FOREST COVER ENHANCES REGULATORY ECOSYSTEM SERVICES AND PHYTO-SOCIOLOGICAL AND SOIL PARAMETERS IN SUBMONTANE RANGELANDS OF THE SALT RANGE

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Abstract

Forest cover is critical for sustaining ecosystem function and regulating environmental conditions in submontane rangelands. This study looked at how forest vegetation affected specific ecosystem services, soil qualities, and phytosociological characteristics of common plant species in Pakistan's Salt Range. The quadrat method (5 m × 5 m) was used to assess vegetation, while soil temperature and organic matter were measured in wooded and open habitats at the Jabba, Khabekki, and Kanhati locations. Soil temperature was consistently lower under forest cover, with mean values of 36.06°C, 35.76°C, and 36.42°C in Jabba, Khabekki, and Kanhati, respectively, compared to 39.78°C, 39.08°C, and 38.66°C in open regions. The one-way ANOVA revealed a highly significant difference between vegetative and open sites ($F = 66.862$, $p < 0.001$). Forest soils also contained more organic matter, with mean values of 0.76%, 0.86%, and 0.80% at the corresponding sites, but open lands only had 0.58%, 0.56%, and 0.54%. This difference was also very significant ($F = 62.227$, $p < 0.001$). Phytosociological research found that Justicia adhatoda had a much higher frequency, density, and cover in forest habitats, with a maximum frequency of 91.67% and a cover of 37.27%. Significant habitat impacts were seen in frequency ($F = 59.888$, $p = 0.002$), density ($F = 28.604$, $p = 0.006$), and cover ($F = 29.621$, $p = 0.006$). Peganum harmala and Cynodon dactylon showed similar significant changes in both forest and open habitats. Overall, the findings show that forest cover improves regulatory ecosystem services by moderating soil temperature, increasing soil organic matter, and promoting increased vegetation abundance and diversity, emphasizing the ecological significance of forest conservation in the Salt Range rangelands.

INTRODUCTION

Ecosystems carry out a variety of tasks that produce services necessary for maintaining life on Earth. By converting environmental resources such as land, water, plants, and atmosphere into a flow of valued products and services such as clean air, water, and food, these ecosystem services benefit humans both directly and indirectly (Costanza, 2024). According to Gray et al. (2024) and Yi (2022), ecosystem services are the advantages that ecosystems offer to people who help make human life both feasible and valuable.

Maintaining ecosystem functioning and guaranteeing the continuous provision of ecosystem services depend heavily on biodiversity. Because vegetation alters environmental conditions and affects energy flow, nutrient cycling, and oxygen dynamics within ecosystems, evaluating vegetation variety is crucial (Dunlap, 2026; Körner, 2023). The diversity and functionality of other creatures in the environment may change as a result of changes in plant diversity. Furthermore, biodiversity protection is closely associated with ecosystem resilience and the ability of ecosystems to sustain ecosystem services (Turck, 2025; Haddad & Solomon, 2023).

Phytosociological research offers important insights into the distribution, composition, and organization of plant communities. Interpreting ecological interactions and ecosystem functioning requires an understanding of the distribution of individuals and populations of each species within a community (Dunlap, 2026; Lerdau et al., 2023). To characterize vegetation features and evaluate ecological conditions, parameters such as frequency, density, and cover are frequently employed (Monteiro-Henriques, 2025; Hart-Fredeluces & Duffy, 2024).

Ecosystem services were divided into four categories by the Millennium Ecosystem Assessment: providing, regulating, sustaining, and cultural services (Bennett et al., 2026). Hydrological management, climate control, soil formation, and carbon sequestration are examples of regulatory ecosystem services, while food, fodder, medicinal plants, fuel wood, and lumber are examples of provisioning services (Rana et al., 2026). Because it affects microbial activity, nitrogen cycling, water and nutrient intake, and root development, soil temperature is a crucial regulating factor (Thakur et al., 2022). In a similar vein, soil organic matter is an indicator of ecosystem health and has a major role in soil fertility and productivity.

Pakistan's Salt Range is renowned for its priceless natural riches and wide variety of flowers. The area is home to degraded scrub vegetation, dry tropical thorn forests, and subtropical semievergreen forests due to its mountainous, dry subtropical environment (Dikshit & Dikshit, 2025; Ali & Maqbool, 2025; Imran et al., 2023). *Justicia adhatoda*, *Acacia modesta*, *Olea ferruginea*, *Peganum harmala*, and *Cynodon dactylon* are examples of dominant plant species, many of which have both ecological and therapeutic value (Hussain et al., 2023). However, the ecological integrity of these habitats is threatened by human influences, especially overgrazing and deforestation. While overgrazing has been shown to significantly reduce floral diversity, grazing, browsing, and trampling have been identified as significant factors influencing community composition and biodiversity (Dharaiya & Rabari, 2022).

The floristic composition and biodiversity of the Salt Range have been the subject of numerous studies (Sadia et al., 2025), but little is known about how forest cover affects phytosociological traits and regulates ecosystem functions in submontane rangelands. The current study's results showed that soil temperatures under forest cover ranged from 34°C to 36°C, whereas temperatures in open regions were higher, ranging from 37°C to 40°C. In a similar vein, woodland locations have higher soil organic matter content (0.76-0.86%) than open areas (0.54-0.58%). The favourable microenvironment that forest cover creates may be responsible for these variations. According to Boutoumit et al. (2022), decreased soil fertility and water availability may be the cause of restricted plant development in open settings. On the other hand, because of increased organic matter accumulation and nutrient availability, forest habitats offer better circumstances.

Thus, the goal of the current study was to measure specific regulating and provisioning ecosystem services that the salt range's natural vegetation provides. The study specifically sought to assess the phytosociological parameters of common plant species by measuring frequency, density, and cover, as well as to compare soil temperature and soil organic matter in wooded and open environments. It is anticipated that the results will advance knowledge of the ecological importance of forest cover and offer empirical support for the preservation and sustainable management of Salt Range submontane rangelands.

MATERIALS AND METHODS

Selection of sites

The study sites selected in Soon Valley were Jabba, Khabekki and Kanhati. The study area was visited for data collection. The quadrat method was used to examine the vegetation of the study area. A 5 m x 5 m quadrat was used for vegetation sampling. Ten quadrats were placed at each study site at a distance of approximately 0.5 km. Five quadrats were placed in the open land of each study site, and five quadrats were placed in forest places.

Estimation of provisional and regulatory ecosystem services

Temperature: Soil temperature is an important property that is essential for many soil processes and reactions. This may include water and nutrient uptake, microbial activities, nutrient cycling, root growth, and many other processes. Soil temperature was measured at a depth of 15 cm. A hole was made approximately 15 cm deep by using a screwdriver. Then, a glass bulb thermometer was put into the hole, and it was made sure that it firmly touched the soil and allowed a few minutes for the temperature measurement.

Readings were noted from two places: one reading was taken from where the study plants were present, and the second was taken from open land that was reserved for forest area. The readings were taken in the morning and late afternoon to take average the total temperature.

Soil organic matter

Organic matter was determined by the dry ignition method using a muffle furnace. Five grams of soil was taken in a crucible and placed in a muffle furnace at 450°C for 12 hours (Schulte, 1996). After 12 hours, it was weighed. The soil weight achieved after ignition was subtracted from its initial weight to determine the weight of organic matter.

Vegetation data analysis

The number of plants of all the species in all quadrats was counted. Soil present below the study plants was also collected for the measurement of soil organic matter. The cover of each plant species was determined by using visual estimation.

Frequency:

Frequency is the measure of the percentage of quadrats in plots in which a species occurs. It was calculated by using the following formula:

$$\text{Frequency} = \frac{\text{Number of quadrats in which a species occurred}}{\text{Total number of quadrats taken}}$$

Density:

Density is the number of a plant species per unit area and is calculated by using the following formula:

Total number of individuals of a species

Density = ---× 100
Total area sampled

Cover:

It tells how much percent of the ground is covered by specific species of plant. The cover of each plant species was determined by using visual estimation (Kent and Coker, 1992) and determined as a percentage.

Relative frequency

It is the parameter that indicates how many individual species are dispersed in an area relative to all the species. It is measured by using the formula:

$$\text{Relative frequency} = \frac{\text{The frequency of individuals of species in all quadrats}}{\text{Total frequency of all the species in all quadrats}} \times 100$$

Relative density

Relative density tells us about the percentage of any species in the field relative to all other individuals and can be measured by using the following formula:

$$\text{Relative density} = \frac{\text{The density of individuals of species in all quadrats}}{\text{Total density of all the species in all the quadrats}} \times 100$$

Relative cover

The relative cover is the ratio of a species cover of all the quadrats to the total cover of all individuals in all quadrats. It is calculated by using the following formula.

$$\text{Relative cover} = \frac{\text{Cover of an individual of species in all quadrats}}{\text{Total cover of all the species in all the quadrats}} \times 100$$

Results

Estimation of regulatory ecosystem services (temperature)

Soil Temperature at the Jabba Site

In the forest quadrats, the soil temperature ranged from 34.6 to 37.4 ^{0} C with a mean value of 36.06 ^{0} C. The maximum soil temperature was recorded in quadrat two (37.4 ^{0} C), and the minimum soil temperature was recorded in quadrat four (34.6 ^{0} C) in the forest site. On open land, the temperature value ranged from 38.9 to 40.3°C, with a mean value of 39.78°C. The soil temperature at the open site was highest in quadrat five (40.3°C), and the minimum was recorded in quadrat one (38.9°C) (Figure 1a, b).

Soil Temperature at the Khabikki Site

In the forest quadrats, the soil temperature ranged from 33.4 to 37.3 ^{0} C with a mean value of 35.76 ^{0} C. The maximum soil temperature was recorded in quadrat three (37.3 ^{0} C), and the minimum soil temperature was recorded in quadrat five (33.4 ^{0} C) in the forest site. On open land, the temperature value ranged from 37.9 to 40.1°C, with a mean value of 39.08°C. The soil temperature at the open site was highest in quadrat three (40.1°C), and the minimum was recorded in quadrat five (37.9°C) (Figure 1a, b).

Soil Temperature at the Kanhati Site

In the forest quadrats, the soil temperature ranged from 34.3 to 37.2 ^{0} C with a mean value of 36.42 ^{0} C. The maximum soil temperature was recorded in quadrat four (37.2 ^{0} C), and the minimum soil temperature was recorded in quadrat three at 34.3 ^{0} C in the forest site.

In open land, the temperature value ranged from 36.4 to 39.9°C, with a mean value of 38.66°C. The soil temperature at the open site was highest in quadrat one (40.1°C), and the minimum was recorded in quadrat three (37.9°C) (Figure 1a, b).

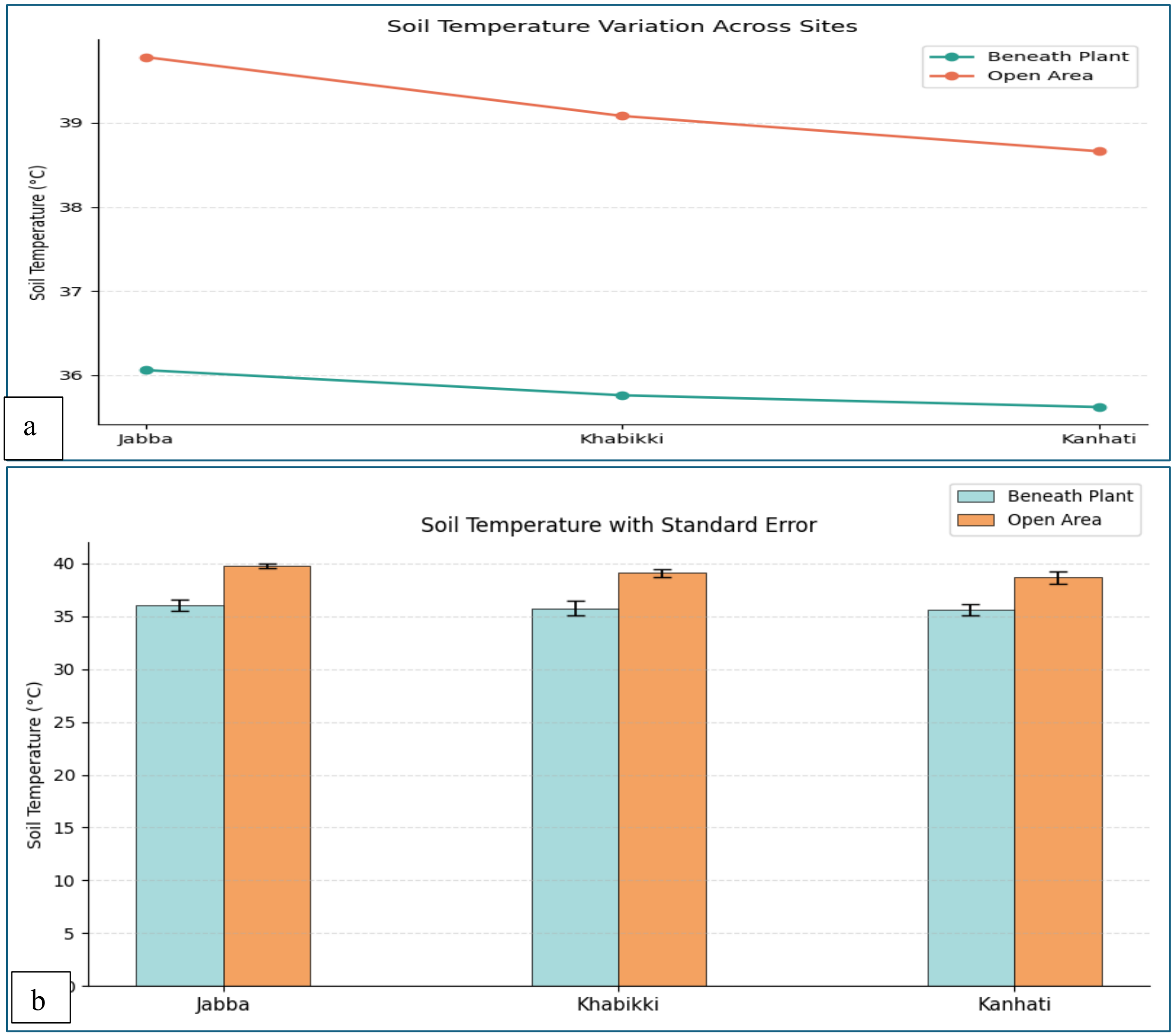


Figure (1a-1b): a) Line graph showing soil temperature variation across sites b) Bar graph showing soil temperature comparison between beneath plants and open areas

A highly significant difference in temperature between the study sites was found by one-way ANOVA (F = 66.862, p = 0.001). The findings show that compared to vegetative land, open land conditions were much warmer. The measured temperature differential of almost 3.09°C indicates that plant cover has a significant impact on local temperature regulation, leading to a colder microclimate in vegetated areas (Table 1).

Comparison of Temperature between the Study Sites

The comparison of temperature between the study sites shows a highly significant value of 0.001.

Table 1: Analysis of variance (ANOVA) showing differences in temperature between vegetative land and open land study sites

Temperature	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	14.353	1	14.353	66.862	.001
Within Groups	.859	4	.215		
Total	15.212	5			

Estimation of provisional ecosystem services (soil organic matter)

Determination of soil organic matter at the Jabba site

In forest area quadrats, soil organic matter ranged from 0.65 to 0.89% with a mean value of 0.76%. The maximum soil organic matter recorded in quadrat five was 0.89%, and the minimum organic matter recorded in quadrat two was 0.65% at the forest site. In open land, the soil organic matter ranged from 0.47 to 0.69% with a mean value of 0.58%. The soil organic matter at the open site was a maximum in quadrat one (0.47%), and a minimum was recorded in quadrat five (0.69%) (Figure 2a, b).

Determination of soil organic matter at the Khabikki site

In forest area quadrats, soil organic matter ranged from 0.85 to 0.91% with a mean value of 0.86%. The maximum soil organic matter was recorded in quadrat five, which was 0.89%, and the minimum soil organic matter was recorded in quadrat two, which was 0.65% in the forest site.

In open land, the soil organic matter value ranged from 0.49 to 0.63%, with a mean value of 0.56%. The soil organic matter at the open site was a maximum in quadrat one (0.47%), and a minimum was recorded in quadrat five (0.69%) (Figure 2a & 2b).

Determination of soil organic matter at the Kanhati site

In the forest area quadrats, the soil organic matter ranged from 0.69 to 0.92% with a mean value of 0.80%. The maximum soil organic matter was recorded in quadrat one, which was 0.92%, and the minimum soil organic matter was recorded in quadrat four, which was 0.69% at the forest site. In open land, the soil organic matter value ranged from 0.45 to 0.61%, with a mean value of 0.54%. The soil organic matter at the open site was a maximum in quadrat four (0.61%), and a minimum was recorded in quadrat five (0.45%) (Figure 2a & 2b).

Comparison of soil organic matter between the sites

The comparison of soil organic matter shows a highly significant value of 0.001.

The vegetative land and open land research locations had significantly different temperatures, according to the ANOVA results (Table 3). With a high F value of 62.227, the between-group variation (SS = 0.091) was significantly larger than the within-group variation (SS = 0.006). Temperature varied significantly across the two site types, according to the significance value (p = 0.001) (Table 2).

Table 2: Analysis of variance (ANOVA) showing differences in temperature between vegetative land and open land study sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.091	1	.091	62.227	.001
Within Groups	.006	4	.001		
Total	.097	5			

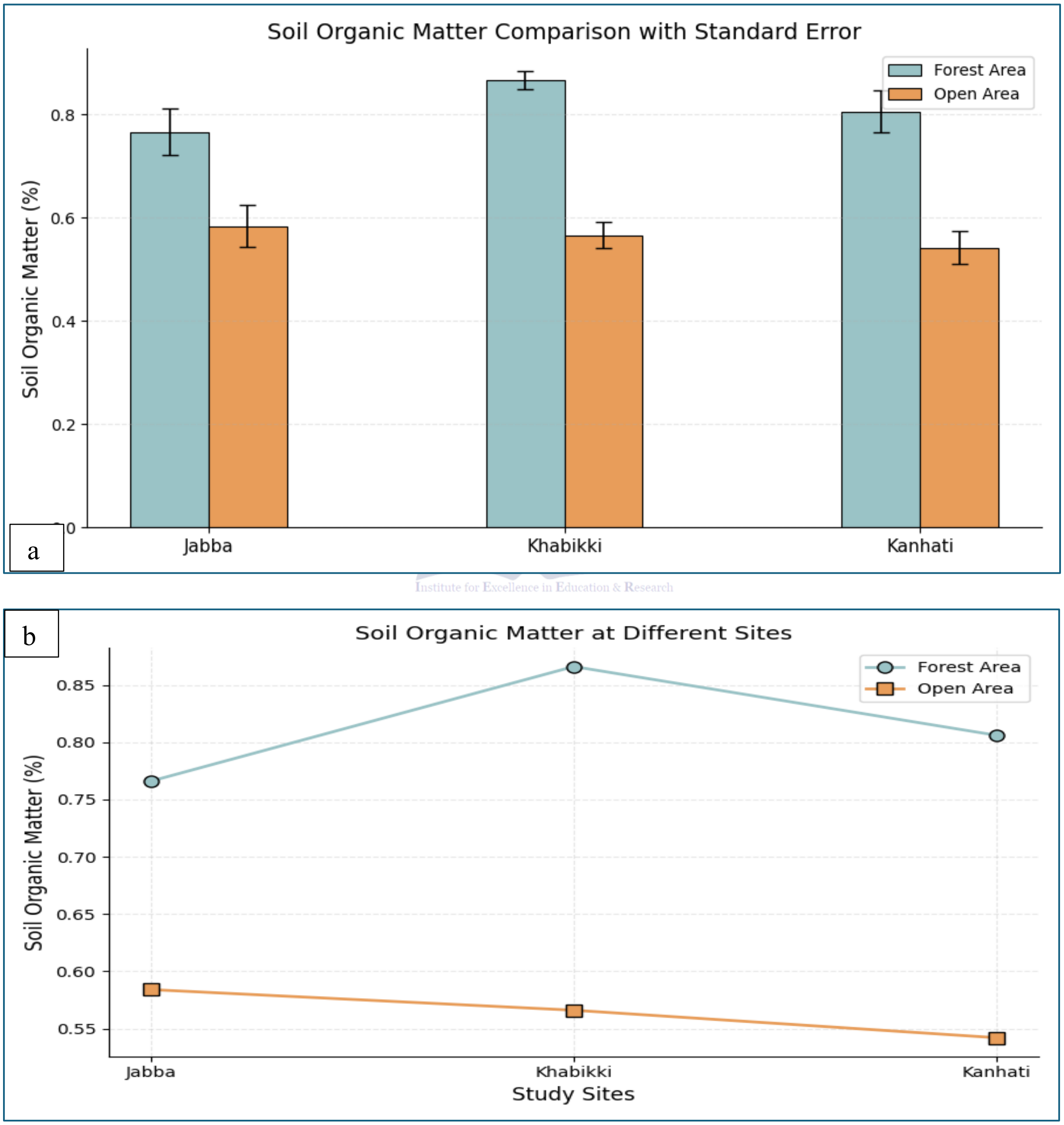


Figure (2a-2b): a) Bar graph showing organic matter comparison between beneath plants and open areas b) Line graph showing organic matter variation across sites

Phytosociological data analysis of *Justicia adhatoda*

Frequency of *Justicia adhatoda*

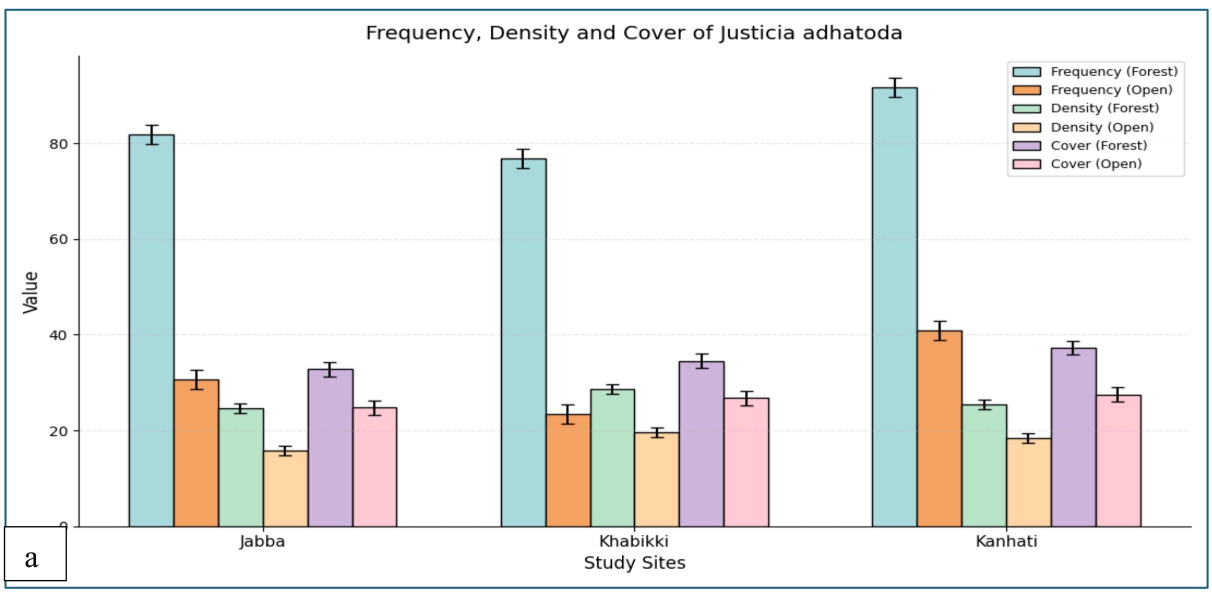
The quadrats were sampled in the open area, and the frequency recorded at the Khabikki site was 23.4% and at the Kanhati site was 40.9% and 30.7% at the Jabba site, with a mean value of organic matter of 0.58% and temperature of 39.78$^{0°C.}$ The order of frequency from low to high was the Khabikki site, Jabba site and Kanhati site, with frequencies of 23.4%, 30.7% and 40.9%, respectively. The frequency of *Justicia adhatoda* in the forest area was lowest at the Khabikki site (76.8%) and highest at the Kanhati site (91.67%), and 81.9% was recorded at the Jabba site, with a mean value of organic matter of 0.76% and a mean temperature of 36.06°C (Figure 3a & 3b).

Density of *Justicia adhatoda*

The quadrats were established in open areas, and the minimum density was recorded at the Jabba site at 15.75, the maximum density was recorded at the Khabikki site at 19.65, and the minimum density was recorded at the Kanhati site at 18.33. The order of density from low to high was the Jabba site, Kanhati site and Khabikki site, with densities of 15.75, 18.33 and 19.65, respectively. At the Jabba site, low organic matter was present, with a mean value of 0.58% and a temperature of 39.78°C. The density of *Justicia adhatoda* in the forest area was minimum at the Jabba site (24.67) and maximum at the Khabikki site (28.67), and 25.50 was recorded at the Kanhati site. At the Khabikki site, the value of organic matter was the highest, with a mean value of 0.86% and a low temperature value of 35.76°C (Figure 3a, b).

Cover of *Justicia adhatoda*

The minimum cover was recorded at the Jabba site (24.75%), and the maximum was recorded at the Khabikki site (26.81%) in the open area. The order of cover from low to high was the Jabba site, Khabikki site, and Kanhati site, with 24.75%, 26.81% and 27.53%, respectively. The cover of *Justicia adhatoda* was low at the Jabba site because the soil contains low organic matter with a mean value of 0.58%. The cover of *Justicia adhatoda* in the forest area of the Jabba site was 32.76%, and the maximum was 37.27% at the Kanhati site. The order of cover from low to high was 32.76%, 34.47%, and 37.27% at the Jabba site, Khabikki site, and Kanhati site, respectively (Figure 3a & 3b).



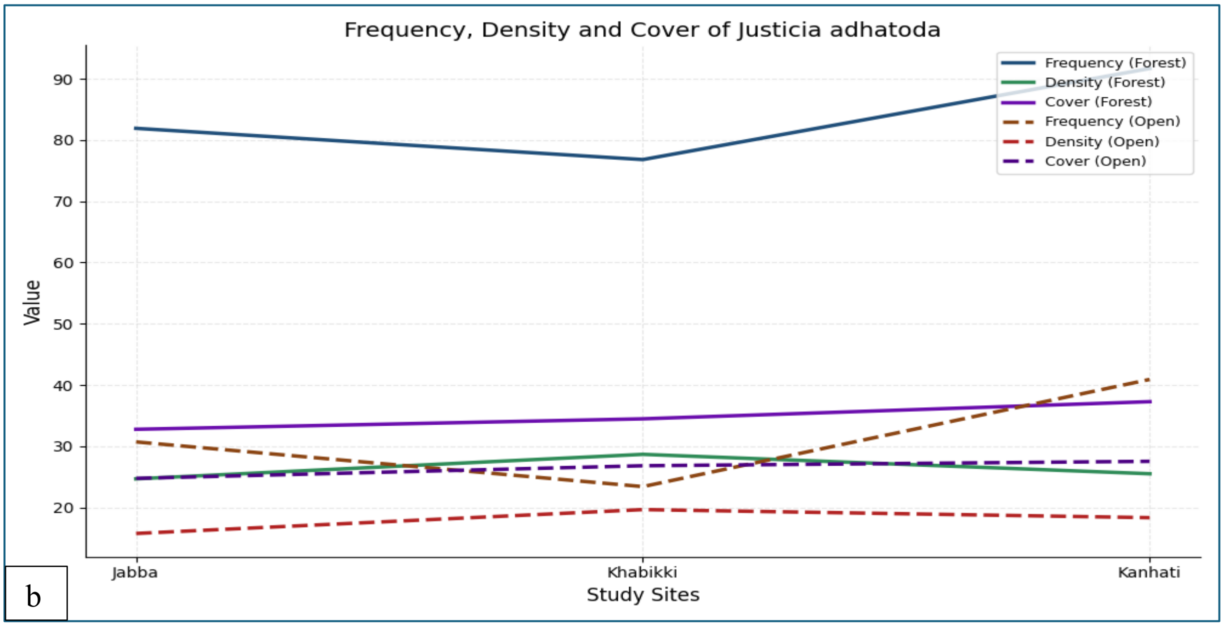


Figure (3a-3b): Frequency (%), density, and cover (%) of *Justicia adhatoda* in forest and open areas across the three study sites (Jabba, Khabikki, and Kanhati) 3b) Distribution pattern of *Justicia adhatoda* based on frequency, density, and cover in forest and open areas of the study sites.

The frequency of *Justicia adhatoda* varied significantly among the examined habitats, according to the ANOVA results (Table 3). A high F value of 59.888 was obtained because the between-group sum of squares (4023.306) was significantly higher than the within-group sum of squares (268.720). The frequency of *J. adhatoda* varied considerably between habitats, according to the significance value (p = 0.002).

Table 3: ANOVA of the frequency of *Justicia adhatoda*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4023.306	1	4023.306	59.888	.002
Within Groups	268.720	4	67.180		
Total	4292.026	5			

The density of *Justicia adhatoda* varied significantly between the habitats under study, according to the ANOVA results (Table 4). The F value was 28.604 because the between-group sum of squares (113.622) was significantly higher than the within-group sum of squares (15.889). The density of *J. adhatoda* differed considerably between habitats, according to the significance value (p = 0.006).

Table 4: ANOVA showing the density of *Justicia adhatoda*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	113.622	1	113.622	28.604	.006
Within Groups	15.889	4	3.972		
Total	129.511	5			

The *Justicia adhatoda* cover varied significantly between the habitats under study, according to the ANOVA results (Table 5). The F value was 29.621 because the between-group sum of squares (107.611) was significantly higher than the within-group sum of squares (14.532). The significant difference in *J. adhatoda* cover between habitats is confirmed by the significance value (p = 0.006).

Table 5: ANOVA showing the cover of *Justicia adhatoda*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	107.611	1	107.611	29.621	.006
Within Groups	14.532	4	3.633		
Total	122.143	5			

Phytosociological data analysis of *Peganum harmala*

Frequency of *Peganum harmala*

The minimum frequency was recorded at the Khabikki site (7.8%), and the maximum frequency was recorded at the Kanhati site (10.07%) in the open area. The order of frequency from low to high was the Khabikki site, Jabba site and Kanhati site, with frequencies of 7.8%, 8.9% and 10.07%, respectively. The mean soil organic matter at the Khabikki site was 0.56% with a temperature of 39.08°C. The frequency of *Peganum harmala* in the forest area was a minimum at the Khabikki site (12.4%) and a maximum at the Kanhati site (16.67%), and 18.6% was recorded at the Jabba site. The order of frequency from low to high was the Khabikki site, Kanhati site and Jabba site, with frequencies of 12.4%, 16.67% and 18.6%, respectively, with mean values of soil organic matter of 0.86% and 35.76°C temperature (Figures 4a & 4b).

Cover of *Peganum harmala*

The minimum cover was recorded at the Khabikki site (0.81%), and the maximum was recorded at the Kanhati site (0.85% of the open area). The order of cover from low to high was the Khabikki site, Jabba site and Kanhati site, 0.81%, 0.83% and 0.85%, respectively, with a mean value of soil organic matter at the Khabikki site of 0.56% and a temperature of 39.08°C°C. The cover of *Peganum harmala* in the forest area was minimum at the Khabikki site (0.90%) and maximum at the Kanhati site (0.97%) and 0.94% was recorded at the Jabba site, with mean values of organic matter at the Kanhati site of 0.54% and 38.66°C temperature (Figures 4a & 4b).

Density of *Peganum harmala*

The minimum density was recorded in the forest area of the Jabba site, at 0.29, and the maximum density was recorded at the Kanhati site at 0.34. The order of density from low to high was the Jabba site, Khabikki site and Kanhati site, with densities of 0.29%, 0.32% and 0.34%, respectively. The soil temperature of the Jabba site under the plant was 36.06°C, with a mean soil organic matter of 0.76%. The density of *Peganum harmala* in the open area was lowest at the Jabba site (0.83) and highest at the Kanhati site (0.85), with a soil temperature of 38.66°C and organic matter of 0.54% (4a & 4b) at the Kanhati site.

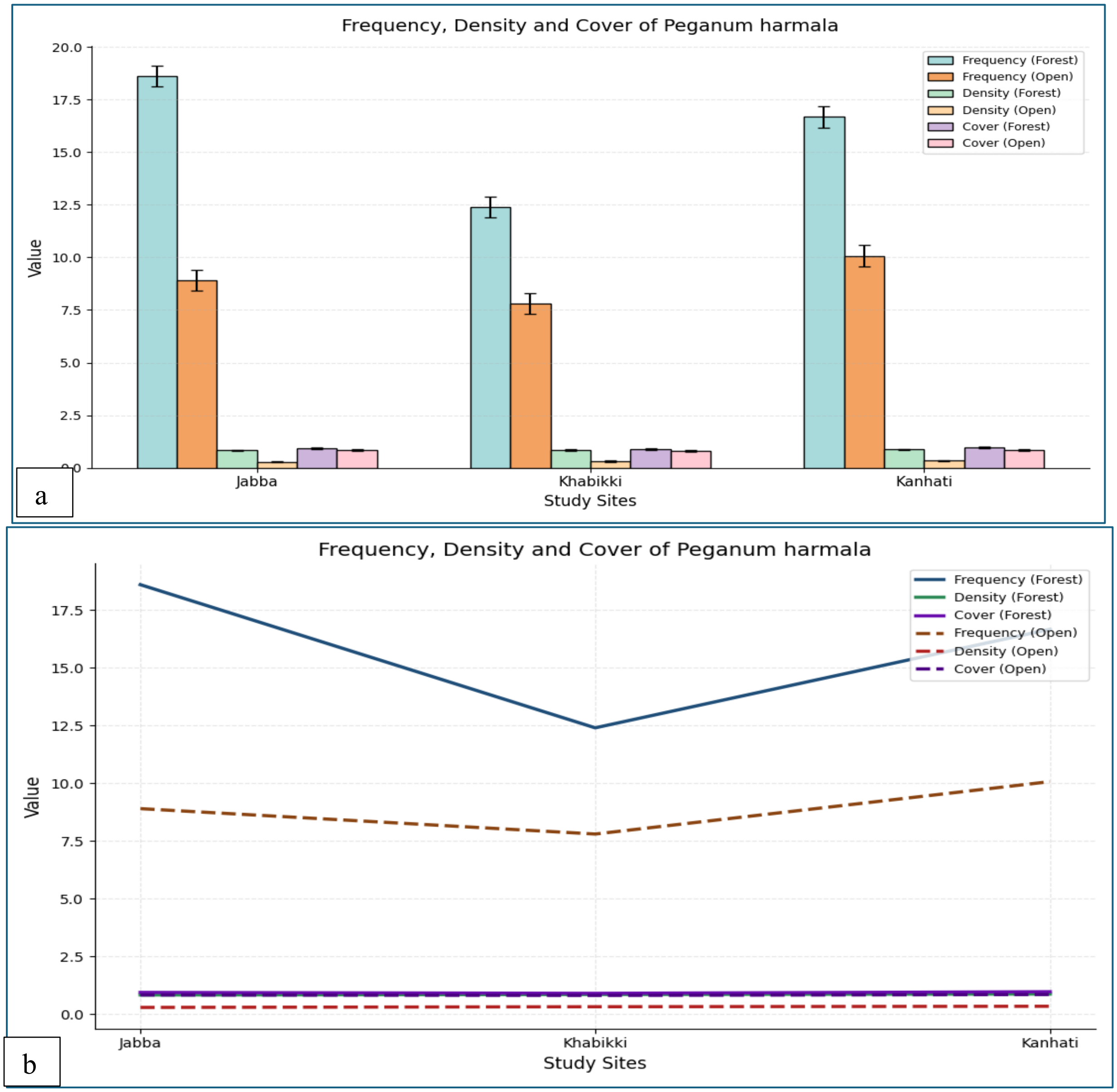


Figure (4a-4b): 4a) Frequency (%), density, and cover (%) of *Peganum harmala* in forest and open areas across the three study sites (Jabba, Khabikki, and Kanhati). 4b) Distribution pattern of *Peganum harmala* based on frequency, density, and cover in forest and open areas of the study sites.

The frequency of *Peganum harmala* varied significantly among the investigated environments, according to the ANOVA results (Table 6). The F value was 12.823 because the between-group variation (SS = 72.802) was significantly greater than the within-group variation (SS = 22.710). The frequency of P. harmala varied considerably between habitats, according to the significance value (p = 0.023).

Table 6: ANOVA showing the frequency of *Peganum harmala*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	72.802	1	72.802	12.823	.023
Within Groups	22.710	4	5.677		
Total	95.512	5			

An extremely high F value of 825.806 was obtained because the between-group sum of squares (0.427) was significantly higher than the within-group sum of squares (0.002). The density of P. harmala varied considerably among environments, according to the significance value ($p < 0.001$) (Table 7).

Table 7: ANOVA showing the density of *Peganum harmala*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.427	1	.427	825.806	.000
Within Groups	.002	4	.001		
Total	.429	5			

The F value was 20.898 because the between-group sum of squares (0.017) was higher than the within-group sum of squares (0.003). The considerable difference in P. harmala cover between habitats is confirmed by the significance value ($p = 0.010$) (Table 8).

Table 8: ANOVA showing the cover of *Peganum harmala*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.017	1	.017	20.898	.010
Within Groups	.003	4	.001		
Total	.020	5			

Phytosociological data analysis of *Cynodon dactylon*

Frequency of *Cynodon dactylon*

The frequency of *Cynodon dactylon* in the open area of the Jabba site was 67.7%, and that in the Khabikki site was 74.6% and 94.56% in the Kanhati site. The order of frequency from lower to higher was the Jabba site, Khabikki site, Kanhati site 83.4%, 87.8% and 94.56%, with a mean value of soil organic matter at the Kanhati site of 0.54% and a 38.66°C temperature. The maximum frequency of *Cynodon dactylon* in the forest area of the Kanhati site was 94.56%, and the minimum frequency at the Jabba site was 83.4%. The order of frequency from low to higher was the Jabba site, Khabikki site and Kanhati site, with frequencies of 83.4%, 87.8% and 94.56%, respectively, and the mean values of soil organic matter at the Kanhati site were 0.80% and 36.42°C (5a & 5b).

Cover of *Cynodon dactylon*

The cover of *Cynodon dactylon* at the Jabba site was 23.76%. The cover at the Khabikki site was 24.47%, and that at the Kanhati site was 27.27%. The maximum cover of *Cynodon dactylon* at the Kanhati site was 28.87%, and the minimum cover at the Jabba site was 25.41% in open land. The order of cover in the low to higher Jabba site, Khabikki site and Kanhati site was 25.41%, 26.37% and 28.87%, respectively (5a & 5b).

Density of *Cynodon dactylon*

The maximum density of *Cynodon dactylon* in the open area of the Jabba site was 12.24, and the density in the Khabikki site was 13.56 and 15.67 in the Kanhati site, with 0.76% soil organic matter and a 36.06°C temperature at the Jabba site. The maximum density of *Cynodon dactylon* at the Kanhati site in the forest area was 20.34, and the minimum density at the Jabba site was 17.77. The order of density from low to high was the Jabba site, Khabikki site and Kanhati site, with densities of 17.77, 18.34 and 20.34, respectively (5a & 5b).

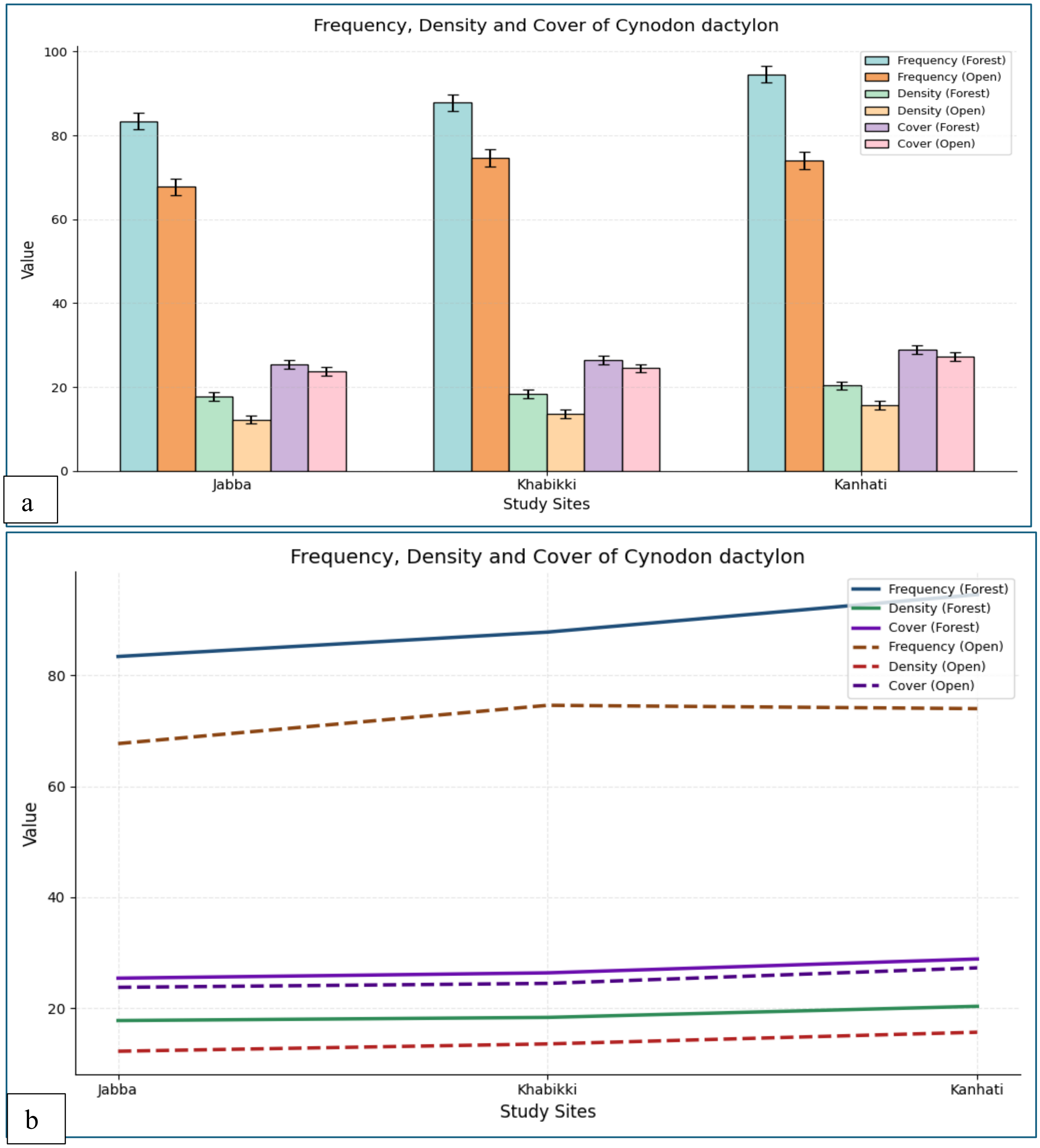


Figure (5a-5b): 5a) Frequency (%), density, and cover (%) of *Cyanodon dactylon* in forest and open areas across the three study sites (Jabba, Khabikki, and Kanhati) 5b) Distribution pattern of *Cyanodon dactylon* based on frequency, density, and cover in forest and open areas of the study sites.

The frequency of *Cynodon dactylon* varied significantly among the environments under study, according to the ANOVA results (Table 9). The F value was 17.646 because the between-group sum of squares (407.715) was significantly higher than the within-group sum of squares (92.421).

Table 9: ANOVA showing the frequency of *Cynodon dactylon*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	407.715	1	407.715	17.646	.014
Within Groups	92.421	4	23.105		
Total	500.136	5			

The density of *Cynodon dactylon* varied significantly between the environments under study, according to the ANOVA results (Table 10). The F value was 15.838 because the between-group sum of squares (36.902) was significantly higher than the within-group sum of squares (9.320). The density of *C. dactylon* varied considerably among habitats, according to the significance value (p = 0.016) (Table 10).

Table 10: ANOVA showing the density of *Cynodon dactylon*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	36.902	1	36.902	15.838	.016
Within Groups	9.320	4	2.330		
Total	46.222	5			

The cover of *Cynodon dactylon* varied significantly between the environments under study, according to the ANOVA results (Table 11). An F value of 24.515 was obtained because the between-group sum of squares (172.270) was significantly greater than the within-group sum of squares (28.109). The *C. dactylon* cover varied considerably between environments, according to the significance value (p = 0.008) (Table 11).

Table 11: ANOVA showing the cover of *Cynodon dactylon*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	172.270	1	172.270	24.515	.008
Within Groups	28.109	4	7.027		
Total	200.380	5			

Discussion

Influence of Forest Cover on Regulatory Ecosystem Services

Because they control biological processes and offer a variety of ecosystem services, forest ecosystems are regarded as crucial elements of natural landscapes. The current study examined how forest cover enhances vegetation features and regulates ecosystem services in the Salt Range submontane rangelands. The findings showed that, in terms of soil temperature regulation and soil organic matter accumulation, forest-covered areas had superior environmental conditions than open areas. These results suggest that by altering microclimatic conditions and enhancing soil quality, forest vegetation functions as an ecological regulator.

The advantages derived from natural ecosystems, such as soil formation, nutrient cycling, climate regulation, and biodiversity preservation, are known as ecosystem services (Kong et al., 2023; Gunderson et al., 2022).

By regulating environmental processes, vegetation is essential to sustaining ecosystem functioning, according to Mutanga et al. (2025). This idea is supported by the current research, which demonstrates how forest cover improves ecological conditions and rangeland ecosystem performance. Through root activity, litter creation, canopy development, and organic matter buildup, forest vegetation affects environmental conditions. These mechanisms support the stability of ecosystems and provide ideal circumstances for plant growth. Haberl et al. (2026) and Roux et al. (2025) showed similar associations between vegetation cover and ecosystem functioning, emphasizing the significance of vegetation shape and biodiversity in sustaining ecosystem services.

Effect of Forest Cover on Soil Temperature Regulation

Numerous biological and physical processes, including microbial activity, nutrient cycling, water flow, and root growth, are influenced by soil temperature, which is a significant ecological element (Thakur et al., 2022). At every study site, the soil temperatures in forest regions were lower than those in open areas. Compared to exposed land settings, the mean soil temperature values beneath forest vegetation were lower, suggesting that forest cover prevented soil heating and preserved a cooler microenvironment. The shading impact of tree canopies, decreased direct solar radiation, and enhanced moisture conservation all contribute to the decrease in soil temperature beneath forest vegetation. Layers of forest litter also serve as insulators, lowering temperature swings and shielding soil from harsh weather.

Kamamba (2025) and Singh et al. (2026) reported similar results, stating that trees maintain favourable environmental conditions and control energy exchange. On the other hand, because soil surfaces were directly exposed to sunshine in open regions, the soil temperatures were greater. Particularly in semiarid habitats, higher soil temperatures can increase evaporation, decrease moisture availability, and adversely impact vegetation performance. Temperature variations have a significant impact on evapotranspiration processes and plant productivity, according to Tolk and Howell (2008).

The apparent distinction between open spaces and forests highlights how crucial vegetation cover is to controlling the climate. According to earlier research, plant development and physiological processes may be impacted by rising temperatures and environmental stress, which could lower ecosystem productivity (Tiwari et al., 2024; Ahmadian et al., 2025).

Role of Forest Cover in Soil Organic Matter Improvement

Because it enhances soil structure, nutrient availability, water retention, and microbial activity, soil organic matter is a crucial indication of soil health and ecosystem production. In comparison to open regions, the current study found that forest areas had a higher soil organic matter level. This suggests that soil fertility and nitrogen cycling are positively impacted by forest growth.

Continuous intake of leaf litter, dead plant debris, and root residues may lead to higher levels of organic matter beneath forests. These compounds' breakdown enhances soil qualities and boosts carbon storage. According to Cortés-Esquivel et al. (2023), increased soil quality and ecosystem production are closely linked to the buildup of organic matter.

Comparatively lower organic matter values were found in open areas, which could be explained by less vegetation input, increased soil exposure, and quicker breakdown brought on by higher temperatures. Removing vegetation can lower soil fertility and interfere with the cycling of nutrients. Rana et al. (2026) and Mallick (2025) highlighted the detrimental effects that vegetation degradation and biodiversity loss might have on ecosystem functioning.

The current results are in line with earlier studies that demonstrate how forest ecosystems greatly enhance soil quality by accumulating organic matter and conserving nutrients (Moroyoqui et al., 2026). To minimize soil deterioration and preserve ecosystem sustainability, it is crucial to maintain forest cover in rangelands.

Effect of Forest Cover on the Phytosociological Characteristics of Vegetation

Plant community structure, species distribution, and ecological interactions can all be learned by phytosociological studies. The frequency, density, and cover of vegetation in the current study demonstrated variations between open and forest habitats. Greater plant abundance was typically observed in forest areas, indicating better habitat conditions under foliage cover.

Environmental elements that affect vegetation structure include soil conditions, temperature, moisture availability, and disturbance levels. According to Botta-Dukát et al. (2023) and Monteiro-Henriques (2025), cover, density, and frequency are crucial metrics for assessing plant communities. In a similar vein, Abide and Asfaw (2022) stressed that these factors aid in the explanation of patterns of species distribution and dominance.

Improved soil organic matter and less environmental stress may be the cause of the greater vegetation values observed in forest environments.

By preserving moisture and lowering temperature swings, forest ecosystems offer more stable conditions for plant development. Plant communities form as a result of interactions between species and environmental factors, according to Nelson et al. (2026). This idea is supported by the current study since vegetation abundance rose in areas where habitat quality was enhanced by forest cover.

Response of Justicia adhatoda to the Forest Environment

When compared to open environments, Justicia adhatoda performed better in forested settings. This species benefits from the favourable microenvironment that vegetation cover creates, as evidenced by higher frequency, density, and cover values under forest circumstances.

Higher soil organic matter, reduced temperature stress, and increased resource availability beneath forests may all contribute to *J. adhatoda*'s improved growth. For native plant species to persist and regenerate, forest ecosystems offer ideal circumstances.

Because diverse plant communities improve ecological stability and resilience, there is a close relationship between plant diversity and ecosystem functioning (Loreau, 2022; Correia & Lopes, 2023). According to Haberl et al. (2005), biodiversity also helps to sustain ecological functions and service provision. Consequently, the increased *J. adhatoda* abundance in forested areas indicates the beneficial impact of forest cover on vegetation development.

Distribution Pattern of *Peganum harmala* and *Cynodon dactylon*

The distribution patterns of *Cynodon dactylon* and *Peganum harmala* differed across open spaces and forests, demonstrating the significant impact of habitat conditions on plant communities. Variations in cover, density, and frequency show how the environmental appropriateness of different habitats varies.

Soil conditions, climate, and grazing intensity all have an impact on the vegetation composition of rangelands. Reduced plant diversity and altered community structure can result from excessive grazing and disturbance. According to Dar et al. (2022), grazing and trampling have an impact on species distribution and regeneration, which in turn affects the composition of vegetation.

In a similar vein, Prasad et al. (2026) noted that overgrazing causes ecological degradation and a reduction in biodiversity. According to the current findings, forest cover promotes more stable vegetation communities and offers protection from environmental stress.

Ecological Importance of Forest Conservation in Salt Range Ranges

Diverse vegetation groups and priceless natural resources define the Salt Range, an ecologically significant area. The region's floral variety and ecological significance have been previously reported (Chhabra, 2022; Hills & Jewitt, 2024; García-Caparrós et al., 2023).

The current study demonstrates that by controlling soil temperature, boosting organic matter, and promoting plant diversity, forest cover enhances ecosystem functioning. As a result, forest patches are crucial ecological components that preserve the stability of ecosystems.

Because varied ecosystems are better able to tolerate environmental changes, biodiversity protection and ecosystem service preservation are closely linked (Zhai et al., 2026). Therefore, preserving ecological balance and halting the deterioration of rangeland ecosystems depend on the conservation of forest vegetation in the Salt Range. Overall, the results show that soil properties, phytosociological traits, and regulating ecosystem functions are all positively impacted by forest cover. Maintaining ecosystem services and biodiversity in submontane rangelands requires sustainable management techniques such as restricted grazing and forest preservation.

Conclusion

This study found that forest cover greatly improves ecological conditions in the Salt Range submontane rangelands. Forested habitats had lower soil temperatures by approximately 3 degrees Celsius and much higher soil organic matter than nearby open plains, indicating improved microclimatic regulation and soil fertility. These environmental gains were linked to increased frequency, density, and cover of critical plant species, including *Justicia adhatoda*, *Peganum harmala*, and *Cynodon dactylon.* Significant differences revealed by ANOVA confirm that forest vegetation is critical in controlling ecosystem processes, maintaining phytosociological stability, and improving ecosystem services. As a result, conserving and managing forest sections within the Salt Range is critical for preserving biodiversity, increasing soil quality, and ensuring the long-term resilience and production of rangeland ecosystems.

References

Kong, L., Wu, T., Xiao, Y., Xu, W., Zhang, X., Daily, G.C. and Ouyang, Z., 2023. Natural capital investments in China undermined by reclamation for cropland. *Nature Ecology & Evolution*, 7(11), pp.1771-1777.

Gunderson, L.H., Allen, C.R. and Garmestani, A. eds., 2022. *Applied panarchy: applications and diffusion across disciplines*. Island Press.

Mutanga, O., Pandey, P.C. and Das, S., 2025. Introduction to Ecosystem Services and the Role of Geospatial Technologies. In *Revealing Ecosystem Services Through Geospatial Technologies: Beyond the Surface* (pp. 3-10). Cham: Springer Nature Switzerland.

Haberl, H., Giljum, S., Krausmann, F., Schaffartzik, A., Staritz, C., Thurner, S., Bruckner, M., Streeck, J., Wiedenhofer, D. and Pachauri, S., 2026. Resilience and malleability: New directions for socio-metabolic research in times of multiple crises. *Ecological Economics*, *243*, p.108938.

Roux, N., Coenen, J., Fleischmann, B., Cotta, B., Dorninger, C., Erb, K.H., Haberl, H., Kaufmann, L., Mayer, A. and Newig, J., 2025. Integrating sufficiency in the trade and biodiversity agenda of the European Union. *One Earth*, 8(7).

Thakur, P., Paliyal, S.S., Dev, P. and Datt, N., 2022. Methods and approaches-soil quality indexing, minimum data set selection & interpretation-A Critical review. *Communications in Soil Science and Plant Analysis*, *53*(15), pp.1849-1864.

Kamamba, M., 2025. *Exploring forest-water nexus in a changing environment of Kafue river basin, Zambia* (Doctoral dissertation, The University of Zambia).

Singh, A.K., Thakur, R., Thakur, S., Thakur, H., Dewangan, S., Singh, R., Singh, H. and Chauhan, V., 2026. The Climate Crisis and Forestry Contribution Towards Sustainable Development Goals (SDGs). In *Forestry for a Carbon-Neutral and Sustainable Future: A Scientific Perspective* (pp. 27-52). Cham: Springer Nature Switzerland.

Tiwari, R., Gupta, D.K., Chauhan, P.K. and Singh, A.K., 2024. Long-term Spatio-temporal vegetation dynamics to climate change in koppen Climatic regions of India. *Earth Systems and Environment*, *8*(4), pp.1327-1346.

Ahmadian, A., Chavoshi, E. and Nadoushan, M.A., 2025. Modeling soil organic carbon loss in arid agroecosystems: A mixed-effects approach to abandoned wheat fields. *Journal of Arid Environments*, *229*, p.105403.

Cortés-Esquivel, J.L., Herrera-Silveira, J. and Quintana-Owen, P., 2023. Organic matter content in mangrove soils from a karstic environment: Comparison between thermogravimetric and loss-on-ignition analytical techniques. *Forests*, *14*(7), p.1469.

Rana, B., Thakur, M. and Jamwal, K., 2026. Sustainability of Plant Communities in the Himalayas: Issues and Prospects. In *Plant Tissue Culture Technology* (pp. 15-56). Apple Academic Press.

Mallick, M.A.I., 2025. From Pixels to Species: A Review of Remote Sensing for Biodiversity Assessment. *Journal of Sustainability and Environmental Management*, *4*(1), pp.40-61.

Moroyoqui, P.G., Tenorio, L.M.D., Ávila, B.G.M., Heraldez, V.L., Barceló, D.O.E. and Soto, L.A.L., 2026. Assessing the capacity of Salicornia bigelovii Torr. to grow and remove enrofloxacin and oxytetracycline in aquaculture wastewater. *Biotecnia*, *28*, pp.e2686-e2686.

Botta-Dukát, Z., Bartha, D., Dancza, I., Lukács, B.A. and Pinke, G., 2023. Adaptation of life form categorisation of Ellenberg and Mueller-Dombois to the Hungarian Flora. *Acta Botanica Hungarica*, *65*(1-2), pp.1-34.

Monteiro-Henriques, T., 2025. TDV-optimization: A novel numerical method for phytosociological tabulation. *Vegetation Classification and Survey*, *6*, pp.99-127.

Abide, E.B. and Asfaw, Z., 2022. On-farm tree species diversity and management in semi-arid of Lemo district, Southern Ethiopia. *Agroforestry systems*, *96*(5), pp.817-828.

Nelson, A.S., Jain, T.B., Reinhardt, J., Strand, E.K., Mutchler, N. and Byrne, J., 2026. Understory floristic composition of planted western white pine stands in the northern Rocky Mountains. *Forest Ecosystems*, *15*(1).

Loreau, M., 2022. Biodiversity and Ecosystem Stability: New Theoretical. *The ecological and societal consequences of biodiversity loss*, p.147.

Correia, A.M. and Lopes, L.F., 2023. Revisiting biodiversity and ecosystem functioning through the lens of complex adaptive systems. *Diversity*, *15*(8), p.895.

Dar, G.H., Bhat, R.A., Qadri, H. and Hakeem, K.R. eds., 2022. *Microbial consortium and biotransformation for pollution decontamination*. Elsevier.

Prasad, S., Prabhakar, C.S., Kumar, A. and Nath, P., 2026. Human-Banbakri Antelope Conflict in India: A Review of Crop Depredation, Ecological Dynamics and Mitigation Strategies. *UTTAR PRADESH JOURNAL OF ZOOLOGY*, *47*(1), pp.175-192.

Chhabra, R., 2022. Nature and origin of salts, classification, area and distribution of salt-affected soils. In *Salt-affected soils and marginal waters: Global perspectives and sustainable management* (pp. 1-47). Cham: Springer International Publishing.

Hills, E.S. and Jewitt, T.N., 2024. Soils of arid lands. In *Arid Lands* (pp. 103-125). Routledge.

Garcia-Caparros, P., Al-Azzawi, M.J. and Flowers, T.J., 2023. Economic uses of salt-tolerant plants. *Plants*, *12*(14), p.2669.

Zhai, X., Lange, E. and Cameron, R.W., 2026. Rethinking ecosystem service trade-offs through perceived synergies and prioritisation: evidence from Haizhu National Wetland Park. *Landscape Ecology*.

Costanza, R., 2024. Misconceptions about the valuation of ecosystem services. *Ecosystem Services*, *70*, p.101667.

Gray, M., Fox, N., Gordon, J.E., Brilha, J., Charkraborty, A., da Glória Garcia, M., Hjort, J., Kubalíková, L., Seijmonsbergen, A.C. and Urban, J., 2024. Boundary of ecosystem services: A response to. *Journal of environmental management*, *351*, p.119666.

Yi, H., 2022. Ecosystem services valuation and research methodology for mapping ecosystem services: concepts, trends, issues, and applications. *Journal of the Korean Geographical Society*, *57*(2), pp.189-208.

Dunlap, R.S., 2026. The Highs and Lows of Life in a Valley: Topographic Controls on Tundra Vegetation in a Warming Arctic.

Körner, C., 2023. Concepts in Alpine Plant Ecology. Plants 2023, 12, 2666. *Arctic and Alpine Plants*, p.5.

Turck, A., 2025. *Balancing Biodiversity and Economic Viability: Farmers' Motivations and Challenges in Nature-Protected Areas* (Doctoral dissertation, Universitäts- und Landesbibliothek Bonn).

Haddad, B.M. and Solomon, B.D. eds., 2023. *Dictionary of ecological economics: terms for the new millennium*. Edward Elgar Publishing.

Dunlap, R.S., 2026. The Highs and Lows of Life in a Valley: Topographic Controls on Tundra Vegetation in a Warming Arctic.

Lerdau, M.T., Monson, R.K. and Ehleringer, J.R., 2023. The carbon balance of plants: economics, optimization, and trait spectra in a historical perspective. *Oecologia*, *203*(3), pp.297-310.

Monteiro-Henriques, T., 2025. TDV-optimization: A novel numerical method for phytosociological tabulation. *Vegetation Classification and Survey*, *6*, pp.99-127.

Hart-Fredeluces, G. and Duffy, D., 2024. A Conversation on the UH Botany Department, Vegetation Ecology, and Life with Professor Emeritus Dr. Dieter Mueller-Dombois. *Pacific Science*, *77*(2-3), pp.349-362.

Bennett, E.M., Reid, W., Carpenter, S., Dietz, T., Peterson, G., Ash, N., Beard Jr, T.D., Beck, S., Biggs, R., Castree, N. and Ehrmann, J., 2026. The future of Global Environmental Assessments: 20 years after the Millennium Ecosystem Assessment. *Current Opinion in Environmental Sustainability*, *79*, p.101618.

Rana, B., Thakur, M. and Jamwal, K., 2026. Sustainability of Plant Communities in the Himalayas: Issues and Prospects. In *Plant Tissue Culture Technology* (pp. 15-56). Apple Academic Press.

Thakur, P., Paliyal, S.S., Dev, P. and Datt, N., 2022. Methods and approaches-soil quality indexing, minimum data set selection & interpretation-A Critical review. *Communications in Soil Science and Plant Analysis*, *53*(15), pp.1849-1864.

Dikshit, K.R. and Dikshit, J.K., 2025. *Regional geography of Pakistan: A study in spatial relations*. Routledge India.

Ali, M.K. and Maqbool, S., 2025. History and memory of the rehabilitation of refugees after partition of 1947: A case study of district Rawalpindi. *International Research Journal of Social Sciences and Humanities*, *4*(1), pp.36-66.

Imran, U., Ullah, A., Mahar, R.B., Shaikh, K., Khokhar, W.A. and Weidhaas, J., 2023. An integrated approach for evaluating freshwater ecosystems under the influence of high salinity: a case study of Manchar Lake in Pakistan. *Environmental Monitoring and Assessment*, *195*(11), p.1340.

Hussain, S., Sharma, S., Bhatti, R.C. and Singh, A.N., 2023. Floral diversity expedition in Ladakh: An insight into the exploration, distribution pattern, ethnobotanical, phytochemical studies and conservation strategies. *Ethnobotany Research and Applications*, *26*, pp.1-32.

Dharaiya, N. and Rabari, V., 2022. A systematic review on the feeding ecology of Sloth Bear Melursus ursinus Shaw, 1791 in its distribution range in the Indian subcontinent. *Journal of Threatened Taxa*, *14*(12), pp.22329-22336.

Sadia, S., Waheed, M., Arshad, F., Al-Andal, A., Munir, M., Jabeen, A. and Aslam, S., 2025. Adaptive floristic diversity and ecological responses to environmental gradients in the saline soil ecosystem. *Journal for Nature Conservation*, *84*, p.126862.

Boutoumit, S., Maanan, M., El Kamcha, R., Bououarour, O., El Hadad, H., Anhichem, M., Baali, A., Pouzet, P. and Bazairi, H., 2022. Seasonal trends in benthic macrofauna communities and their relationship with environmental factors in an Atlantic lagoonal system. *Biologia*, *77*(4), pp.1039-1055.