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Functional Benefits of Shelter Belts for a Sustainable Built Environment in Northwest Nigeria: A Structural Equation Modelling Approach

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Abstract
Shelter belts, as linear plantings of trees and shrubs, are widely recognized for mitigating environmental degradation and supporting sustainable agricultural landscapes. This study evaluated the functional benefits of shelter belts in north-western Nigeria and ranked them according to stakeholder perceptions. A cross-sectional survey was conducted among 221 respondents across seven states, and data were screened for reliability and validity using Cronbach's alpha, Kaiser-Meyer-Olkin measure, and Bartlett's Test of Sphericity. Functional benefits were analyzed through standardised estimates and squared correlations (R^2), highlighting water conservation ($R^2 = 0.768$), biodiversity support ($R^2 = 0.749$), and erosion control ($R^2 = 0.683$) as the most significant. Wind reduction, aesthetic and recreational utility, and microclimate regulation followed in importance. The results indicate that shelter belts provide multifaceted benefits, including soil and water conservation, ecosystem services, and community well-being. These findings have practical implications for policymakers, farmers, urban planners, and environmental organizations in prioritizing shelter-belt interventions, integrating nature-based solutions into landscape planning, and promoting sustainable agricultural practices. The study also identifies gaps for further research, including longitudinal monitoring of ecological impacts and economic valuation of ecosystem services.

Keywords: Shelter belts, Functional benefits, Water conservation, Biodiversity, Erosion control, Environmental management

Introduction

Shelter belts—linear plantings of trees and shrubs designed to reduce wind speed and buffer landscapes against environmental degradation—have gained renewed attention in semi-arid and arid regions for their role in promoting sustainable land use and climate resilience. In north-western Nigeria, where strong winds, soil erosion, desertification, and declining soil moisture increasingly threaten agricultural productivity and rural livelihoods, the strategic use of shelter belts offers a promising natural infrastructure solution (Aili et al., 2025; Mume & Workalemahu, 2021). Despite global consensus on the potential benefits of shelter belts in similar ecological zones, empirical evidence from Nigeria remains limited, with most studies narrowly focused on technical planting strategies rather than comprehensive assessments of multi-functional benefits as perceived by local stakeholders. This lack of integrated data on functional benefits, community perceptions, and relative prioritisation of ecosystem services limits effective policy formulation and resource allocation for landscape management.

Recent research suggests that shelter belts can significantly improve soil moisture retention, reduce erosion, enhance biodiversity, and provide socio-economic benefits such as aesthetic value and recreational spaces (Guan et al., 2026; Isbell et al., 2017). However, studies often examine individual outcomes in isolation, and there is a need for holistic assessments that capture how local stakeholders rank different benefits and how these perceptions align with environmental priorities in transitional landscapes. In particular, there is a gap in understanding how functional benefits such as water conservation, biodiversity support, erosion control, wind reduction, aesthetics, and microclimate regulation compare in perceived importance within a single analytical framework.

The objectives of this study were to evaluate the preliminary reliability and validity of survey data, determine the functional benefits of shelter belts in north-western Nigeria, and establish the ranking of these benefits based on stakeholder perceptions. By addressing these objectives, the study generates context-specific insights that are valuable for policymakers, environmental planners, farmers, and community leaders. The results provide evidence to inform policy prioritisation of shelter-belt interventions, encourage adoption of nature-based solutions for soil and water conservation, and support ecosystem service valuation in regional landscape planning.

Materials and Methods

This study on shelter belts in north-western Nigeria was founded on relativist and realist ontological assumptions and a post-positivist epistemological orientation, which recognises that environmental planning problems involve both measurable physical realities and human perceptions. Post-positivism supports empirical measurement while accepting that knowledge is probabilistic and influenced by context, making it suitable for studies that combine environmental assessment with human judgement (Creswell & Poth, 2016; Maksimovic & Evtimov, 2023). Quantitative measurement using structured instruments is consistent with post-positivist research, in which hypotheses are tested using observable data and statistical analysis (Creswell & Poth, 2016). The study therefore adopted a mixed-method logical framework combining deductive and inductive reasoning, allowing theoretical assumptions about shelter belts to be tested while also interpreting respondents' experiences. Mixed-method approaches are recommended for complex environmental and planning studies because they integrate numerical data with subjective perceptions and improve validity through triangulation (Oranga et al., 2025; Mertens, 2012). Such integration enables a broader and deeper understanding of environmental management strategies than a single-method approach (Creswell & Poth, 2016).

A cross-sectional survey design was used because the research sought to obtain data from respondents across a wide geographical area at a single point in time. Survey methodology is appropriate when the aim is to make statistical inferences about a population using structured questionnaires (Bryman, 2016). Data were collected using a five-point ordinal Likert-scale questionnaire administered through Google Forms, where 1 represented strong disagreement, and 5 represented strong agreement. Likert-type scales are widely used to measure attitudes, perceptions, and environmental awareness because they yield ordinal data suitable for descriptive and inferential statistical analysis (Dalka et al., 2022). The online survey format ensured uniform data collection across multiple states and improved accessibility, both of which are recommended for geographically dispersed populations. The study population covered the seven states of north-western Nigeria — Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara — where wind erosion and desert encroachment make shelter belts an important environmental strategy. An area-stratified sampling approach was adopted to ensure representation from all states, and participation depended on respondents' availability to complete the online survey, yielding 221 valid responses. Stratified and convenience sampling are commonly used in large regional surveys to balance representativeness with practical constraints (Saunders et al., 2019).

Data were analysed using SPSS version 22 for coding, screening, and descriptive statistics, while AMOS version 24 was used for Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) to test relationships among variables influencing shelter-belt adoption and effectiveness. SEM is widely applied in social and environmental research because it allows simultaneous analysis of multiple latent variables and improves model validity (Aule et al., 2022a, 2022b; Elnagar et al., 2021; 2022). Results were presented using cross-tabulations, factor rankings, regression outputs, and SEM path diagrams to enhance interpretation of relationships among environmental perceptions, policy awareness, and landscape strategies. The philosophical assumptions, research logic, sampling structure, instruments, and analytical tools used in this study are summarised in Table 1.

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Table 1: Methodological foundation for examining the benefits of shelter-belts

S/N	Philosophy	Nominated Strategy
1	Oncology	The study primarily focused on relativism and realism, with research based on human perceptions, experiences, and values.
2	Epistemology	Post-Positivism: A quasi-quantitative study based on Likert scale measurements for informed policy formulation.
3	Logic	A mixed-method study based on deductive and inductive logic, combining objective quantities with human perceptions, experiences, and values.
4	Method	The study used an ordinal Likert scale (1 = strong disagreement, 5 = strong agreement) via Google Forms.
5	Data Collection Instruments	A trans-sectional Google Forms online survey, where data was collected across different levels of respondents' experiences at the same time.
6	Nature of Data	Ordinal Likert-scaled quantitative data, for descriptive and inferential statistical analysis.
7	Study Population	Covering all seven (7) states in the north-western geopolitical zone of Nigeria, namely Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara.
8	Study Sample	Area strata sample covering the seven (7) states in the north-western geopolitical zone of Nigeria, and 221 respondents for this study, based on respondents' online availability and convenience to participate in the survey.
9	Data Analysis Tools	The Statistical Package for the Social Sciences (SPSS 22) was used for preliminary data checks and descriptive analysis, while the Analysis of Moment Structures (AMOS 24) was used for regression analysis in CFA and SEM.
10	Graphical Output	Cross-tabulation factor rankings, regression analysis, CFA, and SEM path diagrams.

Results

The Introduction section outlines the study's focus on shelter belts in north-western Nigeria, emphasizing their environmental and socio-ecological significance. It highlights the research objectives, the rationale for examining functional benefits, and the methodological approach, including survey design and reliability checks. The section also situates the study within existing literature, establishing the importance of shelter belts for water conservation, biodiversity support, soil protection, and community well-being.

Preliminary screening of the survey data was conducted to ensure the reliability and validity of responses obtained from the 221 participants across the north-western states of Nigeria. The raw dataset was first examined in Microsoft Excel to identify redundant responses, particularly in questionnaires where respondents selected the same Likert-scale value for all items. Such responses are often regarded as non-discriminatory and may reduce the quality of statistical inference; their removal is recommended in survey-based behavioural and environmental studies (Hair et al., 2018). After initial cleaning, the dataset was exported to SPSS version 22 for further screening. Outliers were detected using graphical boxplot analysis through the Legacy Dialogs option with simple summaries of separate variables, a widely accepted procedure for identifying extreme values that may distort regression and factor analysis results (Field, 2024). Removing outliers improves normality, stabilises variance, and enhances the robustness of multivariate analysis, particularly when Structural Equation Modelling (SEM) and factor analysis are intended (Hair et al., 2018). After the screening process, all retained responses were subjected to reliability and sampling adequacy tests to confirm the suitability of the data for further statistical modelling.

Internal consistency reliability of the instrument was evaluated using Cronbach's alpha, one of the most commonly used indicators for assessing the stability and consistency of Likert-scale items in social and environmental research. The computed Cronbach's alpha value of 0.947 (0.949 based on standardised items) for the 35 questionnaire variables indicates excellent reliability, as values above 0.60 are considered acceptable, while values above 0.80 indicate high internal consistency (Taber, 2018; Hair et al., 2018). Sampling adequacy and suitability for factor analysis were tested

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using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO value of 0.786 exceeds the recommended threshold of 0.60, confirming that correlations among variables are sufficient for factor analysis. At the same time, Bartlett's Test produced a significant result ($\chi^2 = 6153.131$, df = 595, $p < 0.001$), indicating that the correlation matrix is not an identity matrix and that factor extraction is appropriate (Achoba et al. 2021a, 2021b; Kaiser, 1974; Shrestha, 2021). The total variance explained of 76.159 % further confirms strong construct validity, since values above 70 % are considered excellent in multivariate environmental and social science studies (Aule et al., 2022a; Hair et al., 2018). In addition, most communalities exceeded 0.50, indicating that the extracted factors adequately represent the observed variables. The detailed results of the reliability and validity tests are presented in Table 2.

Table 2: Preliminary reliability and validity checks confirming appropriateness of the dataset

(a) Reliability Statistics

Cronbach's alpha	Cronbach's Alpha Based on Standardised Items	N of Items
0.947	0.949	35

Recommended alpha value is >0.6

(b) KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.786
Bartlett's Test of Sphericity	Approx. Chi-Square	6153.131
	df	595
	Sig.	0.000

Recommended alpha KMO is >0.6 and significance is <0.005
Total variance explained is 76.159 (>70% Excellent value)
Communalities are beneficial, as most of the study variables have loading values greater than 0.5.

Functional Benefits of Shelter-Belts in North West Nigeria

The study's analysis of the functional benefits of shelter belts in north-western Nigeria revealed multiple environmental and socio-economic advantages, as measured through standardised estimates, squared correlations (R^2), and internal consistency (Cronbach's alpha) (Table 3). Wind reduction, represented by the variable FuncBen_Aesthetics, demonstrated a standardised estimate of 0.613 and R^2 of 0.613, with a Cronbach's alpha of 0.810, indicating strong reliability and confirming that shelter belts effectively protect crops, soil, and buildings from wind damage. Similarly, erosion control (FuncBen_WaterConserv) showed a standardised estimate of 0.683 and an R^2 of 0.683, highlighting that shelter belts mitigate soil loss and maintain soil productivity by reducing wind velocity. These findings align with global studies emphasizing that linear tree plantations act as effective windbreaks and soil stabilisers in semi-arid regions (Aili et al., 2025; Mume & Workalemahu, 2021).

Table 3: Standardized Regression Weights for Functional Benefits of Shelter-Belts

Factor Code	**Variable Name**	**Standardised Estimates**	**(R^2) Squared Correlation**	**Cronbach's Alpha**
FuncBen_Aesthetics	Wind Reduction: Shelter belts reduce wind speed, protecting crops, soil, and buildings from wind damage.	0.613	0.613	0.810
FuncBen_WaterConserv	Erosion Control: Shelter belts help prevent soil erosion and maintain soil health and productivity by reducing wind speed.	0.683	0.683	
FuncBen_Biodiversity	Microclimate Regulation: Shelter belts can create a more favorable microclimate by reducing wind chill, retaining soil moisture, and moderating temperature extremes.	0.452	0.452	

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FuncBen_Microclimate	Biodiversity Support: They provide habitat for wildlife, increasing biodiversity and supporting ecosystem services such as pollination and pest control.	0.749	0.749	
FuncBen_ErosionControl	Water Conservation: By reducing wind evaporation, shelter belts help conserve soil moisture, benefiting crops and natural vegetation.	0.768	0.768	
FuncBen_WindReduction	Aesthetic and Recreational Utility: Shelter belts can enhance the landscape's visual appeal and provide recreational spaces for communities.	0.612	0.612	
	Recommended value	Greater than 0.5	Greater than 0.25	Greater than 0.6

Microclimate regulation (FuncBen_Biodiversity) and biodiversity support (FuncBen_Microclimate) further demonstrated critical ecological functions. Microclimate regulation had a standardised estimate of 0.452 ($R^2 = 0.452$), suggesting moderate but significant capacity to retain soil moisture, reduce temperature extremes, and create favorable conditions for crops. Biodiversity support recorded a higher standardised estimate of 0.749 and R^2 of 0.749, confirming that shelter belts provide habitats for wildlife and ecosystem services, such as pollination and pest control. These results support prior research indicating that shelter belts enhance ecosystem resilience and provide crucial habitat corridors in degraded landscapes (Guan et al., 2026; Isbell et al., 2017).

Additional benefits include water conservation (FuncBen_ErosionControl) with a standardised estimate of 0.768 ($R^2 = 0.768$) and aesthetic/recreational utility (FuncBen_WindReduction) with an estimate of 0.612 ($R^2 = 0.612$), underscoring the contribution of shelter belts to both ecological sustainability and community well-being. Overall, all factor loadings exceeded the recommended thresholds for construct validity (>0.5) and reliability (>0.6), confirming the robustness of the measurement (Table 3). As briefed in Figure 1, shelter belts in north-western Nigeria provide multifaceted functional benefits, from environmental protection to biodiversity support and community utility.

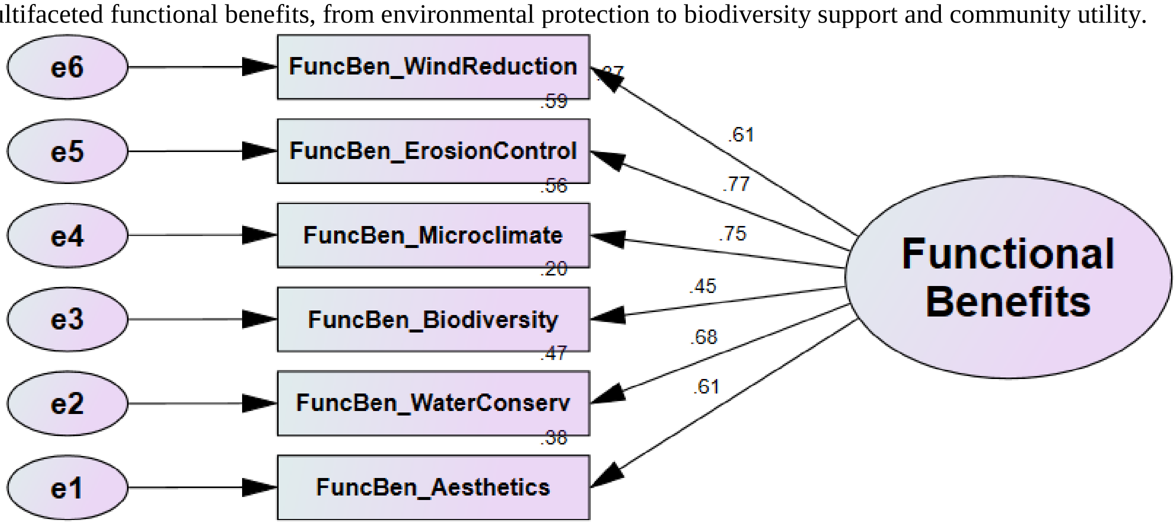

Figure 1: Shelter belts in north-western Nigeria providing multifaceted functional benefits

Ranking Functional Benefits of Shelter-Belts in North West Nigeria

The ranking of functional benefits of shelter belts in north-western Nigeria was determined using standardised estimates and squared correlations (R^2) derived from survey responses, providing insight into which environmental

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and socio-ecological functions are most strongly perceived by stakeholders (Table 4). Water conservation emerged as the highest-ranked benefit, with a standardised estimate of 0.768 and R^2 of 0.768, highlighting that reducing wind-driven soil moisture loss is the most valued function of shelter belts. This finding aligns with research in semi-arid regions, where conservation of soil moisture is critical for sustaining agricultural productivity and mitigating desertification (Aili et al., 2025; Aule et al., 2022b; Mume & Workalemahu, 2021). The high Cronbach's alpha of 0.810 for this variable confirms the reliability of responses and reinforces the consistency of stakeholder perceptions regarding water conservation benefits.

The second and third-ranked benefits were biodiversity support (R^2 = 0.749) and erosion control (R^2 = 0.683), respectively, indicating that respondents recognize shelter belts as vital for providing wildlife habitats, supporting ecosystem services, and preventing topsoil loss. These results are consistent with studies showing that well-planned linear vegetation structures enhance ecosystem resilience by creating microhabitats, improving pollination, and reducing soil degradation in fragile landscapes (Guan et al., 2026; Isbell et al., 2017). Following these, wind reduction (R^2 = 0.613) and aesthetic and recreational utility (R^2 = 0.612) were moderately ranked, reflecting both practical environmental and community-centered advantages, including crop protection and landscape enhancement. Microclimate regulation received the lowest ranking (R^2 = 0.452), suggesting that while respondents acknowledge its importance, it is perceived as less immediate or tangible than other direct benefits, such as water conservation and biodiversity support. This pattern is typical in stakeholder surveys where immediate, observable impacts tend to be valued more than indirect ecological functions (Aule et al., 2024; Hair et al., 2018).

In General, the ranking indicates that shelter belts in north-western Nigeria are primarily valued for water conservation, biodiversity support, and soil erosion control, with secondary importance assigned to wind mitigation, aesthetics, and microclimate regulation (Table 4). These findings provide practical guidance for policymakers and landscape planners in prioritizing shelter-belt interventions to maximize ecological and socio-economic benefits.

Table 4: Ranking the Functional Benefits of Shelter-Belts

Factor Code	**Variable Name**	**Standardised Estimates**	**(R^2) Squared Correlation**	**Cronbach's Alpha**
FuncBen_ErosionControl	Water Conservation: By reducing wind evaporation, shelter belts help conserve soil moisture, benefiting crops and natural vegetation.	0.768	0.768	0.810
FuncBen_Microclimate	Biodiversity Support: They provide habitat for wildlife, increasing biodiversity and supporting ecosystem services such as pollination and pest control.	0.749	0.749	
FuncBen_WaterConserv	Erosion Control: Shelter belts help prevent soil erosion and maintain soil health and productivity by reducing wind speed.	0.683	0.683	
FuncBen_Aesthetics	Wind Reduction: Shelter belts reduce wind speed, protecting crops, soil, and buildings from wind damage.	0.613	0.613	
FuncBen_WindReduction	Aesthetic and Recreational Utility: Shelter belts can enhance the landscape's visual appeal and provide recreational spaces for communities.	0.612	0.612	
FuncBen_Biodiversity	Microclimate Regulation: Shelter belts can create a more favorable microclimate by reducing wind chill, retaining soil moisture, and moderating temperature extremes.	0.452	0.452	

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Recommended value	Greater than 0.5	Greater than 0.25	Greater than 0.6

Discussion

This study investigated the functional benefits of shelter belts in north-western Nigeria, focusing on environmental protection, ecosystem services, and socio-economic contributions. The main results indicate that water conservation, biodiversity support, and erosion control are the most significant benefits perceived by stakeholders, followed by wind reduction, aesthetic and recreational utility, and microclimate regulation (Tables 3 and 4). Water conservation ranked highest ($R^2 = 0.768$), highlighting the role of shelter belts in reducing wind-driven soil moisture loss, which is critical in the semi-arid conditions of north-western Nigeria. Biodiversity support ($R^2 = 0.749$) and erosion control ($R^2 = 0.683$) were also highly rated, indicating the ecological importance of shelter belts in providing wildlife habitats, pollination services, and soil stabilization. The remaining benefits, including wind reduction ($R^2 = 0.613$), aesthetic/recreational utility ($R^2 = 0.612$), and microclimate regulation ($R^2 = 0.452$), were moderately valued, suggesting that while they are recognized, their immediate impacts are less tangible to stakeholders compared with direct ecological and agronomic benefits (Hair et al., 2018; Aili et al., 2025).

The results of this study are consistent with previous research in semi-arid and arid regions, which emphasises that linear vegetation structures effectively conserve soil moisture, reduce wind erosion, and enhance biodiversity (Guan et al., 2026; Isbell et al., 2017; Mume & Workalemahu, 2021). For instance, Aili et al. (2025) demonstrated that shelter belts significantly improve soil moisture retention and crop productivity in areas experiencing frequent wind erosion, while Isbell et al. (2017) highlighted their role in creating microhabitats and supporting ecosystem services. Similarly, the aesthetic and recreational benefits observed in this study align with those reported by Guan et al. (2026), who found that shelter belts enhance landscape visual appeal and provide community spaces, thereby linking ecological functionality to socio-cultural utility.

The practical significance of these findings is multifaceted. For policymakers, the high ranking of water conservation and biodiversity support underscores the need for prioritizing shelter-belt programs in environmental management and agricultural planning, especially in regions facing desertification and soil degradation. For farmers, the results demonstrate that investing in shelter belts can improve crop yields and protect farmlands from wind and soil erosion. Urban planners and landscape designers can leverage the aesthetic and microclimate benefits to create sustainable and resilient urban and peri-urban green spaces. Furthermore, environmental organizations and NGOs can use these insights to advocate for ecosystem restoration initiatives that integrate functional and socio-economic benefits.

Despite the robust findings, gaps remain for further exploration. The study primarily relied on online survey responses, which may underrepresent populations with limited internet access or differing perceptions. Additionally, while the study captured stakeholder perceptions, longitudinal field measurements of microclimate, soil moisture, and biodiversity indicators would complement survey data and provide a more comprehensive understanding of shelter-belt impacts over time. Finally, evaluating the economic valuation of ecosystem services associated with shelter belts could strengthen the evidence base for investment and policy prioritization.

In brief, the study confirms that shelter belts in north-western Nigeria provide critical environmental, ecological, and social benefits, particularly in water conservation, biodiversity support, and soil protection, while also offering secondary advantages in wind reduction, aesthetics, and microclimate regulation. These findings have practical relevance for multiple stakeholders and highlight areas for further research to optimize the design and implementation of shelter-belt interventions.

Conclusion

This study examined the functional benefits of shelter belts in north-western Nigeria, focusing on environmental, ecological, and socio-economic contributions. Survey data from 221 respondents across seven states were first screened and validated for reliability and sampling adequacy, with Cronbach's alpha (0.947) and KMO (0.786) confirming the robustness of the dataset. The study identified water conservation, biodiversity support, and erosion control as the most significant benefits of shelter belts, followed by wind reduction, aesthetic and recreational utility, and microclimate regulation. The ranking of these benefits reflects stakeholder perceptions of the immediate and

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tangible impacts of shelter belts on agricultural productivity, soil protection, and ecosystem services. These findings align with existing literature, confirming that shelter belts not only mitigate wind erosion and maintain soil moisture but also enhance biodiversity, support pollination, and provide recreational and aesthetic value (Aili et al., 2025; Guan et al., 2026; Isbell et al., 2017).

The results have practical significance for multiple stakeholders. Policymakers can use the findings to prioritize shelter-belt interventions that maximize environmental and socio-economic benefits. Farmers gain evidence-based guidance on the most effective benefits of shelter belts for crop protection and soil conservation. Urban planners and landscape designers can leverage the aesthetic and microclimatic advantages to create sustainable green spaces, while environmental organizations and NGOs can integrate these insights into ecosystem restoration programs. However, gaps remain, particularly in long-term field-based monitoring of microclimate and soil moisture impacts, and in the economic valuation of ecosystem services, which can further inform investment decisions and policy prioritization.

Recommendations

Based on the study insights, the following recommendations for policy and practice were put forward:

1. Government and environmental agencies should prioritize establishing shelter belts in regions most vulnerable to wind erosion and desertification to maximize water-conservation and soil-protection benefits.
2. Land-use planners and agricultural extension services should integrate shelter belts into farm layouts and community landscapes to simultaneously enhance biodiversity, crop yields, and recreational spaces.
3. Awareness programs should be implemented to educate farmers and local communities about the multifaceted benefits of shelter belts, promoting adoption and sustainable maintenance.
4. Longitudinal studies should be conducted to monitor microclimate, soil moisture, and biodiversity impacts over time, providing empirical data to refine shelter-belt designs and management strategies.
5. Future studies should assess the economic value of ecosystem services provided by shelter belts to guide investment, incentivize adoption, and support policy formulation in sustainable landscape management.

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