value of 0.137.

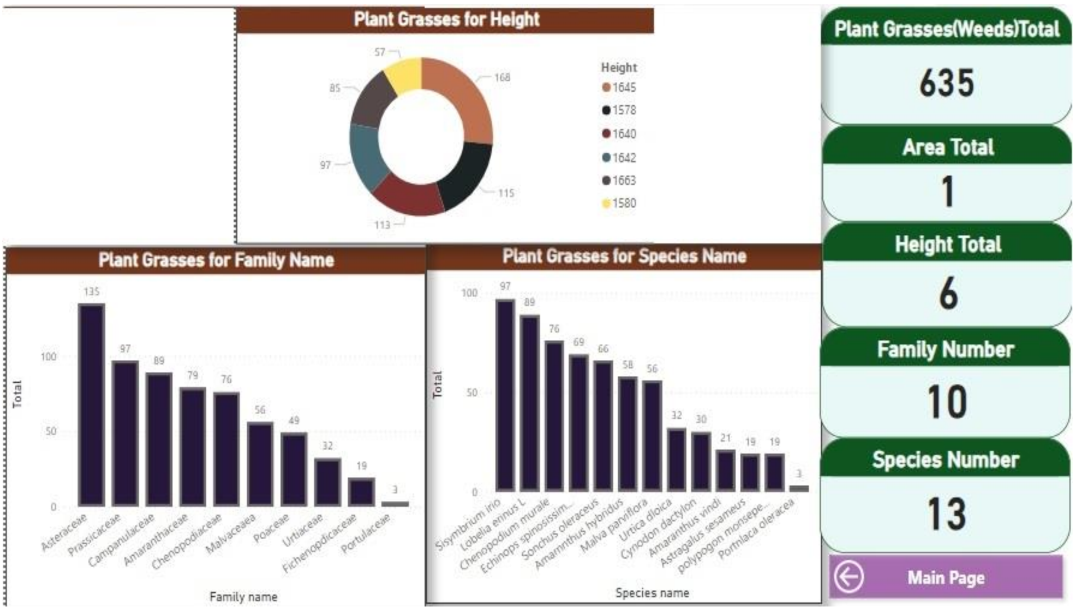

Figure 13. *Weed diversity and density at various altitudes of the Saiysad area (https://n9.cl/rznab)*

Weed distribution in the Wadi Afare area

A total of 1296 weed samples were collected from an altitude (1420 m) of the Wadi Afare area. The data revealed the presence of 23 weed species belonging to 14 weed families. The *Asteraceae* family had the highest representation in this area with a plant density of 279 followed by *Poaceae* (274), *Lamiaceae* (211), and *Crassulaceae* (120). The other families included *Amaranthaceae* (59), *Aizoaceae* (56), *Zygophyllaceae* (54),

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Montiaceae (53), *Solanaceae* (46), *Urticaceae* (41), *Boraginaceae* (38), *Fabaceae* (33), and *Euphorbiaceae* (20) whereas the *Heliotropiaceae* family presented the lowest weed density of only 12. *The species Cenchrus clandestinus* had the highest density of 151 followed by *Marrubium vulgare* (116), *Sedum lineare* (94), *Brickellia californica* (75), *and Chrysanthemum morifolium* (73). The densities of other species were noted as *Scleropogon brevifolius* (69), *Oncosiphon pilulifer* (68), *Clinopodium nepeta* (62), *Aerva javanica* (59), *Aizoon canariense* (56), *Cynodon dactylon* (54), *Tribulus terrestris* (54), *Montia Fontana (53)*, *Salpichroa origanifolia* (46), *Urtica dioica* (41), *Heliotropium curassavicum* (38), *Artemisia schmidtiana (37), Alhagi sparsifolia (33), Leucas chinensis* (33), *Baileya multiradiata (26), Crassula perforate (26),* and *Ditaxis lanceolate (25)* whereas *Euphorbia cyparissias* had the lowest density of 13 (*Fig. 14*). One-way ANOVA analysis revealed non-significant weed species variations in Wadi Afare area with an F-value of 1.890 and P-value of 0.068.

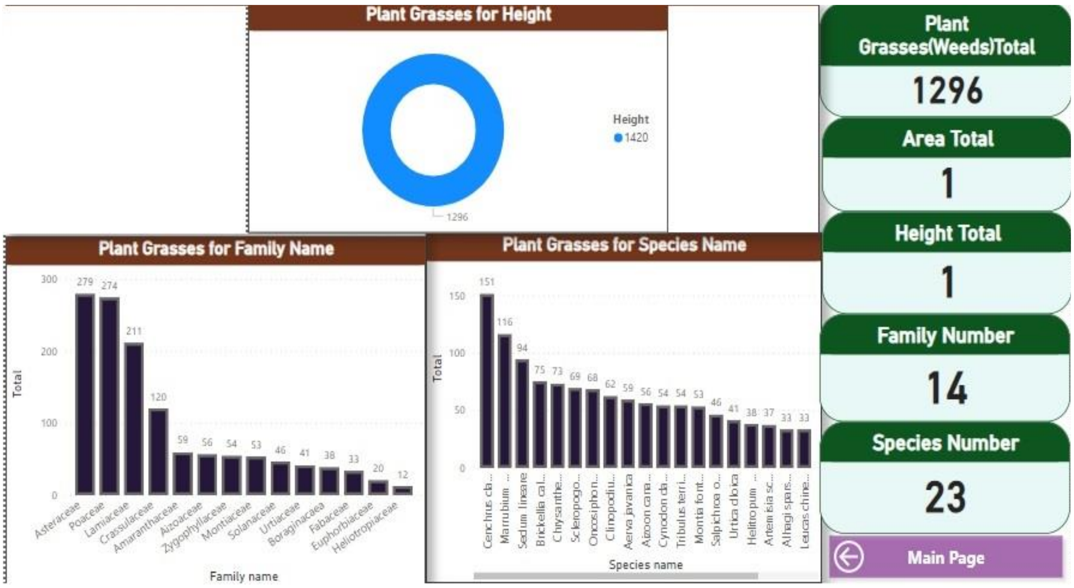

Figure 14. *Weed diversity and density at various altitudes of the Wadi Afare area (https://n9.cl/rznab)*

Weed distribution in the Wadi Dhi-Kazal area

A total of 1073 weed samples were collected from 3 different altitudes (2001 to 2005 m) of the Wadi Dhi-Kazal area where the weed distribution ranged from 160 to 441 specimens at different altitudes. The data revealed the presence of 17 weed species belonging to 11 weed families. The maximum numbers of weed plants were found at the highest altitude of 2004 m (441) followed by 2005 m (161), and 2001 m (160). *Poaceae* family had the highest representation in this area with a plant density of 276 followed by *Asteraceae* (196), *Lamiaceae* (109), *Solanaceae* (63), and *Brassicaceae* (48). The weed densities of other families were noted as *Amaranthaceae* (33), *Cupressaceae* (13), *Boraginaceae* (10), *Apiaceae* (5), and *Resedaceae* (5) whereas *Apocynaceae* family presented the least weed density of only 4. T*he species Cenchrus clandestinus* had the highest density of 233 followed by *Erigeron bonariensis* (114), *Lavandula multifida* (109), *Kleinia neriifolia* (71), and *Solanum incanum* (63). The densities of other species were found as *Nasturtium officinale* (48), *Aristida purpurea*

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(30), *Aerva javanica* (24), *Cortaderia selloana* (13), *Juniperus communis* (13), *Centauria iberica* (11), *Heliotropium curassavicum* (10), *Dysphania ambrosioides* (5), *Foeniculum vulgare* (5), *Reseda Arabica* (5), and *Amaranthus hybridus* (4) whereas *Carissa bispinosa* had the lowest density of 4 (*Fig. 15*). One-way ANOVA analysis depicted non-significant variations among weed species at various altitudes of Wadi Dhi-Kazal area with an F-value of 0.538 and P-value of 0.587.

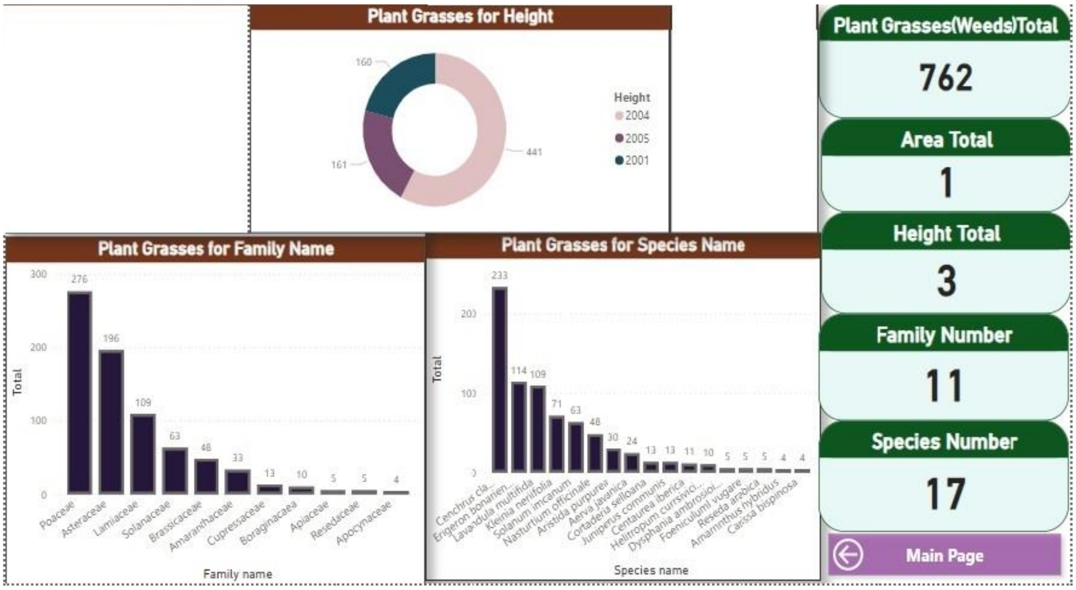

Figure 15. *Weed diversity and density at various altitudes of the Wadi Dhi-Kazal area (https://n9.cl/rznab)*

Weed distribution in the Wadi Kamace area

A total of 532 weed samples were collected from 6 different altitudes (1250 to 2150 m) of the Wadi Kamace area where the weed distribution ranged from 42 to 206 specimens at different altitudes. The data revealed the presence of 39 weed species belonging to 19 weed families. The maximum numbers of weed plants were found at the highest altitude of 2150 m (206) followed by 2135 m (96), and 2145 m (69). The weed density at other altitudes was observed at 2136 (64), and 1250 (55) whereas the lowest weed distribution was noted at 2140 m (42). *Asteraceae* family had the highest representation in this area with a plant density of 90 followed by *Lamiaceae* (88), *Portulaceae* (74), *Solanaceae* (47), and *Asphodelaceae* (44). The weed densities of other families were recorded as *Capparaceae* (44), *Euphorbiaceae* (34), *Urtiaceae* (28), *Poaceae* (22), *Sapindaceae* (11), *Apocynaceae* (10), *Papaveraceae* (9), *Amaranthaceae* (8), *Malvaceae* (7), *Cupressaceae* (5), *Apiaceae* (4), *Zygophyllaceae* (4), and *Convolvulaceae* (2) whereas *Resedaceae* family presented the lowest weed density of only 1. T*he species Portulaca oleracea* had the highest density of 74 followed by *Asphodelus fistulosus* (44), *Caparis spinosa* (44), *Lavandula multifida* (43), and *Euphorbia cyparissias* (34). The densities of other species were found as *Urtica dioica* (28), *Marrubium vulgare* (23), *Withania somnifera* (22), *Eclipta prostrate* (21), *Teucrium polium* (17), *Phagnalon saxatile (16)*, *Erigeron bonariensis* (15), *Gymnosperma glutinosum* (12), *Lycium ferocissimum* (12), *Dodonaea viscosa* (11), *Carissa bispinosa* (10), *Centauria iberica* (10), *Solanum incanum* (10), *Argemone*

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ochroleuca (9), Echinops spinosissimus (8), *Oxybasis glauca* (8), *Setaria viridus* (8), *Malva parviflora* (7), *Juniperus communis* (5), *Cenchrus clandestinus* (4), *Clinopodium nepeta* (4), *Dichanthium annulatum (4), Foeniculum vulgare* (4), *Oncosiphon pilulifer (4), Tribulus terrestris* (4), *Cynodon dactylon* (3), *Datura wrightii* (7), *Stipagrrostis bemralri* (3), *Carduus pycnocephalus* (2), *Convolvulus arvensis* (2), *Caryopteris mongholica* (1), *Flaveria trinervia* (1), and *Reseda arabica* (1) whereas *Verbesina encelioides* had the lowest density of 1 (*Fig. 16*). One way ANOVA anlayis presented highly significant variations among weed species at various altitudes of Wadi Kamace area with an F-value of 6.818 and P-value of 0.00.

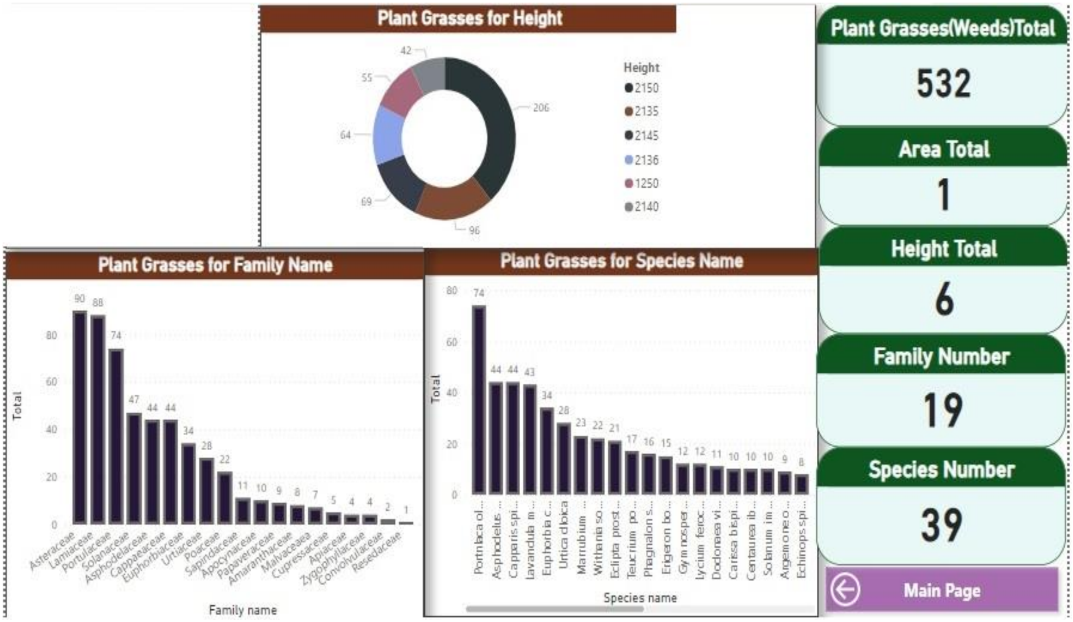

Figure 16. *Weed diversity and density at various altitudes of the Wadi Kamace area (https://n9.cl/rznab)*

Comparative weed distribution in all sampling sites

A total of 15,213 weed samples were collected during the survey from 64 different altitudes of studied sites. The data revealed the presence of 98 weed species belonging to 33 weed families in all the studied sites. The highest weed distribution and density were recorded in the Al-Qayam area (3161, 20.78%) followed by Al-Sayl (2346, 15.42%), Al-Hada Road (2104, 13.83%), and Al-Wahat and Al-Whit (2074, 13.63%). The weed distribution and density in other areas were noted as Wadi Afare (1296, 8.52%), Wadi Al-Arje (772, 5.07%), Wadi Dhi-Kazal (762, 5.01%), Liyah (720, 4.73%), Saiysad (635, 4.17%), Al-Shifa Road (545, 3.58%), and Wadi Kamace (532, 3.5%), and areas whereas Bani-Saad area depicted the lowest weed distribution and density (266, 1.75%). The data of weed diversity and density at various altitudes revealed the highest weed population at the height of 1562 m (2005, 13.18%) followed by 1420 (1296, 8.52%), 1620 (858, 5.64%), 1490 (800, 5.26%), 1545 (794, 5.22%), 1739 (525, 3.45%), 1741 m (492, 3.23%), and 1570 (468, 3.08.86%). The weed distribution and density at other altitudes were recorded at 1558 (445, 2.93%), 2004 (441, 2.9%), 1560 (421, 2.77%), 1555 (410, 2.7%), 1561 (401, 2.64%), 1245 (335, 2.2%), 1794 (335, 2.2%), 1260 (292, 1.92%), 1440 (279, 1.83%), 1797 (269, 1.77%),

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1790 (233, 1.53%), 1565 (223, 1.47%), 1742 (213, 1.4%), 2150 (206, 1.35%), 1270 (182, 1.2%), 1422 (180, 1.18%), 1793 (174, 1.14%), 1527 (172, 1.13%), 1645 (168, 1.1%), 2005 (161, 1.06%), 2001 (160, 1.05%), 1755 (155, 1.02%), 1265 (149, 0.98%), 1578 (115, 0.76%), 1640 (113, 0.74%), 1915 (111, 0.73%), 1530 (110, 0.72%), 1642 (97, 0.64%), 2135 (96, 0.63%), 1550 (91, 0.6%), 1532 (87, 0.57%), 1663 (85, 0.56%), 1548 (74, 0.49%), 2145 (69, 0.45%), 1800 (68, 0.45%), 1787 (66, 0.43%), 1576 (64, 0.42%), 2136 (64, 0.42%), 1580 (57, 0.37%), 1250 (55, 0.36%), 1815 (55, 0.36%), 1805 (50, 0.33%), 1546 (46, 0.3%), 1551 (45, 0.3%), 1745 (45, 0.3%), 1554 (42, 0.28%), 2140 (42, 0.28%), 1410 (40, 0.26%), 1820 (36, 0.24%), 1391 (31, 0.2%), 1454 (30, 0.2%), 1795 (22, 0.14%), 1830 (22, 0.14%), 1509 (15, 0.1%), 1510 (14, 0.09%), and 1810 m (14, 0.09%).

Portulacaceae family had the highest weed density of 2627 in all the studied areas followed by *Poaceae* (2222), *Asteraceae* (2024), *Chenopodioideae* (1678), *Brassicaceae* (864), *Amaranthaceae* (741), *Malvaceae* (730), *Boraginaceae* (690), *Urticaceae* (642), *Lamiaceae* (453), *Solanaceae* (386), *Convolvulaceae* (370), *Crassulaceae* (312), *Zygophyllaceae* (211), *Montiaceae* (194), *Cyperaceae* (129), *Aizoaceae* (121), *Tamaricaceae* (109), *Prassicaceae* (97), *Campanulaceae* (89), *Fabaceae* (82), *Apiaceae* (65), *Capparaceae* (55), *Euphorbiaceae* (54), *Apocynaceae* (50), *Plantaginaceae* (48), *Asphodelaceae* (44), *Cupressaceae* (39), *Sapindaceae* (28), *Fichenopdicaceae* (19), *Resedaceae* (17), *Heliotropiaceae* (12), and *Papaveraceae* (11). The weed species *Portulaca oleracea* had the highest weed density (2627) among all the studied areas followed by *Chenopodium murale* (1594), *Malva parviflora* (730), *Cynodon dactylon* (695), *Heliotropium curassavicum* (688), *Cenchrus clandestinus* (665), *Urtica dioica (642)*, *Descurainia Sophia* (498), *Xanthium orientale* (396), and *Amaranthus vindi* (305). The weed density of other species were noted as *Echinops spinosissimus* (266), *Sedum lineare* (239), *Tribulus terrestris* (211), *Setaria viridus* (201), *Oncosiphon pilulifer* (200), *Ipomoea sp.* (199), *Montia Fontana* (194), *Nasturtium officinale* (193), *Lavandula multifida* (191), *Solanum incanum* (186), *Convolvulus arvensis* (171), *Amaranthus hybridus* (166), *Astrebla pectinata* (145), *Sonchus oleraceus* (144), *Marrubium vulgare* (139), *Launaea capitata* (131), *Erigeron bonariensis* (130), *Cyperus laevigatus* (129), *Polypogon monspeliensis* (123), *Aizoon canariense* (121), *Stipagrrostis bemralri* (111), *Tamarix ramosissima* (109), *Sisymbrium irio* (97), *Oxybasis glauca* (92), *Agropyron repens* (90), *Lobelia erinus* (89), *Brassica tournefortii* (88), *Phagnalon saxatile* (88), *Aerva javanica* (86), *Matthiola incana* (85), *Atriplex leucoclada* (84), *Kleinia neriifolia* (76), *Brickellia californica* (75), *Chrysanthemum morifolium* (73), *Crassula perforate* (73), *Scleropogon brevifolius* (71), *Clinopodium nepeta* (66), *Emilia sonchifolia* (66), *Eclipta prostrate* (65), *Lycium ferocissimum* (58), *Capparis spinosa* (55), *Withania somnifera* (55), *Verbesina encelioides* (53), *Carissa bispinosa* (50), *Salpichroa origanifolia* (49), *Bacopa monnieri* (48), *Astragalus nutallianus* (47), *Cornulaca monacantha* (45), *Asphodelus fistulosus* (44), *Euphorbia cyparissias* (41), *Saussurea japonica* (41), *Hydrocotyle nepalensis* (39), *Datura wrightii* (38), *Artemisia schmidtiana* (37), *Alhagi sparsifolia* (35), *Cirsium arvense* (35), *Dysphania ambrosioides* (35), *Leucas chinensis* (33), *Eleusine indica* (31), *Aristida purpurea* (30), *Gymnosperma glutinosum* (30), *Dodonaea viscosa* (28), *Baileya multiradiata* (26), *Foeniculum vulgare* (26), *Ditaxis lanceolate* (25), *Teucrium polium* (23), *Panicum dichotomiflorum* (22), *Centauria iberica* (21), *Coreopsis drummondii* (20), *Juniperus communis* (20), *Astragalus sesameus* (19), *Pressus sempervirens* (19), *Aster*

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subulatus (14), *Bothriochloa ischaemum* (13), *Cortaderia selloana* (13), *Caroxylon passerinum* (12), *Argemone ochroleuca* (11), *Lactuca sativa* (11), *Bebbia juncea* (10), *Coleogyne ramosissima* (9), *Pleurocoronis pluriseta* (9), *Agrostis stolonifera* (8), *Reseda Arabica* (8), *Flaveria trinervia* (5), *Dichanthium annulatum* (4), *Amsinckia tessellata* (2), *Carduus pycnocephalus* (2), and *Caryopteris mongholica* (1) (*Table 1*; *Fig. 17*). A comprative statistical analysis (One way ANOVA) of weed species among 12 studied regions of Taif presented highly significant weed variations with an F-value of 5.774 and P-value of 0.00. The data of weeds at 64 studied altitudes in all studied regions was also statistically (One-way ANOVA) compared, which demonstrated non-significant weed species variations at studied altitudes with an F-value of 2.743 and P-value of 0.138.

Table 1. *Population density of weed families and related weed species in 12 sampling areas of the Taif region, Saudi Arabia*

Family Name	Species name	Wadi Afare	Al Hada R.	Bani Saad	Al Wahat and Al Whit	Al Sayl	Al Arje	Al Qayam	Al Shifa R.	Liyah	Saiysad	Wadi Dhi-Kazal	Wadi Kamace	Density
Aizoaceae	*Aizoon canariense*	15	4	51	10									80
Amaranthaceae	Aerva javanica	24				3						24		51
	Amaranthus vindi		165		32		30	27		30	21			305
	Amarnnthus hybridus				70	28	3			3	58	4		166
	Caroxylon passerinum						6			6				12
	Cornulaca monacantha								45					45
	Dysphania ambrosioides						14	8	10	6		5		43
	Oxybasis glauca				18	4	35		2	30			8	97
Apiaceae	*Foeniculuml vugare*							2	15			5	4	26
	Hydrocotyle nepalensis					3		6	30					39
Apocynaceae	*Carissa bispinosa*								36			4	10	50
Asphodelaceae	*Asphodelus fistulosus*												44	44
Asteraceae	*Artemisia schmidtiana*	91												91
	Aster subalatus							14						14
	Baileye multiradiata	26												26
	Bebbia juncea								10					10
	Brickellia californice	36												36
	Carduus pycnocephalus												2	2
	Centaurea iberica												21	21
	Chrysanthemum morifolium	73												73
	Cirsium arvense							35						35

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	Coreopsis drummondii							20						20
	Echinops spinosissimus		30	37	115			1	6		69		8	266
	Eclipta prostrate				17	7	11			10			21	66
	Emilia sonchifolia							66						66
	Erigeron bonariensis				6							114	15	135
	Flavaria trnervia					4							1	5
	Gymnosperma glutinosum								18				12	30
	Kleinia neriifolia								5			71		76
	Lactuca sativa				10	4			1					15
	Launaca capitata				131									131
	Oncosiphon pilulifer	94						128					4	226
	Pennsylvania state								45					45
	Phagnalon saxatile				27								16	43
	Pleurocoronis pluriseta					6		1	2					9
	Saussurea japonica							41						41
	Sonchus oleraceus		3		8	30		37			62			140
	Verbesina encelioides				3		3		47	1			1	55
	Xanthium orientale						198			154				352
Boaceae	*Eleusine inelica sp.*		5			26								31
Boraginacaea	*Amsinckia tessellata*								2					2
	Helitropum currsivicium	38	77			448	9	96	11	1		10		690
Brassicaceae	*Brassica tournifortil*		30	19				39						88
	Descrainia sophia					12		486						498
	Matthiola incana							85						85
	Nasturtium officinale						68			65		48		181
	Sisymbrium irio										97			97
Campanulaceae	*Lobelia erinus* L										89			89
Cappaeaceae	*Capparis spinosa*			3					8				34	45
Chenopodiaceae	*Atriplex lencoclada*				26	54								80
	Chenopodium murale		421	51	130	263		653			76			1594
Convolvulaceae	*Convolvulac alvensis*		73		81	15							2	171
	Ipomoea sp.		81		118									199
Crassulaceae	*Crassula perforata*	26						47						73
	Sedum lineare	94				89		56						239
Cupressaceae	*Juniperus communis*								2			13	5	20
	Pressus sempervirens						10	15		2				27

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Cyperaceae	*Cyperus laevigatus*						59		11	59				129
Euphorbiaceae	*Ditaxis lanceolata*	13												13
	Euphorbia cyparissias	7											34	41
Fabaceae	*Alhagi sparsifolia*	7							2					9
	Astragalus nuttallianus					18			29					47
	Astragalus sesameus										19			19
Heliotropiaceae	*Cenodon dactylon*	54												54
	Ditaxis lanceolata	12												12
Lamiaceae	*Caryopteris mongholica*												1	1
	Clinopodium nepeta	88											4	92
	Lavandula multifida								39			109	43	191
	Leucas chinensis	33												33
	Marrubium vulgare	110											23	133
	Teucrium polium							6					17	23
Malvaceaea	*Malva parviflora*		323		39	62		238	5		56		7	730
Montiaceae	*Montia fontana*	63	4				68		3	67				205
Papaveraceae	*Argemone ochroleuca*				2								9	11
Plantaginaceae	*Bacopa monnieri*						28			24				52
Poaceae	*Agropyron repons*							90						90
	Agrostis stolonifera						10			4				14
	Aristida purpurea											30		30
	Astrebla pectinata				145									145
	Bothriochloa ischaemum								13					13
	Cenchrus clandestinus	140					101		57	100		233	4	635
	Cortaderia selloana											18		18
	Cynodon dactylon		132		38	378	16			43	30		3	640
	Dichanthium annulatum												24	24
	Panicum dichotomiflorum						20			11				31
	polypogon monsepeliensis				70			34			19			123
	Scleropogon brevifolius	89							2					91
	Setaria viridis			9		182							8	199
	Stipagrrostis bemralri		5		46			57					3	111
Portulaceae	*Portnlaca oleracea*		193	71	796	657		833			3		64	2617
Resedaceae	*Coleogyne ramosissima*					5			4					9
	Reseda arabica							2				10	1	13
Sapindaceae	*Dodonaea viscosa*								17				11	28
Solanaceae	*Datura wrightii*				11	8	15			9			3	46
	Lycium ferocissimum					7	8		29	5			12	61

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	Salpichroa origanifolia	46						3	2					51
	Solanum imcanum				82			21	10			64	10	187
	Withania somnifera		6	25					2				21	54
Tamaricaceae	*Tamarix ramosissima*					4	50			50				104
Urtiaceae	*Urtica dloica*	51	455		43	29		14			36		18	646
Zygophyllaceae	*Tribulus terriestris*	66	97				10		25	40			4	242

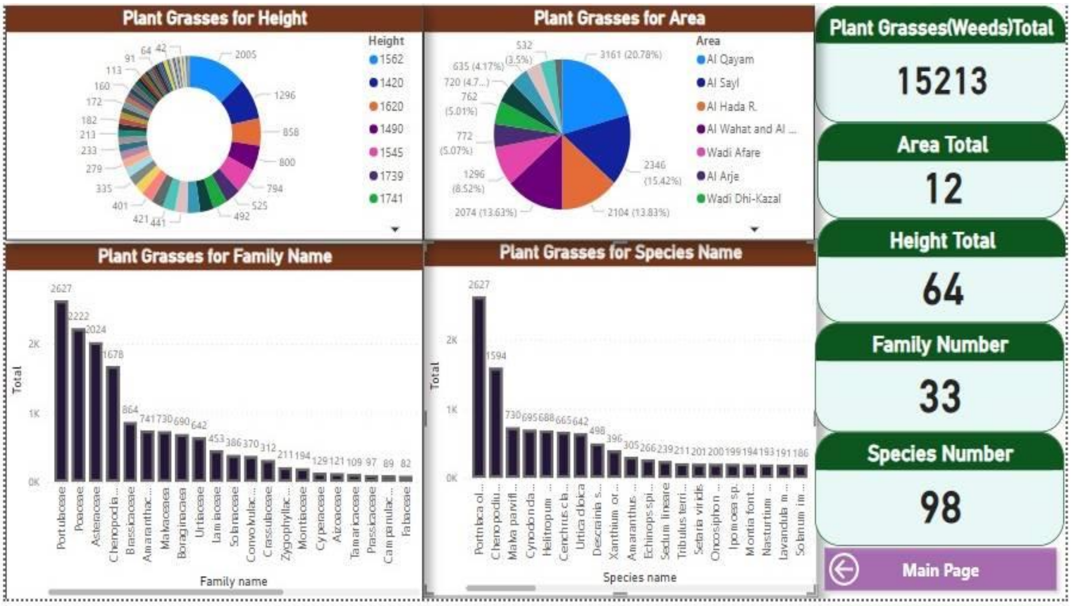

Figure 17. *Comparative weed diversity and density in all studied areas (https://n9.cl/rznab)*

Discussion

The rise of novel intelligence tools has overshadowed all aspects including agricultural research. The data collection, storage, processing, analysis, and visualization tools effectively reveal real-time, easily understandable, and accurately displayed information. These flexible platforms can also be customized to devise unique consoles for attractive and precise data visualization (Khilari et al., 2022). Moreover, improved computing power, the designing of models, and easy access to massive datasets have facilitated the overcoming of complications associated with old-school approaches (Gounder and Al Mazyad, 2016). The data visualization tool of the Power BI dashboard presents key points in a single view and can display the data from SQL Server databases, Excel spreadsheets, and cloud services (Salesforce and Google Analytics). It allows real-time monitoring of data metrics through trend analysis and key performance indicators (KPIs). Power BI dashboard automatically updates with the induction of new data and creates interactive visuals (maps, indicators, and charts). Real-time data updates on the dashboard facilitate decision-making according to the most current scenario. The users can filter the information to obtain specific details and data perspectives, and it can individually reflect the metrics and indicators (team or a user) in charts, maps, and graph format. Power BI seamlessly integrates with other

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Microsoft services (Teams, Excel, and SharePoint) to efficiently maximize the usage of various platforms and tools. The agricultural systems require continuous oversight, expertise, and maintenance. Hence, automation of collected data could provide reliable and practical real-time information for a quick and timely response. Power BI can efficiently employ multiple types of data sources to generate data-based reports, and provides flexible connectivity and report-editing options among organizations and team members (Shoaib and Nandi, 2022). The integration and visualizations in unique formats offer deeper insights into the collected data. All types of big data can be integrated with this platform for analysis, sharing, and better understanding across working teams while securing data accuracy, confidentiality, and consistency for rapid data-driven decisions and actions (Schaefer, 2016; Wu and Qin, 2011).

This study integrates the biological data of weeds (diversity, density, and distribution) with Power BI to generate attractive and easy-to-understand output visualizations. Weeds demonstrate better adaptability to agricultural lands than cultivated crops through potent multidimensional capabilities such as dormancy under unfavorable environments, large seed production, rapid growth, and multiple spreading modes. Early flowering, fruiting, and deep root systems help in their rapid expansion as well. The impacts of weeds on global farming systems are multidimensional, and management practices contribute to a significant rise in the cost of production in addition to poor crop quality and yield. They compete with the crops in terms of irrigation water, nutrients, sunlight, and root space. On the other hand, the growing human population also puts considerable pressure on the agriculture sectors by requiring 70% higher agricultural produce to cater to human needs up to 2025 (Corceiro et al., 2023; European Commission, 2020). Diverse types of weed toxins (nitrates, resinoids, alkaloids, oxalates, glycosides, and saponins) also affect livestock food intake in the pastures leading to poor health, lower milk production, abortions, and mortalities in severe cases (Ekwealor et al., 2019). Thus, comprehensive information on area-wise weed diversity and distribution is crucial for effective weed management practices and sustainable yield (Swami et al., 2017).

During the current study, 12 agricultural pockets of Taif, Saudi Arabia were investigated for weed diversity and density. A total of 15,213 weed samples were collected from 64 different altitudes of study sites, which depicted the presence of 98 weed species belonging to 33 weed families. The highest and lowest weed distribution and density were recorded in the Al-Qayam (3161, 20.78%) and Bani-Saad (266, 1.75%) areas, respectively. The weed distribution trend in other areas was recorded as Al-Sayl (2346, 15.42%), Al-Hada Road (2104, 13.83%), and Al-Wahat and Al-Whit (2074, 13.63%). The weed distribution and density in other areas were noted as Wadi Afare (1296, 8.52%), Wadi Al-Arje (772, 5.07%), Wadi Dhi-Kazal (762, 5.01%), Liyah (720, 4.73%), Saiysad (635, 4.17%), Al-Shifa Road (545, 3.58%), and Wadi Kamace (532, 3.5%). The differential weed diversity and density in these areas could be attributed to their varying altitudes. The results revealed the highest weed population at an altitude of 1562 m (2005, 13.18%) whereas other significant altitudes included 1420 (1296, 8.52%), 1620 (858, 5.64%), 1490 (800, 5.26%), 1545 (794, 5.22%), 1739 (525, 3.45%), 1741 m (492, 3.23%), and 1570 (468, 3.08.86%). The lowest weed diversity and density were noted at an altitude of 1810 m (14, 0.09%). Alwadi and Moustafa (2016) conducted a weed survey at various elevations in the Aseer region of Saudi Arabia and concluded a direct impact of altitude on the spatial distribution, composition, and density of weeds in an area.

The weed families' distribution significantly varied among studied sites where the highest number of families were recorded in the Wadi Kamaci area (19) followed by Al-Sayl (16), Al-Shifa Road (17), Al-Hada Road (16), Al-Qayam (15), Al-Wahat and Al-Whit (12), Wadi Afare (14), Liyah (12), Wadi Al-Arje (12), Wadi Dhi-Kazal (11), Saiysad (10), and Bani-Saad (8). The species distribution in studied sites varied as Wadi Kamaci (39), Al-Shifa Road (34), Al-Qayam (32), Al-Sayl (26), Al-Wahat and Al-Whit (27), Wadi Afare (23), Wadi Al-Arje (22), Liyah (22), Wadi Dhi-Kazal (17), Al-Hada Road (18), Saiysad (13), and Bani-Saad (8). Overall, weed species belonging to *Portulacaceae* family had the highest weed density (2627) in all the areas followed by *Poaceae* (2222), *Asteraceae* (2024), *Chenopodioideae* (1678), *Brassicaceae* (864), *Amaranthaceae* (741), *Malvaceae* (730), *Boraginaceae* (690), and *Urticaceae* (642).

This diverse richness of weed species belonging to different families could be related to varying preferences of climatic conditions in the studied sites at different altitudes (Alwadi and Moustafa, 2016). The highest presence of weed species of the *Asteraceae* family is understandable as it is the largest weed family worldwide, which can acclimatize to a variety of environmental conditions at different altitudes. Its dominant growth in the agricultural fields is supported by the production of secondary metabolites (flavonoids, terpenes, saponins, polyacetylenes, phenolic acids, and sesquiterpene lactones), which restrict other plants in the field (Araújo et al., 2021). Similarly, *Poaceae* is another large global plant family that can withstand a broad range of climatic and environmental conditions. *Poaceae* weeds can initiate their growth from any part of the plant making other plants unable to compete with their growth capabilities. Moreover, allelochemical secretion in *Poaceae* weeds hinders other plants' growth to attain maximum benefit of available field nutrients (Majrshi and Khandaker, 2020; Scrivanti, 2010). Among weed species, *Portulaca oleracea* had an overall maximum distribution across all studied sites. This annual grass particularly flourishes in subtropical and tropical regions of the world but can conveniently grow in other conditions as well (Rahimi et al., 2019). Furthermore, a wide range of important weed plants were identified in the studied sites. These unwanted plants cause significant economic losses to the farmers and thus demand for broad-scale remedial measures in the Taif region.

Conclusion

This study integrates massive biological data of weed diversity and density with the Power BI platform to produce real-time and attractive visualization. This novel strategy accurately describes the presence of different weed families and species in specific sites that can assist in devising site-specific management approaches corresponding to different altitudes and cropping patterns. Power BI also offers the flexibility of swift data sharing among corresponding institutes for timely measures according to the growth seasons of various weed species. The massive weed data of this study will pave the way to devise and implement future weed management programs for better agricultural production in the Taif region of Saudi Arabia.

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