

Selection of Suitable Plants for Green Walls and Their Maintenance in Kabul City: A Survey-Based Study

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ABSTRACT

Green walls (GWs) are increasingly recognized as effective nature-based solutions to improve urban environmental quality. However, data on suitable plant species (SPS) and maintenance practices (MP) for GWs in Kabul City under arid and semi-arid conditions remain limited. This study aimed to identify SPS and evaluate MP for GW development in Kabul. The study was conducted in Kabul City in 2025 with 202 respondents through a structured questionnaire. Data were collected using Kobo Toolbox and analyzed in SPSS using descriptive statistics, correlation, and regression. Results showed that most respondents were male gardeners and agriculturists, and most had bachelor's degrees. GW occurred at 74.8% of respondent sites, but exotic species were used more frequently for GW, while native species were used less often. The most common plants were climbing willow, boxwood, and ivy, while grapevine and rose were less common. Preferred species were drought-tolerant, evergreen, and aesthetically valuable. MP showed moderate irrigation dependence, dependence on furrow irrigation, and limited use of advanced pest management techniques. A moderate positive correlation was found between green wall problems and the main green wall pests ($\rho = 0.404$, $p < 0.001$). No significant relationship was found between MP and SPS. Regression analysis also showed that MP significantly affected SPS selection (Nagelkerke $R^2 = 0.736$). Water shortage and plant diseases were major constraints. The study concludes that, for sustainable GW development in Kabul, selecting stress-tolerant ornamental species with integrated maintenance strategies is essential.

ARTICLE INFO

Article history:

Received: April 27, 2026

Revised: May 26, 2026

Accepted: June 20, 2026

Published: Sep 30, 2026

Keywords:

Green walls; Kabul; Kobo Toolbox; Maintenance practices; Questionnaires Suitable plant

To cite this article: Khyal, K. B., & Sayeed, M. (2026). Selection of Suitable Plants for Green Walls and Their Maintenance in Kabul City: A Survey-Based Study. *Journal of Natural Science Review*, 4 (3), 745-769. <https://doi.org/10.62810/jnsr.v4i3.501>

To link to this article: <https://kujnsr.com/JNSR/article/view/501>



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INTRODUCTION

Green walls (also called vertical gardens or living walls) are innovative urban greening systems that grow plants on the vertical surfaces of buildings. These systems offer a good alternative for reintroducing vegetation in densely built environments amid rapid urbanization, where horizontal green spaces are constantly reduced. Beyond aesthetic benefits, green walls have significant environmental value because they improve air quality

by absorbing carbon dioxide, reducing air pollution, and lowering urban temperatures through shading and evapotranspiration (Navarini-Valdameri et al., 2026; Wang et al., 2022; Zhao et al., 2024). They also attenuate urban heat island effects and create microclimatic conditions that increase comfort and energy efficiency in cities (Susca et al., 2024; Tabibi, 2024). From a socio-psychological perspective, vertical green systems can support well-being by reducing stress and encouraging human-nature interactions in highly urbanized areas (Fonseca et al., 2023; Liu et al., 2026). Furthermore, they promote the city's biodiversity by providing habitat for small organisms and support sustainable development by improving building performance and reducing energy consumption (Manso et al., 2021; Mi et al., 2025; Navarini-Valdameri et al., 2026).

Plant selection plays a vital role in the successful application of green wall systems. Environmental problems in vertical plant systems include limited rooting volume, variable water availability, and exposure to wind and temperature fluctuations. The best species are shallow-rooted, compact, and tolerant of sun and shade. Common plant types include climbing plants such as *Hedera helix* and *Parthenocissus tricuspidata*, ferns such as *Nephrolepis exaltata* and *Asplenium nidus*, ornamental grasses, succulents such as *Sedum* and *Echeveria*, and herbaceous perennials such as *Ajuga reptans* and *Lysimachia nummularia* (Salisbury et al., 2023; Stollberg & Birgelen, 2023). Survival, aesthetic performance, and ecological functions such as supporting biodiversity and thermal regulation depend heavily on plant selection, which emphasizes the importance of choosing species adapted to local environmental conditions (Salisbury et al., 2023; Stollberg & Birgelen, 2023).

Choose plants that are heat-tolerant, drought-resistant, and suitable for the vertical growing conditions of warm temperate climates. Plants such as *Hedera helix*, *Trachelospermum jasminoides*, and *Parthenocissus tricuspidata* are often used because of their adaptability and dense foliage. Other drought-tolerant species, such as *Bougainvillea*, *Rosmarinus officinalis*, *Vitis vinifera*, and *Sedum*, also perform well under high solar radiation and water-limited conditions. These species help regulate urban ecosystem temperatures and improve biodiversity (Detommaso et al., 2023; Salisbury et al., 2023; Stollberg & Birgelen, 2023).

Green wall systems offer advantages but also present challenges. The main disadvantages are high maintenance requirements, such as irrigation, fertilization, and regular monitoring. Vertical structures may have uneven moisture distribution and water management issues such as root rot or dehydration. High installation costs and structural complexity limit wider adoption in developing regions. Lack of maintenance causes long-term system degradation and other issues, such as low plant diversity, pest infestation, and fungal diseases (Čufer et al., 2026; Dominici et al., 2022; Manso et al., 2021).

For the system to be sustainable in the long run, it needs to be well maintained. Green walls need regular watering, fertilizing, pruning, and health checks. Plants need good irrigation systems because substrate volume is limited, and failure could quickly lead to stressed or lost plants. The system will be regularly checked for pests, diseases, and

blockages, and any problems will be addressed in time. Fertilizing supplies needed nutrients, and pruning improves the tree's shape and aesthetics. Even with more efficient irrigation automation, technical monitoring is needed to prevent failures (Manso & Castro-Gomes, 2015; Pérez-Urrestarazu & Urrestarazu, 2018; Segovia-Cardozo et al., 2019).

Integrated management is sustainable management. Controlled-release fertilizers, fertigation systems, and organic amendments are often used to achieve nutrient balance (Chen & Wei, 2018; Lawrencía et al., 2021; Visconti et al., 2023). In addition, moisture sensors in drip irrigation systems can distribute water efficiently (Wang et al., 2022; Wang et al., 2024). Examples of lightweight substrates with potential water-holding capacity and structural stability include coco coir, peat mixes, perlite, and LECA (Segovia-Cardozo et al., 2019). Pruning is usually carried out every 1 to 3 months of growth (Borna & Yeganeh, 2024; Manouchehri et al., 2024). Integrated Pest Management (IPM) is receiving more attention for pest and disease control (Zhou et al., 2024). It includes biological, cultural, and minimal chemical control options to maintain ecological balance and prevent system degradation.

Kabul's rapid growth has reduced green space and worsened problems such as air pollution, the urban heat island effect, and declining urban well-being. Green walls (vertical gardens) are a promising nature-based solution to improve microclimate, increase biodiversity, and support sustainable urban development (Reyhani et al., 2023; Safi, 2024). Such programs are rare in Kabul. Scientific information on suitable plant species and standardized maintenance practices is lacking. Most studies have focused on ornamental and temperate-climate plants, which are not well suited to Kabul's arid to semi-arid conditions, including drought, extreme temperatures, dust, and limited water resources. Plant selection is a major determinant of the success and long-term maintenance of green wall systems (Carlucci et al., 2023). Hence, there is a need to identify locally adapted species and suitable management practices. This study aims to fill this gap by identifying suitable plant species and maintenance strategies for green walls in Kabul to support sustainable urban greening and environmental improvement. We asked the following three basic research questions to explore this:

1. What plant species are suitable for green walls in Kabul, and how do they adapt to the conditions of the local climate?
2. What are the key maintenance requirements for the plants of the green wall in Kabul?
3. What do the experts say about plant selection for the green wall and the sustainability aspect in Kabul?

Selecting appropriate plant species and maintenance practices for adaptation, performance, and long-term sustainability of green wall systems in Kabul City's climatic conditions is very important.

METHODS AND MATERIALS

Research Design

This descriptive-analytic study uses a social survey to evaluate public perceptions of suitable plant species and maintenance practices for green walls in Kabul city. Preferences and practices were investigated using descriptive methods, while correlation analysis was used to identify relationships between socio-demographic factors and plant selection and maintenance variables (Amegah et al., 2023). In addition, binomial and multinomial logistic regression models were used to identify factors influencing the presence of green walls and plant species selection. These models are widely used to analyze categorical outcomes and estimate the probability and influence of multiple explanatory variables, with multinomial logistic regression extending to multi-category responses (Chiruță et al., 2023; Pate et al., 2022). This interdisciplinary analytical framework provides a solid basis for evaluating decision-making in urban green infrastructure systems and enables accurate interpretation of environmental data collected via surveys (Drosou et al., 2019; Essuman-Quainoo & Jim, 2023).

Research Site

This study was conducted in 2025 in Kabul City and focused on selecting suitable plant species for green walls and their maintenance using a survey-based research approach.

Research Materials

This study employed structured questionnaires to collect primary data from respondents in Kabul City. Data were collected using smartphones integrated with the Kobo Toolbox platform, which facilitates mobile-based survey administration, offline and online data capture, and real-time data management in field-based research environments (Ben-Ali et al., 2025; Traoré et al., 2026).

Questionnaires Design

A structured questionnaire was developed to meet the study objectives and ensure validity and reliability based on existing empirical studies. Survey methods commonly measure perceptions, behaviors, and practices by collecting standardized data (Lewis et al., 2025). The questionnaire included questions covering key aspects of the topic, such as plant selection, maintenance, irrigation, environmental conditions, and problems. Likert-scale questions were used to enable statistical analysis through correlations and regressions (Gómez-Caballero et al., 2026). The data collection tool, Kobo Toolbox, was used because it has recently been shown to be effective for conducting structured field surveys (Hossain et al., 2025; Ben-Ali et al., 2025).

Data Collection

The target population was the urban population of Kabul city, estimated at 5 million people. Data were collected in Kabul City by using a structured questionnaire. Face-to-face interviews

were conducted for illiterate respondents, and their responses were entered directly into the Kobo Toolbox system. Furthermore, the questionnaire link was shared through social media platforms throughout the city, allowing respondents to complete the survey online, with all data automatically stored in real time in Kobo Toolbox. The required sample size was determined using Cochran's formula, and 202 respondents were selected for data collection (Lorber et al., 2023).

1. Cochran's Formula (for Large Populations):

$$n_0 = \frac{Z^2 \times p(1 - p)}{e^2}$$

Parameters:

- **Z = 1.96** (95% confidence level)
- **p = 0.5** (maximum variability, when unknown)
- **e = 0.07** (acceptable margin of error = 7%)

2. Initial Sample Size Calculation:

$$n_0 = \frac{1.96^2 \times 0.5(1 - 0.5)}{0.07^2} \Rightarrow$$

$$n_0 = \frac{3.84 \times 0.25}{0.0049} \Rightarrow$$

$$n_0 = 195.9$$

3. Finite Population Correction (for population = 5,000,000):

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \Rightarrow$$

Where:

- **N = 5,000,000**

4. Final Result

$$n = \frac{195.9}{1 + \frac{195.9 - 1}{5000000}} \Rightarrow \mathbf{195.89}$$

Based on these calculations, it was determined that 196 questionnaires were required. However, to ensure reliability and account for potential data loss or incomplete responses, 202 questionnaires were distributed.

Data Analysis

The collected data were analyzed using SPSS (Version 25). First, descriptive statistics were used to describe the dataset's main characteristics. Then, correlation analysis was performed to see the relationships between the study variables, particularly socio-demographic

variables and behavioral patterns, which is common in survey-based research. Finally, binomial and multinomial logistic regression analyses were performed to identify key factors affecting the outcomes and to estimate the relative effects of the explanatory variables on categorical dependent variables. These statistical methods are often applied in social and environmental research to ensure strong interpretation of relationships and to improve the reliability, validity, and explanatory power of survey data analysis.

FINDINGS

Socio-Demographic Information

This section presents information on respondents' gender, educational level, profession, and age. The results indicate that most respondents were male, accounting for approximately 99.5% of participants, while only one respondent was female, representing the smallest proportion. Regarding educational level, most respondents held a bachelor's degree (36.1%), while the smallest group was illiterate individuals (8.4%). In terms of profession, the largest group of respondents were farmers (orchardists), representing about 50% of the sample. This was followed by agricultural engineers, who made up around 32.7%, while teachers represented the smallest proportion at 2.5% (Table 1).

Table 1. *The socio-demographic information of respondents*

Variable	Categories	Frequency	Percent
Gender	Male	201	99.5
	Female	1	0.5
Education Level	Illiterate	17	8.4
	Primary education	39	19.3
	High school graduate	45	22.3
	Bachelor	73	36.1
	Master	28	13.9
Occupations	Teacher	5	2.5
	Gardener	101	50.0
	Park Manager	30	14.9
	Agricultural Engineer	66	32.7

The results show that, by age, most respondents were between 25 and 35 years old, accounting for about 47.5% of participants. When this age interval is expanded by 20 years, around 83.6% of respondents fall within the 25 to 45 age group. Furthermore, the findings indicate that the smallest proportion of respondents belonged to the 55 to 65 years' age group, representing only about 1.5% of the total sample (Figure 1).

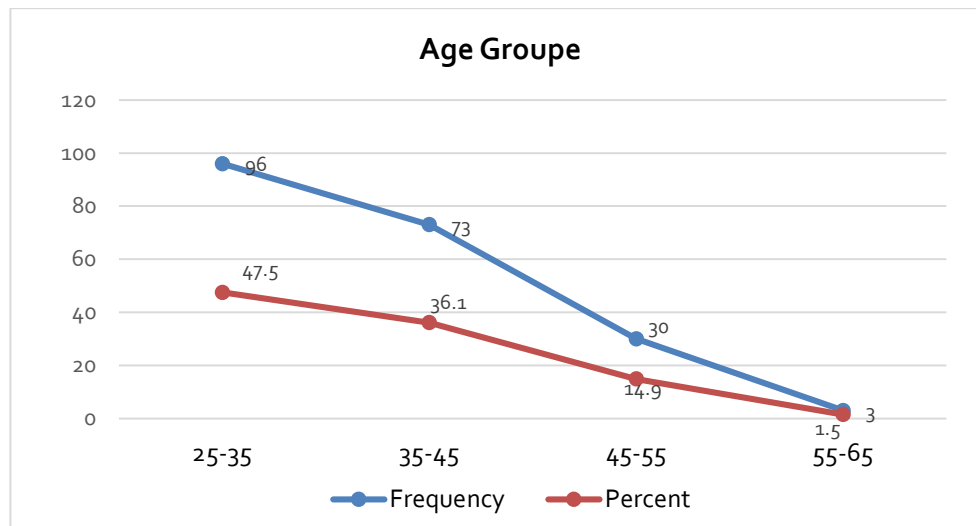


Figure 1. Frequency and percentage distribution of respondents by age group

To clarify this issue, we performed a Spearman correlation analysis between the socio-demographic variables and the presence of green walls. This was considered more appropriate because it is more fundamental to identify users of green wall systems rather than focusing only on plant maintenance practices. Factors such as plant type and care practices may increase analytical complexity and make interpretation less straightforward. The Spearman correlation test results indicated no significant correlation between gender, education level, occupation, and age and the presence of green walls ($p > 0.05$). But the socio-demographic variables themselves showed significant relationships. In particular, education level was significantly positively correlated with occupation ($\rho = 0.765$, $p < 0.01$). In contrast, occupation was significantly negatively correlated with age ($\rho = -0.142$, $p < 0.05$). Education level was also significantly inversely correlated with age ($\rho = -0.225$, $p < 0.01$), Table 2.

Table 2. Correlation between socio-demographic variables and presence of green wall

Variable	Correlation	Age	Gender	Education	Occupation
Gender	ρ	0.042			
	p	0.557			
Education	ρ	-.225**	0.109		
	p	0.001	0.122		
Occupation	ρ	-.142*	0.090	.765**	
	p	0.043	0.203	0.000	
PGW	ρ	0.071	-0.114	0.080	0.095
	p	0.317	0.107	0.258	0.179

PGW: Presence of Green Wall in home/area, **p:** significance, **ρ :** Spearman Correlation, *: $p < 0.05$, **: $p < 0.01$.

Presence of Green Wall

The results showed that 151 respondents reported having green walls in their homes or surrounding areas, or about 74.8% of the sample. Of these 151 respondents, 80 (about 52.3%) indicated that they use exotic plant species for their green walls. The most popular plant species was Climbing Willow (*Salix* spp.), used by 21.85% of respondents. Boxwood (*Buxus*

spp.) and Ivy (*Hedera* spp.) followed with 15.23% each. Grapevine (*Vitis* spp.) and Rose (*Rosa* spp.) had the lowest numbers of users, accounting for 2.65% and 3.31% of users, respectively. Among 202 respondents, 100 respondents (49.5%) had high soil fertility, and 14.85% had low soil fertility (Table 3).

Table 3. Frequency distribution for the presence of green walls and their related variable

Variable	Categories	Frequency	Percent
PGW	No	51	25.2
	Yes	151	74.8
Plant origin	Local	71	47.02
	Exotic (Imported)	80	52.98
	Boxwood	23	15.23
	Ivy	23	15.23
	Cypress	6	3.97
	Wall willow (climbing willow)	33	21.85
	Jasmine	12	7.95
PSUGW	Climbing rose / creeper	17	11.26
	Thuja (<i>Arborvitae</i>)	8	5.3
	Honeysuckle	20	13.25
	Rose	5	3.31
	Ornamental grape	4	2.65
	Highly fertile	100	49.5
	Moderately fertile	72	35.64
SFS	Low fertility	30	14.85

PSUGW: Plant Species Used for Green Walls, **SFS:** Soil Fertility Status

The correlation analysis showed no statistically significant correlation between occupation, soil fertility, and the presence of green walls (Table 4). Specifically, occupation showed a weak and non-significant positive correlation with the presence of green walls ($p = 0.122$, $p = 0.084$). Similarly, soil fertility showed a very weak and non-significant correlation with both occupation ($p = 0.058$, $p = 0.416$) and the presence of green walls ($p = -0.046$, $p = 0.515$).

Table 4. Correlation between Soil fertility, occupation, and the presence of green walls

Variable	Correlation	Occupation	PGW
PGW	ρ	0.122	
	p	0.084	
SFS	ρ	0.058	-0.046
	p	0.416	0.515

Furthermore, the logistic regression model showed very low explanatory power (Nagelkerke $R^2 = 0.037$), meaning that the independent variables included (PGW, SFS and Occupation) had limited capacity to predict the presence of green walls. We used multinomial logistic regression to determine the effect of respondents' occupation, soil fertility status, and the presence of green walls on plant species selection. The results showed that the model had moderate explanatory power (pseudo-R-square, Cox & Snell (0.304); Nagelkerke

(0.308)), indicating that the model explained about 30% of the variation in the dependent variable.

Different Characteristics of Green Walls

This section explained the various characteristics of the existing green walls used by the respondents. Results indicated that most green wall users preferred plants with a pure green color, which accounted for 64.24% of the 151 respondents who reported having green walls. This was followed by green mixed with other colors, which accounted for 24.5% of respondents. The least preferred colors were white, red, and pink, at 1.32%, 1.99%, and 1.99%, respectively. The majority of respondents (84.77%, $n = 128$) preferred plants with esthetic value, long lifespan, resistance to heat and cold, disease resistance, and low water requirements. Meanwhile, 15.23% of the respondents preferred plants based on aesthetic value, good climatic adaptation, and long life.

Most respondents (61.59%) preferred plants with a moderate growth habit, while the least preferred was a slow growth habit (7.95%). Out of the 151 respondents who had green walls, the majority (74.83%) also indicated that their wall dimensions were 1-5 meters in length and 50 cm in width. In contrast, the fewest respondents (9.93%) had green walls longer than 10 meters and 50 cm wide (Table 5).

Table 5. Frequency distribution for different characteristics of green walls

Variable	Categories	Frequency	Percent
Preferred plant color for green walls	Pure green	97	64.24
	Green mixed with other colors	37	24.5
	Yellow	9	5.96
	White	2	1.32
	Red	3	1.99
	Pink	3	1.99
Preferred plant characteristics	Aesthetic value, long lifespan, resistance to heat and cold, disease resistance, low water requirement	128	84.77
	Aesthetic value, good climatic adaptation, long lifespan	23	15.23
Growth rate preference of plants	Slow	12	7.95
	Moderate	93	61.59
	Fast	46	30.46
Dimensions of existing green walls	1–5 m length and 50 cm width	113	74.83
	5–10 m length and 50 cm width	23	15.23
	More than 10 m in length and 50 cm in width	15	9.93

Spearman correlation analysis between plant species used in green walls and other selected preference-related variables showed that most relationships were weak and statistically insignificant ($p > 0.05$), indicating little association among the studied factors. Plant species and green wall dimensions had a statistically significant negative correlation ($\rho = -0.216$, $p = 0.008$), meaning that some plant species are associated with small or large green wall sizes. Moreover, a weak but significant negative correlation was observed between

preferred plant color and the reason for selecting plants ($p = -0.176$, $p = 0.031$), indicating that plant color preference has a slight influence on the reason for plant selection (Table 6).

Table 6. Correlation between Plant species for green wall and other Preferred Characteristics

Variable	Correlation	PSUGW	GWD	PGT	PPC	RUSP
GWD	ρ	-0.216**				
	p	0.008				
PGT	ρ	0.044	-0.024			
	p	0.593	0.768			
PPC	ρ	0.096	-0.097	-0.125		
	p	0.241	0.234	0.126		
RUSP	ρ	-0.038	0.053	-0.056	-0.176*	
	p	0.647	0.514	0.497	0.031	
Occupation	ρ	0.014	-0.024	-0.104	0.045	0.048
	p	0.863	0.767	0.206	0.584	0.557

GWD: Green Wall Dimensions, **PGT:** Plant Growth Type, **PPC:** Preferred Plant Color, **RUSP:** Reason for Using Selected Plants.

The multinomial logistic regression results indicate that green wall dimensions (length and width) and reasons for plant selection significantly influence the types of plants used in green walls. The pseudo-R-square values (Cox & Snell = 0.355; Nagelkerke = 0.360; McFadden = 0.103) suggest that the model has moderate explanatory power, explaining approximately 36% of the variation in the dependent variable.

Management and Maintenance Practices of Green Walls

One of the most important activities for ensuring the sustainability and protection of green walls is management. The study found that of the 151 respondents with green walls, most (55%) irrigated their green walls twice a week. Irregular watering was the least common irrigation frequency, reported by only 3.3% of respondents. In terms of irrigation systems, most respondents (89.4%) used furrow irrigation, while a small proportion used more modern systems such as drip irrigation. For fertilization practices, farmyard manure (FYM) was the most prevalent fertilizer used (45.7%). It was followed by a mixture of urea, DAP, and FYM (25.2%). Urea alone was the least used fertilizer, reported by only 2% of respondents—Table 7.

Table 7. Frequency distribution for maintenance practices of green walls and their related variable

Variable	Categories	Frequency	Percent
Irrigation frequency	Once per week	56	37.1
	Twice per week	83	55.0
	Twice per month	7	4.6
	Irregular	5	3.3

Variable	Categories	Frequency	Percent
Irrigation system	Drip irrigation	16	10.6
	Furrow irrigation	135	89.4
Fertilizer used	FYM (Farmyard manure)	69	45.7
	NPK	5	3.3
	Urea	3	2.0
	Urea, DAP, FYM	38	25.2
	Urea, FYM	8	5.3
	DAP, FYM	24	15.9
	Urea, DAP	4	2.6

The results indicated that among 151 respondents, 44.4% reported that green walls should be pruned once per year. The second most common response was monthly pruning, reported by 29.1% of respondents. The least frequently reported pruning interval was every three months, indicated by 9.3% of respondents (Figure 2).

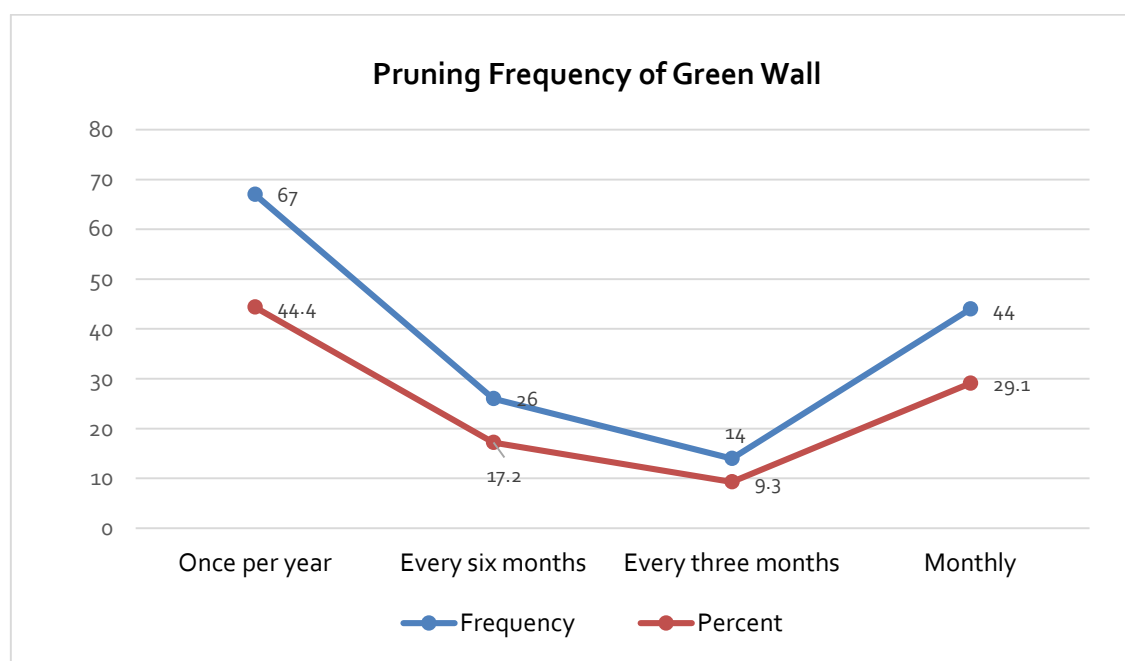


Figure 2. Frequency and percentage distribution of green wall Pruning interval.

Pest and disease management is one of the most important aspects of green wall maintenance. Of the 202 respondents, 151 reported having green walls and were further analyzed. Among these respondents, responses varied regarding pest and disease control practices. The results showed that 43% of respondents reported not knowing pest and disease control methods. This was followed by 39.7% of respondents who indicated that they use chemical control methods. In contrast, only 2% of respondents reported using natural (biological) methods for pest and disease management Figure 3.

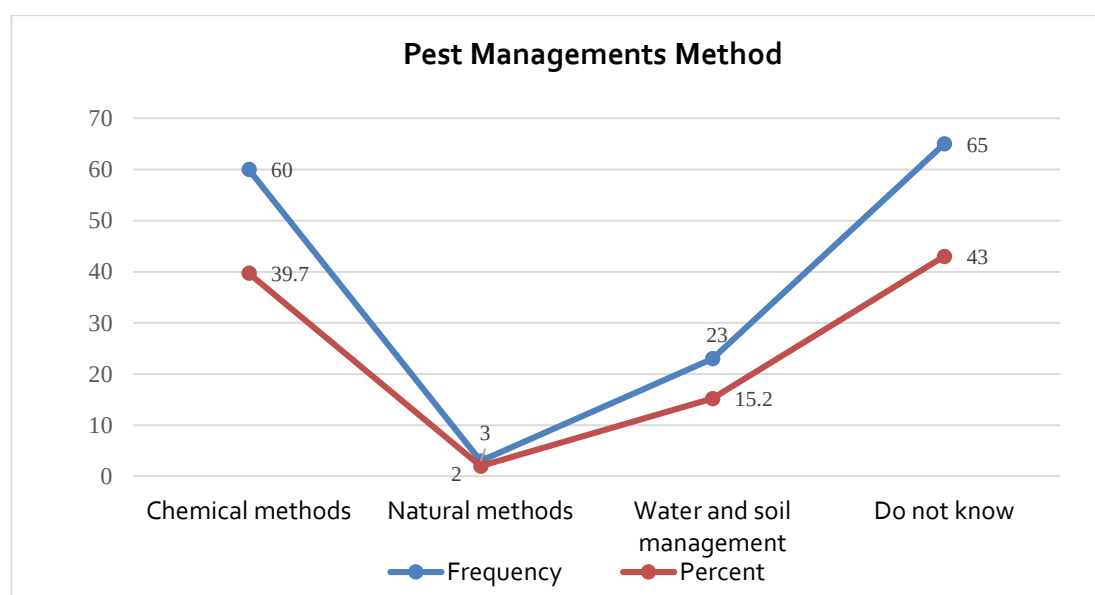


Figure 3. Frequency and percentage distribution for pest management methods.

Correlation analyses reveal that most inter-variable relationships are weak and not statistically significant. However, some important associations were noted. The relationship between occupation and irrigation frequency was weak and negative ($\rho = -0.180$, $p < 0.05$). Irrigation frequency was also significantly and negatively correlated with irrigation system type ($\rho = -0.180$, $p < 0.05$). The irrigation regime and pruning frequency showed a moderate negative correlation ($\rho = -0.34$, $p < 0.01$), the strongest relationship in the table. The irrigation system was also weakly positively correlated with pest and disease control methods ($\rho = 0.200$, $p < 0.05$). Fertilizer use was significantly negatively correlated with pest control methods ($\rho = -0.208$, $p < 0.05$) and soil fertility status ($\rho = -0.188$, $p < 0.05$)—Table 8. No significant correlations were observed between the plant species used and other variables.

Table 8. Relationship between occupation, plant selection for green walls, and maintenance practices

Variable	Correlation	Occupation	IRF	IRS	PRF	FR	PDCM	PSUGW
IRF	ρ	-0.180*						
	p	0.03						
IRS	ρ	0.04	-0.180*					
	p	0.62	0.03					
PRF	ρ	0.01	-0.06	-0.34**				
	p	0.89	0.50	0.00				
FR	ρ	0.03	0.03	-0.15	0.04			
	p	0.73	0.68	0.07	0.61			
PDCM	ρ	-0.09	0.16	0.200*	-0.08	-0.208*		
	p	0.27	0.06	0.01	0.34	0.01		
PSUGW	ρ	0.01	0.02	-0.02	-0.12	-0.11	0.02	
	p	0.86	0.77	0.82	0.13	0.19	0.81	
SFS	ρ	0.03	0.08	0.09	0.04	-0.188*	0.07	-0.05
	p	0.70	0.32	0.29	0.61	0.02	0.41	0.53

IRF: Irrigation Frequency, **IRS:** Irrigation System, **PRF:** Pruning Frequency, **FR:** Fertilizer, **PDCM:** Pest/disease Control Method.

In the multinomial logistic regression analysis, the model fit results showed that the final model did not statistically significantly improve the intercept-only model ($\chi^2 = 195.192$, $p = 0.363$). This shows that the independent (IRF, IRS, PRF, FR, PDCM, SFS) variables entered in the model were not strong predictors of the dependent (PSUGW) variable overall. The pseudo-R-square values (Cox & Snell = 0.725; Nagelkerke = 0.736; McFadden = 0.304) are relatively high, but in logistic regression these measures do not reflect explained variance directly and should be interpreted with caution.

The likelihood ratio tests showed that some variables, such as occupation, soil type, frequency of pruning, and use of fertilizer, had statistically significant effects ($p < 0.001$). However, singularities in the Hessian matrix prevented estimation of several variables because of sparse data and a large number of categories. Therefore, while some individual effects are significant, the overall model is not robust, and the results should be interpreted with caution. These limitations may stem from the data structure, such as uneven response distributions and small sample sizes in some categories.

Problems and Limitations of Green Walls

In this section, respondents reported the main problems they face with green walls. Out of 202 participants, the highest proportion (37.6%) reported water scarcity as the major challenge. This was followed by plant diseases, mentioned by 27.7% of respondents. The least reported issue was high maintenance cost, indicating that relatively fewer people considered it a major problem for green wall management (Table 9).

Table 9. Frequency distribution for the main problems of green walls

Category	Items	Frequency	Percent
Main problems of green walls	Disease	56	27.7
	High maintenance cost	9	4.5
	Sensitivity to shade	13	6.4
	Soil problems	29	14.4
	Poor air conditions	19	9.4
	Water scarcity	76	37.6

Respondents were asked about the major pests affecting green walls. The results showed that the largest proportion of participants (about 45%) reported not knowing the specific pests. Around 21.8% identified leaf-eating insects as the main pest problem. The smallest proportion of respondents mentioned fungal diseases as a concern for green walls (Figure 4).

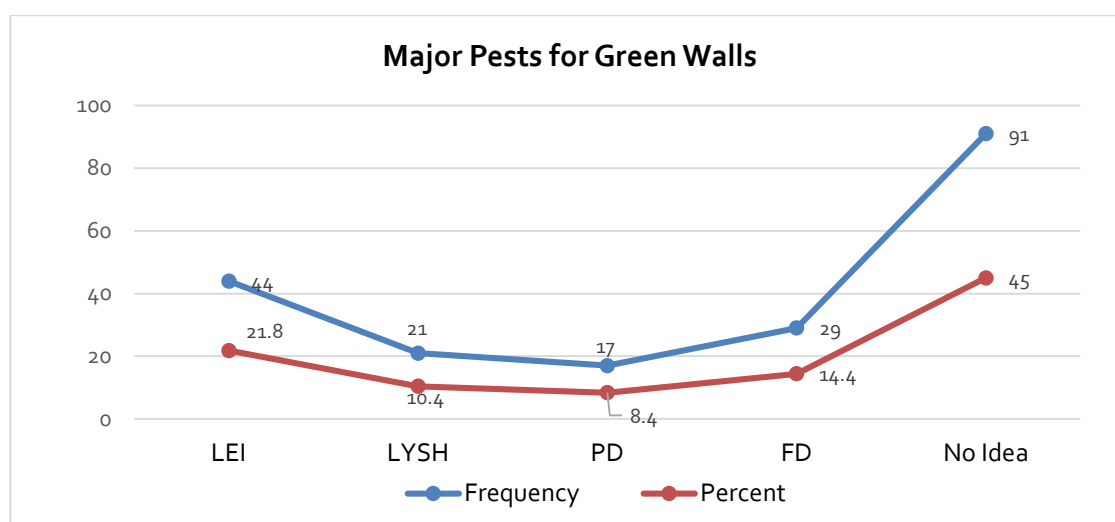


Figure 4. Frequency and percentage distribution of major pests for green walls.

LEI: Leaf-eating insects, **LYSH:** Leaf yellowing or shedding, **PD:** Plant drying/wilting, **FD:** Fungal diseases.

The Spearman correlation results show generally weak relationships among the variables. Occupation has a weak, non-significant negative correlation with major pests for green walls (MPGW) ($\rho = -0.061$, $p = 0.391$) and a weak but significant negative correlation with major pests of green walls (MPSGW) ($\rho = -0.141$, $p = 0.046$). A moderate and statistically significant positive relationship was observed between main problems of green walls (MPGW) and MPSGW ($\rho = 0.404$, $p < 0.001$), indicating that increases in MPGW are associated with increases in MPSGW. In contrast, PGW showed weak and non-significant correlations with occupation ($\rho = 0.122$, $p = 0.084$), MPGW ($\rho = 0.023$, $p = 0.742$), and MPSGW ($\rho = -0.095$, $p = 0.179$), suggesting no meaningful association with the studied variables. Overall, only the relationship between MPGW and MPSGW is statistically strong and meaningful (Table 10).

Table 10. The correlation between the presence of green walls, MPGW, and MPSGW

Variable	Correlation	Occupation	MPGW	MPSGW
MPGW	ρ	-0.061		
	p	0.391		
MPSGW	ρ	-.141 *	.404 **	
	p	0.046	0.000	
PGW	ρ	0.122	0.023	-0.095
	p	0.084	0.742	0.179

In the binomial logistic regression analysis, the model shows very weak explanatory power, as indicated by Cox & Snell R^2 (0.012) and Nagelkerke R^2 (0.018), meaning that the independent variables explain only about 1.2% to 1.8% of the variation in the dependent variable. The model fit is also poor, as indicated by the -2 Log Likelihood value (225.850). In the regression equation, neither major problems associated with green wall plants ($B = 0.093$, $p = 0.283$) nor common pests and diseases ($B = -0.162$, $p = 0.152$) had a statistically significant effect on the outcome variable. Although the constant term was significant ($B = 1.314$, $p = 0.003$), it only represents the baseline level of the dependent variable. Overall, the results

indicate that the predictors included in the model do not significantly explain the outcome variable.

Recommendation & Improvement for Green Wall

In this section, respondents were asked to suggest suitable practices to address green wall problems and suitable plant species for green wall establishment. The findings indicate that most respondents (55%) recommended an integrated approach comprising suitable soil, regular irrigation, pest and disease control, and proper plant shaping as the best strategy to improve green wall performance. 22% stressed the need for regular irrigation only, and a small proportion (4.5%) thought that proper shaping was sufficient. The most often recommended species were ornamental flowers (39.6%), showing a strong preference for plants that are pleasant to the eye. Ivy (18%) and wall willow (19.8%) were also often mentioned, indicating their suitability for vertical growth systems. Conversely, respondents least recommended Thuja (3.5%). In summary, the results show a strong preference for integrated maintenance practices and ornamental, fast-growing plant species for successful green wall development (Table 11).

Table 11. Frequency distribution for recommended practices and plants

Variable	Categories	Frequency	Percent
Recommended Practices	Proper shaping.	9	4.5
	Suitable soil.	24	11.9
	Suitable soil and regular irrigation.	12	5.9
	Suitable soil, regular irrigation, pest and disease control, and proper shaping.	111	55.0
	Regular irrigation.	46	22.8
Recommended Plants	Spanish broom.	22	10.9
	Ivy.	36	17.8
	Wall willow.	40	19.8
	Flowers.	80	39.6
	Cypress.	17	8.4
	Thuja.	7	3.5

The Spearman correlation results show generally weak and mostly non-significant relationships among the variables. Occupation has a weak positive correlation with PGW ($\rho = 0.122$, $p = 0.084$) and weak, non-significant relationships with recommended plants for green walls (RPGW), recommended practices for green walls (RPRGW), and MPGW, while showing a weak but significant negative correlation with MPSGW ($\rho = -0.141$, $p = 0.046$). PGW also showed weak, non-significant associations with RPGW, RPRGW, MPGW, and MPSGW. The strongest and only statistically significant relationship is observed between MPGW and MPSGW ($\rho = 0.404$, $p < 0.01$), indicating a moderate positive association. Overall, most variables show no meaningful correlations except MPGW and MPSGW, which are significantly related (Table 12).

Table 12. Correlation between the presence of green walls, RPGW, RPRGW, and another variable.

Variable	Correlation	Occupation	PGW	RPGW	RPRGW	MPGW
PGW	ρ	0.122				
	p	0.084				
RPGW	ρ	0.082	0.077			
	p	0.246	0.275			
RPRGW	ρ	0.078	-0.051	-0.015		
	p	0.272	0.467	0.832		
MPGW	ρ	-0.061	0.023	-0.069	0.084	
	p	0.391	0.742	0.331	0.233	
MPSGW	ρ	-.141*	-0.095	-0.136	-0.026	.404**
	p	0.046	0.179	0.053	0.708	0

We conducted a binomial logistic regression analysis to examine the effect of suggested plant types and maintenance practices on the occurrence of green walls. The findings show a very weak model fit, as indicated by the Cox & Snell R^2 (0.016) and Nagelkerke R^2 (0.024), suggesting that the independent variables explain only about 1.6% to 2.4% of the variation in the dependent variable. The -2 log-likelihood value of 225.004 also indicates that the model improved only to a limited extent. In the regression model, neither the recommended plant types for green walls ($B = 0.196$, $p = 0.131$) nor the suggested maintenance practices ($B = -0.155$, $p = 0.342$) were statistically significant. The constant term was not significant either ($p = 0.170$). Overall, the results suggest that these predictors do not significantly explain or influence the presence of green walls in the study area.

A multinomial logistic regression was carried out to examine the effect of proposed plant types and maintenance practices on problems with green walls. The model's explanatory power is low to moderate (Cox & Snell = 0.220, Nagelkerke = 0.231, McFadden = 0.081). However, the Likelihood Ratio Tests indicated that neither recommended plant types ($p = 0.084$) nor maintenance practices ($p = 0.425$) had a statistically significant effect. In summary, these predictors do not significantly explain the variance in green wall problems.

DISCUSSION

The study provides important information on the status, characteristics, and management of green wall systems in Kabul City, highlighting opportunities and challenges for sustainable development. The socio-demographic profile of the respondents shows a high representation of male participants and people with higher levels of education, especially those with a bachelor's degree. This reflects the current state of participation in horticulture and agriculture in Kabul, where educated professionals have the technical and practical knowledge. Most respondents were farmers and agricultural specialists; therefore, the study results are largely shaped by people with direct experience in plant management. Also, most of the respondents were from the working age group (25-45 years), suggesting that awareness and interest in green wall systems are more prevalent among the working population, which is consistent with prior research indicating the participation of proactive populations in the adoption of urban green infrastructure (Manouchehri et al., 2024; Sañudo-Fontaneda et al., 2026).

Presence of green walls and socio-demographic variables. However, the study did not establish a statistically significant relationship between these patterns. Thus, gender, age, education, and occupation do not directly affect the adoption of green wall systems in Kabul. This is consistent with earlier studies showing that environmental awareness, policy support, and technical feasibility, rather than demographic factors alone, determine the adoption of green infrastructure (Amegah et al., 2023; Dede & Ozer, 2024; Essuman-Quainoo & Jim, 2023). However, the socio-demographic variables were significantly related. For example, in our data, education was strongly positively correlated with job. This implies that more educated personnel are more often employed in specialized jobs. Younger respondents had higher levels of education than older respondents, suggesting a possible generational improvement in access to education and modern agricultural knowledge (Fu et al., 2025; Tayouga & Gagné, 2016; Zhang et al., 2024). The results show that socio-demographic factors do not directly affect green wall adoption but indirectly influence management capacity and technical knowledge, which are important for long-term sustainability (Elkadi et al., 2024; Rasoulinezhad & Taghizadeh-Hesary, 2025).

Results also indicate a relatively high penetration rate of green walls, with 74.8% of respondents having green walls nearby. This suggests greater awareness and recognition of urban greening practices in Kabul. Respondents also showed a slight preference for exotics (52.3%), suggesting that aesthetic value and fast growth are the main drivers of plant selection. These findings align with earlier studies highlighting the suitability of climbing and evergreen species for vertical greening systems because of their high coverage potential and environmental adaptability (Borna & Yeganeh, 2024; Salisbury et al., 2023). Common species like climbing willow, ivy and boxwood are popular due to their adaptability, climbing ability and tolerance of urban conditions; Soil fertility was reported to be relatively high, but literature suggests that the performance of green walls is more dependent on the design of the system, irrigation efficiency and plant selection than on soil conditions alone, especially in controlled urban environments (Liu et al., 2026; Mankiewicz et al., 2022; Wang et al., 2024).

The correlation analysis did not reveal significant relationships between occupation, soil fertility, and the presence of green walls, further supporting the idea that adoption is not strongly determined by socio-economic or environmental variables in isolation. Awareness, perception, and motivation are considered more important aspects in implementing green infrastructure (Borna & Yeganeh, 2024; Drosou et al., 2019). The regression analysis showed low explanatory power in predicting the presence of green walls (Nagelkerke $R^2 = 0.037$), suggesting that the variables in the model are insufficient to explain adoption patterns. Plant species choice explained only moderate variation (~30%), suggesting that environmental and functional considerations influence plant selection. This is consistent with previous studies that found plant selection is mainly driven by functional traits, aesthetic preferences, and maintenance needs rather than demographic constraints (Liu et al., 2026; Salisbury et al., 2023).

The research also highlights the main features of green wall systems in Kabul. Most installations were small-scale (1-5 meters), indicating household-level implementation rather than large commercial or institutional projects. This aligns with the global trend in urban green infrastructure, where small-scale systems are more prevalent because of lower costs, easier maintenance, and limited space (Wang et al., 2022; Zhao et al., 2024). Plant selection largely reflected aesthetic preferences, especially the prevalence of green-colored plants, which are associated with a natural look and psychological benefits. Respondents also preferred functional traits such as drought tolerance, disease resistance, and low water needs. The choice of plants balances aesthetics and practicality, and recent studies support this (Farrell et al., 2022; Irawati & Basuki, 2020; Kang & Yoon, 2026; Lartey et al., 2025).

Moderate growth rates were preferred at the time of selection, and growth characteristics were also important. It's a practical way to get coverage quickly, without much maintenance. Correlation analysis showed that most correlations between variables were weak, and the effect of socio-demographic variables on plant preferences was largely independent. However, the strong negative correlation between plant species and wall dimensions suggests that the scale of the structure affects species selection, as found in other studies (Alkadri et al., 2025; Irga et al., 2023).

The study revealed a strong dependence on traditional irrigation practices, especially furrow irrigation. In terms of management practices, most respondents irrigate twice a week. The study observed low technology uptake, with drip systems and other modern irrigation technologies rarely used. Nevertheless, the literature indicates that advanced irrigation systems can significantly improve water efficiency, plant health, and overall system performance (Lyu et al., 2024; Nasr et al., 2024). Fertilizers were applied mainly as organic inputs, particularly farmyard manure, reflecting dependence on locally available, low-cost inputs. Integrated nutrient management approaches combining organic and chemical inputs are considered more effective at optimizing plant growth and nutrient availability than organic fertilizers alone, which have long-term effects (Perini et al., 2017; Tayouga & Gagné, 2016).

Most respondents pruned only once a year, so pruning practices were relatively infrequent. Low maintenance intensity may negatively affect plant performance and system sustainability. The literature emphasizes the importance of regular pruning to reach plant density, aesthetics, and structural stability in vertical systems (Borna & Yeganeh, 2024; Pérez-Urrestarazu & Urrestarazu, 2018). Further, a considerable knowledge gap remained in pest and disease management, with many respondents unaware and only a small proportion using biological control methods. This points to the need for improved training and implementation of integrated pest management (IPM) strategies, which are highly recommended for sustainable urban green systems (Elkadi et al., 2024).

The problems and limitations analysis further confirms that green wall systems in Kabul face several constraints, including dependence on traditional practices, limited use of advanced technologies, and a lack of technical knowledge. Water management is a major

concern because irrigation systems are often inefficient, leading to plant stress, reduced growth, and higher maintenance needs. Studies show that better irrigation systems can improve plant survival, reduce maintenance costs, and minimize environmental impacts (Lyu et al., 2024; Vranayová et al., 2025). Poor pruning and pest management can also cause long-term system degradation. Data imbalance and categorical constraints limited model performance, aligning with other research on urban green infrastructure (Dede & Ozer, 2024; Salisbury et al., 2023).

This study's recommendations highlight integrated management approaches. Most respondents understood that effective green wall management combines practices such as selecting appropriate soil, periodic irrigation, pest and disease control, and appropriate plant shaping. This aligns with scientific literature showing that green wall performance depends on the interaction of several factors, not isolated interventions (Pérez-Urrestarazu & Urrestarazu, 2018; Tayouga & Gagné, 2016). The plant selection problems also show the need for a combination of aesthetic and functional features, with ornamental and fast-growing species most frequently recommended.

In summary, the statistical analysis found weak relationships among variables overall, consistent with the complexity of green wall systems and the effects of multiple interacting factors. The moderate correlation between broad green wall problems and pest-related problems indicated a strong link between environmental stress and management deficiencies (Elkadi et al., 2024). The regression models showed weak predictive power, suggesting that single variables do not explain green wall adoption and performance, but rather complex interactions among environmental conditions, technical practices, and user behavior. This is consistent with recent studies that have illustrated the complex nature of urban green infrastructure systems (Borna & Yeganeh, 2024; Wang et al., 2024).

CONCLUSION

This study surveyed appropriate plant species and maintenance practices for green walls in Kabul City. The results indicate that the best plants are ornamental, fast-growing, and adaptable species such as climbing willow, ivy, and boxwood, which offer strong aesthetic value, vertical coverage, and resilience under urban conditions. Key considerations include aesthetics and functional features such as drought tolerance, low water requirements, and low maintenance.

Regarding management, green walls are mostly managed using traditional methods (furrow irrigation, organic fertilization, and limited pruning), and few modern technologies are used. The results suggest that successful maintenance requires an integrated approach, including proper soil selection, efficient irrigation, pruning, and pest control. Key challenges are water scarcity, limited technical knowledge, and weak pest management practices. Future research should develop integrated management frameworks and investigate advanced irrigation and planting systems under local climatic and socio-economic conditions to support evidence-based urban greening policies in Afghanistan.

Authors Contributions

- Masood Sayeed conceptualized and supervised the study.
- Khyal Bashar Khyal investigated, analyzed the data, and wrote the manuscript with input from all authors.
- All authors reviewed and approved the final version.

Acknowledgements

The authors thank the Department of Horticulture, Faculty of Agriculture, Kabul University, for their technical support.

Funding Information

No funding supported this manuscript.

Conflict of Interest Statement

The authors declare no conflict of interest.

Data Availability Statement

Data are available upon request from the corresponding author, subject to the approval of the relevant ethics committee.

REFERENCES

- Alkadri, M. F., Yolanda, A., Alifa, R. P., Purbaya, R., Susanto, D., Farah Istiani, N. F., & Suryanegara, M. (2025). Systematic review of plant selection in vertical greenery systems for urban sustainability: Current research, knowledge gaps, and future directions. *Energy and Buildings*, 346, 116136. <https://doi.org/10.1016/j.enbuild.2025.116136>
- Amegah, A. K., Yeboah, K., Owusu, V., Afriyie, L., Kyere-Gyeabour, E., Appiah, D. C., Osei-Kufuor, P., Annim, S. K., Agyei-Mensah, S., & Mudu, P. (2023). Socio-demographic and neighbourhood factors influencing urban green space use and development at home: A population-based survey in Accra, Ghana. *PloS One*, 18(6), e0286332. <https://doi.org/10.1371/journal.pone.0286332>
- Ben-Ali, M., Chtioui, B., Bouchrit, H., Laamiri, H., & Attia El Hili, H. (2025). Antibiotic use in poultry farming: A cross-sectional study of veterinary practices in Tunisia. *Frontiers in Antibiotics*, 4. <https://doi.org/10.3389/frabi.2025.1646766>
- Borna, M., & Yeganeh, M. (2024). Analysis of the impact of growing green walls based on the reduction of PM_{2.5} particles in the resilient central urban fabric. *Frontiers in Built Environment*, 10. <https://doi.org/10.3389/fbuil.2024.1443554>
- Carlucci, S., Charalambous, M., & Tzortzi, J. N. (2023). Monitoring and performance evaluation of a green wall in a semi-arid Mediterranean climate. *Journal of Building Engineering*, 77, 107421. <https://doi.org/10.1016/j.jobe.2023.107421>

- Chen, J., & Wei, X. (2018). Controlled-Release Fertilizers as a Means to Reduce Nitrogen Leaching and Runoff in Container-Grown Plant Production. In *Nitrogen in Agriculture—Updates*. IntechOpen. <https://doi.org/10.5772/intechopen.73055>
- Chiruță, C., Stoleriu, I., & Cojocariu, M. (2023). Prediction Models for the Plant Coverage Percentage of a Vertical Green Wall System: Regression Models and Artificial Neural Network Models. *Horticulturae*, 9(4), 419. <https://doi.org/10.3390/horticulturae9040419>
- Čufer, T., Šegula, S., & Ribič, P. (2026). *Maintenance of Vertical Greening Systems | Arnes Učilnice*. https://ucilnice.arnes.si/mod/book/tool/print/index.php?id=606539&utm_source=chatgpt.com
- Dede, O. H., & Ozer, H. (2024). Investigating the Impact of Various Growing Media on the Expansion of Green Wall Plant Coverage with Image Analysis. *Horticulturae*, 10(6), 654. <https://doi.org/10.3390/horticulturae10060654>
- Detommaso, M., Costanzo, V., Nocera, F., & Evola, G. (2023). Evaluation of the cooling potential of a vertical greenery system coupled to a building through an experimentally validated transient model. *Building and Environment*, 244, 110769. <https://doi.org/10.1016/j.buildenv.2023.110769>
- Dominici, L., Comino, E., Torpy, F., & Irga, P. (2022). Vertical Greening Systems: A Critical Comparison of Do-It-Yourself Designs. *Plants*, 11(23), 3230. <https://doi.org/10.3390/plants11233230>
- Drosou, N., Soetanto, R., Hermawan, F., Chmutina, K., Boshier, L., & Hatmoko, J. U. D. (2019). Key Factors Influencing Wider Adoption of Blue–Green Infrastructure in Developing Cities. *Water*, 11(6), 1234. <https://doi.org/10.3390/w11061234>
- Elkadi, H., Seifhashemi, M., & Lauwerijssen, R. (2024). Thermographic Analysis of Green Wall and Green Roof Plant Types under Levels of Water Stress. *Sustainability*, 16(19), 8685. <https://doi.org/10.3390/su16198685>
- Essuman-Quainoo, B., & Jim, C. Y. (2023). Understanding the drivers of green roofs and green walls adoption in Global South cities: Analysis of Accra, Ghana. *Urban Forestry & Urban Greening*, 89, 128106. <https://doi.org/10.1016/j.ufug.2023.128106>
- Farrell, C., Livesley, S. J., Arndt, S. K., Beaumont, L., Burley, H., Ellsworth, D., Esperon-Rodriguez, M., Fletcher, T. D., Gallagher, R., Ossola, A., Power, S. A., Marchin, R., Rayner, J. P., Rymer, P. D., Staas, L., Szota, C., Williams, N. S. G., & Leishman, M. (2022). Can we integrate ecological approaches to improve plant selection for green infrastructure? *Urban Forestry & Urban Greening*, 76, 127732. <https://doi.org/10.1016/j.ufug.2022.127732>
- Fonseca, F., Paschoalino, M., & Silva, L. (2023). Health and Well-Being Benefits of Outdoor and Indoor Vertical Greening Systems: A Review. *Sustainability*, 15(5), 4107. <https://doi.org/10.3390/su15054107>

- Fu, Z., Zhang, C., Huang, Z., Jia, L., Sun, G., & Wang, W. (2025). Advancing sustainable and innovative agriculture: An empirical study of farmers' livelihood risks and the green transformation of food production. *Journal of Innovation & Knowledge*, 10(4). <https://doi.org/10.1016/j.jik.2025.100732>
- Gómez-Caballero, M., Soto Vázquez, J., & Pérez Parejo, R. (2026). Validation of a Likert questionnaire for creative writing and critical thinking in five Spanish universities. *Frontiers in Education*, 10. <https://doi.org/10.3389/feduc.2025.1698270>
- Hossain, H., Sakib, M. A. N., Sayeed, S. S. B., Rahman, M., Brishty, K. A., Pal, S. K., Rahman, T., Marma, C. S. S., Rafi, M. K. A., Islam, S., Shahriar, F., Chowdhury, M. S. R., & Rahman, M. M. (2025). Community knowledge and response to Nipah virus infection and its transmission, prevention and control measures: Insights from a cross-sectional survey in Bangladesh. *PLOS Neglected Tropical Diseases*, 19(12), e0013855. <https://doi.org/10.1371/journal.pntd.0013855>
- Irawati, E. B., & Basuki. (2020). Plant Characteristics for Green Wall Systems. *Proceeding International Conference on Science and Engineering*, 3, 77–80. <https://doi.org/10.14421/icse.v3.472>
- Irga, P. J., Torpy, F. R., Griffin, D., & Wilkinson, S. J. (2023). Vertical Greening Systems: A Perspective on Existing Technologies and New Design Recommendation. *Sustainability*, 15(7), 6014. <https://doi.org/10.3390/su15076014>
- Kang, M., & Yoon, H. (2026). Effect of urban green infrastructure on psychological and physiological responses under outdoor heat exposure: An experimental study. *Building and Environment*, 287, 113811. <https://doi.org/10.1016/j.buildenv.2025.113811>
- Lartey, D., Lomans, A., Zarei, S., Lomans, A., Skevich, M., & van Hasselaar, D. (2025). Key plant traits for sustainable urban greening: A framework for plant selection. *Journal of Environmental Management*, 393, 127065. <https://doi.org/10.1016/j.jenvman.2025.127065>
- Lawrencia, D., Wong, S. K., Low, D. Y. S., Goh, B. H., Goh, J. K., Ruktanonchai, U. R., Soottitantawat, A., Lee, L. H., & Tang, S. Y. (2021). Controlled Release Fertilizers: A Review on Coating Materials and Mechanism of Release. *Plants*, 10(2), 238. <https://doi.org/10.3390/plants10020238>
- Lewis, A. R., Willcock, S., Casas, A., Kupiec-Teahan, B., Mendoza Sanchez, J., Anciano, F., Barrington, D. J., Dube, M., Hutchings, P., Karani, C., Llaxacondor, A., López, H., Mdee, A. L., Nou, K., Ofori, A. D., Riungu, J. N., Russel, K. C., Haque Tamal, M. E., Parker, A. H., & Bell, A. R. (2025). Realities of using self-administered smartphone surveys to solve sustainability challenges. *Humanities and Social Sciences Communications*, 12(1), 1134. <https://doi.org/10.1057/s41599-025-05305-w>
- Liu, Y., Wang, H., Li, W., & Li, Y. (2026). Effects of green-wall layouts on psychological and physiological responses in office environments: A virtual-environment study. *Frontiers*

- in *Psychology*, 16. <https://doi.org/10.3389/fpsyg.2025.1711317>
- Lorber, M., Kmetec, S., Davey, A., Mlinar Reljić, N., Fekonja, Z., & Kegl, B. (2023). Associations between Sleep Quality, Frailty, and Quality of Life among Older Adults in Community and Nursing Home Settings. *International Journal of Environmental Research and Public Health*, 20(6), 4937. <https://doi.org/10.3390/ijerph20064937>
- Lyu, L., Matheson, S., Fleck, R., Torpy, F. R., & Irga, P. J. (2024). Modulating phytoremediation: How drip irrigation system affect performance of active green wall and microbial community changes. *Journal of Environmental Management*, 370, 122646. <https://doi.org/10.1016/j.jenvman.2024.122646>
- Mankiewicz, P., Borsuk, A., Ciardullo, C., Hénaff, E., & Dyson, A. (2022). Developing design criteria for active green wall bioremediation performance: Growth media selection shapes plant physiology, water and air flow patterns. *Energy and Buildings*, 260, 111913. <https://doi.org/10.1016/j.enbuild.2022.111913>
- Manouchehri, M., Santiago López, J., & Valiente López, M. (2024). Sustainable Design of Vertical Greenery Systems: A Comprehensive Framework. *Sustainability*, 16(8), 3249. <https://doi.org/10.3390/su16083249>
- Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews*, 41, 863–871. <https://doi.org/10.1016/j.rser.2014.07.203>
- Manso, M., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renewable and Sustainable Energy Reviews*, 135, 110111. <https://doi.org/10.1016/j.rser.2020.110111>
- Mi, H., Wang, S., Wang, T., & Li, T. (2025). The Influence of Vertical Greening Systems on Building Energy Consumption and Comprehensive Carbon Emission. *Buildings*, 15(3), 471. <https://doi.org/10.3390/buildings15030471>
- Nasr, Y., El Zakhem, H., Hamami, A. E. A., El Bachawati, M., & Belarbi, R. (2024). Comprehensive Assessment of the Impact of Green Roofs and Walls on Building Energy Performance: A Scientific Review. *Energies*, 17(20), 5160. <https://doi.org/10.3390/en17205160>
- Navarini-Valdameri, C., Hollas, C. E., do Amaral, K. G. C., Lange, M. V., Sanches-Pereira, A., Bortoli, M., Mela, D., Conceição, P. S. da, & Westphal, F. S. (2026). Environmental impacts and benefits of vertical greenery systems in humid subtropical climate: A comprehensive life cycle perspective. *Journal of Cleaner Production*, 538, 147351. <https://doi.org/10.1016/j.jclepro.2025.147351>
- Pate, A., Riley, R. D., Collins, G. S., Smeden, M. van, Calster, B. V., Ensor, J., & Martin, G. P. (2022). *Minimum Sample Size for Developing a Multivariable Prediction Model using Multinomial Logistic Regression*. Cornell University. <https://doi.org/10.48550/arXiv.2207.12892>

- Pérez-Urrestarazu, L., & Urrestarazu, M. (2018). Vertical Greening Systems: Irrigation and Maintenance. In *Nature Based Strategies for Urban and Building Sustainability* (pp. 55–63). Butterworth-Heinemann. <https://doi.org/10.1016/B978-0-12-812150-4.00005-7>
- Perini, K., Ottel , M., Giulini, S., Magliocco, A., & Roccotiello, E. (2017). Quantification of fine dust deposition on different plant species in a vertical greening system. *Ecological Engineering*, 100, 268–276. <https://doi.org/10.1016/j.ecoleng.2016.12.032>
- Rasoulnezhad, E., & Taghizadeh-Hesary, F. (2025). Assessing the role of education in promoting green growth in urban areas. *Discover Sustainability*, 6(1), 867. <https://doi.org/10.1007/s43621-025-01836-z>
- Reyhani, M., Santolini, E., Tassinari, P., & Torreggiani, D. (2023). Environmental assessment of design choices of green walls based for materials combination and plants. *The International Journal of Life Cycle Assessment*, 28(9), 1078–1091. <https://doi.org/10.1007/s11367-023-02181-x>
- Safi, L. (2024). Articles Green Spaces and Urban Forest's Role in Mitigating Air Pollution in Kabul City: A Review. *Journal of Natural Sciences – Kabul University*, 7(2), 57–71. <https://doi.org/10.62810/jns.v7i2.79>
- Salisbury, A., Blanus, T., Bostock, H., & Perry, J. N. (2023). Careful plant choice can deliver more biodiverse vertical greening (green fa ades). *Urban Forestry & Urban Greening*, 89, 128118. <https://doi.org/10.1016/j.ufug.2023.128118>
- Sa udo-Fontaneda, L.  ., Robina Ram rez, R., Rodr guez, J. P., Roc s-Garc a, J., Hunt, W. F., Allende-Prieto, C., & Coupe, S. J. (2026). Mapping practitioners' socio-technical perception on blue-green infrastructure for urban climate resilience: Demographic factors, barriers, costs-benefits, and opportunities for implementation. *Urban Forestry & Urban Greening*, 120, 129455. <https://doi.org/10.1016/j.ufug.2026.129455>
- Segovia-Cardozo, D. A., Rodr guez-Sinobas, L., & Zobelzu, S. (2019). Living green walls: Estimation of water requirements and assessment of irrigation management. *Urban Forestry & Urban Greening*, 46, 126458. <https://doi.org/10.1016/j.ufug.2019.126458>
- Stollberg, M., & Birgelen, A. von. (2023). Vertical plants: Plant design of Living walls – evaluation of 34 perennials in a textile based Living wall over a three years experiment. *Frontiers in Horticulture*, 2. <https://doi.org/10.3389/fhort.2023.1091026>
- Susca, T., Iaria, J., & Zanghirella, F. (2024). Development of predictive indices for evaluating the UHI adaptation potential of green roof- and wall-based scenarios in the Mediterranean climate. *Scientific Reports*, 14(1), 21675. <https://doi.org/10.1038/s41598-024-67567-9>
- Susca, T., Zanghirella, F., Colasuonno, L., & Del Fatto, V. (2022). Effect of green wall installation on urban heat island and building energy use: A climate-informed systematic literature review. *Renewable and Sustainable Energy Reviews*, 159, 112100. <https://doi.org/10.1016/j.rser.2022.112100>

- Tabibi, A. (2024, January 30). Environmental Benefits of Vertical Gardens. *Green.Org*.
<https://green.org/vertical-gardens/environmental-benefits-of-vertical-gardens/>
- Tayouga, S. J., & Gagné, S. A. (2016). The Socio-Ecological Factors that Influence the Adoption of Green Infrastructure. *Sustainability*, 8(12), 1277.
<https://doi.org/10.3390/su8121277>
- Traoré, M. B., Belmin, R., Ouedraogo, R., Fernandes, P., Sy, D. S., Founoune, H., Djigal, D., Ba, M., Samaké, O., Feder, F., Kane, A., & Vermeire, M.-L. (2026). From pesticides use to agroecology: Survey dataset on farming systems in the Lake Guiers area in Senegal. *Data in Brief*, 65, 112577. <https://doi.org/10.1016/j.dib.2026.112577>
- Visconti, D., Ventrino, V., Fagnano, M., Woo, S. L., Pepe, O., Adamo, P., Caporale, A. G., Carrino, L., & Fiorentino, N. (2023). Compost and microbial biostimulant applications improve plant growth and soil biological fertility of a grass-based phytostabilization system. *Environmental Geochemistry and Health*, 45(3), 787–807.
<https://doi.org/10.1007/s10653-022-01235-7>
- Vranayová, Z., Kocúrková, M., Káposztásová, D., & Kozlovská, M. (2025). Basic aspects of caring for green facades in the city of Košice. *Frontiers in Sustainability*, 6.
<https://doi.org/10.3389/frsus.2025.1704207>
- Wang, P., Wong, Y. H., Tan, C. Y., Li, S., & Chong, W. T. (2022). Vertical Greening Systems: Technological Benefits, Progresses and Prospects. *Sustainability*, 14(20), 12997.
<https://doi.org/10.3390/su142012997>
- Wang, W., Zhou, X., Wu, S., Zhao, M., Jin, Z., Bei, K., Zheng, X., & Fan, C. (2024). Vertical Green Wall Systems for Rainwater and Sewage Treatment. *Sustainability*, 16(17), 7593.
<https://doi.org/10.3390/su16177593>
- Zhang, X., Yang, Q., Al Mamun, A., Masukujjaman, M., & Masud, M. M. (2024). Acceptance of new agricultural technology among small rural farmers. *Humanities and Social Sciences Communications*, 11(1), 1641. <https://doi.org/10.1057/s41599-024-04163-2>
- Zhao, J., Rao, Q., Sun, C., Ikram, R. M. A., Fan, C., Li, J., Wang, M., & Zhang, D. (2024). A Systematic Review of the Vertical Green System for Balancing Ecology and Urbanity. *Water*, 16(11), 1472. <https://doi.org/10.3390/w16111472>
- Zhou, W., Arcot, Y., Medina, R. F., Bernal, J., Cisneros-Zevallos, L., & Akbulut, M. E. S. (2024). Integrated Pest Management: An Update on the Sustainability Approach to Crop Protection. *ACS Omega*, 9(40), 41130–41147.
<https://doi.org/10.1021/acsomega.4c06628>