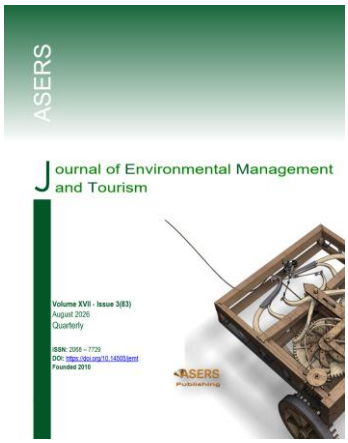
Plural Valuation of Nature in a Peri-Urban Mountain Trail: An Exploratory Analysis Using Principal Component and Cluster Analysis



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Abstract: This study examines how visitors to a peri-urban mountain trail organize the ecological, hydrological, recreational, cultural, and spiritual dimensions of nature valuation.

An exploratory quantitative design analyzed eight five-point ordinal items from 22 visitors to Bogotá's Kilómetro 11 trail, Colombia. Principal component analysis was used descriptively to examine associations among valuation dimensions, and k-means clustering was applied to the scores of the first two components to explore provisional respondent configurations. The analyses were not intended to validate the latent structure or establish population-level typologies.

All eight dimensions obtained mean scores above the scale midpoint. The first component revealed a shared association pattern across dimensions, while the second positioned cultural, spiritual, and hydrological meanings apart from biodiversity, recreation, landscape, and air quality, with ecological connectivity occupying an intermediate position between them. The selected three-cluster solution provided a provisional description of three overlapping respondent configurations.

This study advances plural valuation research by examining how multiple dimensions are jointly organized rather than treating them as isolated preferences. It connects the IPBES plural-value framework with a visitor-based multivariate analysis in a peri-urban mountain setting.

The small, non-probabilistic sample may affect the stability of the PCA loadings and cluster assignments. These findings should be interpreted as provisional patterns that require validation with larger, heterogeneous, and independent samples.

The results suggest that environmental interpretation and trail management should combine water-related meanings, biodiversity, landscape, cultural significance, and responsible recreation rather than assuming a homogeneous visitor profile.

Keywords: nature valuation; plural values of nature; relational values; peri-urban ecosystems; mountain trails; principal component analysis; cluster analysis; environmental perception; hydrological regulation; human-nature relationships

JEL Classification: C38; Q51; Q56; Q57; Z13.

Introduction

Peri-urban mountain ecosystems are socioecological spaces where ecological processes, urban dynamics, and diverse human-nature relationships converge. These environments are associated with hydrological regulation, biodiversity conservation, ecological connectivity, and landscape continuity, while also supporting cultural, recreational, and experiential values. However, environmental management in these contexts often relies on partial assessments centered on biophysical indicators, overlooking the plurality of ways in which nature is valued.

Recent studies have emphasized the need to incorporate multiple dimensions of nature valuation, including relational and cultural aspects, to better inform environmental decision-making. From this perspective, valuation is not limited to isolated preferences but involves configurations of meaning shaped by experience, perception, and interaction with specific territories.

This study examines how ecological, hydrological, recreational, cultural, and spiritual valuation dimensions are organized among visitors to the Kilómetro 11 trail in Bogotá, Colombia. It addresses the following research question: How are multiple dimensions of nature valuation associated and expressed through exploratory visitor configurations in a peri-urban mountain trail? To answer this question, principal component analysis and cluster analysis were used as complementary exploratory techniques. This study contributes to the literature by moving beyond the separate description of individual values and examining their joint multivariate organization in a visitor-based peri-urban setting. In doing so, it connects the plural-values framework with empirical evidence relevant to environmental management, environmental interpretation, and trail-based tourism.

1. Literature Review

Nature valuation has traditionally been approached from an instrumental perspective, emphasizing measurable ecosystem services, economic valuation, and biophysical indicators in environmental decision-making processes. While these approaches have provided useful analytical tools, they have also been criticized for overlooking the diversity of ways in which people relate to nature, assign meaning to ecosystems, and construct responsibilities toward the territories they inhabit or visit (Gómez-Baggethun and Ruiz-Pérez, 2011; Chan *et al.* 2016; Pascual *et al.* 2017).

In response, conceptual and policy-oriented frameworks have advanced the notion of the plural values of nature, particularly through the work of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2022). This perspective recognizes that nature is valued through multiple dimensions, including instrumental, intrinsic, and relational values, and highlights the importance of integrating this plurality into environmental governance and decision-making processes (Díaz *et al.* 2018; Pascual *et al.* 2023; Luque-Lora, 2024). Recent debates have emphasized that plural valuation requires careful attention to the frameworks used to classify, compare, and communicate values, as these frameworks can shape what becomes visible or invisible in environmental decisions and influence the values prioritized in environmental governance (Jacobs *et al.* 2016; IPBES, 2022; Vatn *et al.* 2024).

Relational values are particularly relevant because they explain how individuals and communities construct meanings, attachments, responsibilities, and forms of connection with ecosystems (Arias-Arévalo, Martín-López, and Gómez-Baggethun 2017; Muradian and Pascual 2018). These values broaden the scope of environmental assessment by situating valuation within social contexts, lived experiences, and human-nature relationships that cannot be fully captured through monetary or biophysical indicators (Himes and Muraca 2018; Grubert 2018; Pascual, Balvanera, and Christie 2023; Kleespies *et al.* 2025). This perspective is also connected to debates on shared and social values, which emphasize that valuation involves collective, deliberative, and place-based meanings rather than individual preferences (Raymond *et al.* 2010; Kenter *et al.* 2015; Kenter 2016).

Empirical research increasingly examines how plural values are expressed in specific socioecological contexts, showing that valuation processes are shaped by perceptions, experiences, interactions, and situated environmental meanings. Recent studies have shown the importance of recognizing and articulating plural values in water-related systems to make the different ways of relating to aquatic ecosystems and their contributions to social life visible (Ricart and Kirk 2022; Suarez *et al.* 2022). These perspectives are particularly relevant to peri-urban mountain ecosystems, where hydrological regulation, biodiversity, landscape, recreation, and cultural meanings are closely linked.

Urban and peri-urban ecosystems reveal this complexity with particular clarity and precision. Natural spaces in and around cities are associated not only with ecological processes but also with cultural, recreational, educational, spiritual, and symbolic significance. Studies on urban ecosystem assessment and green spaces have shown that urban nature is valued through multiple dimensions that exceed conventional biophysical and economic

metrics (Haase *et al.* 2014; Kabisch, Qureshi, and Haase 2015; Kondolf and Pinto 2017; Zambrano-Monserrate and Tarupi-Montenegro 2024). Urban ecology research has further shown that green and peri-urban spaces contribute to ecological functions, well-being, social interaction, and place-based experiences, reinforcing the need to examine valuation beyond single indicators (Andersson *et al.* 2014; Elmqvist *et al.* 2015; Madrigal-Martínez *et al.* 2025).

Although research on urban and peri-urban ecosystems has documented the coexistence of ecological functions, recreational experiences, and cultural meanings, these dimensions are frequently reported through separate indicators or descriptive summaries (Haase *et al.* 2014; Kabisch, Qureshi, and Haase 2015; Madrigal-Martínez *et al.* 2025). Less attention has been paid to how multiple dimensions of nature valuation are jointly associated and expressed through respondent-level configurations, particularly in visitor-based studies of peri-urban mountain trails. Multivariate techniques, such as principal component analysis and cluster analysis, can support an exploratory examination of these relationships by reducing dimensionality and describing provisional groupings within observed data (Everitt *et al.* 2011; Jolliffe and Cadima 2016; Hair *et al.* 2022).

This gap is particularly relevant for tourism and visitor management because trail use involves not only recreational demand but also ecological, hydrological, cultural, and relational meanings that may influence conservation, environmental interpretation, and management strategies of the area. This study addresses this gap by examining how eight nature valuation dimensions are jointly organized among visitors to the Kilómetro 11 trail in a peri-urban mountain ecosystem in Bogotá, Colombia.

The original contribution of the study lies in moving beyond the separate description of individual valuation dimensions to analyze their multivariate organization and expression in exploratory visitor configurations. By combining principal component analysis with cluster analysis, the study provides empirical evidence on how ecological, hydrological, recreational, cultural, and spiritual dimensions may coexist, overlap, and acquire different relative emphases within the same peri-urban setting. This approach complements existing research on the plural values of nature by connecting the IPBES conceptual framework with a visitor-based empirical analysis relevant to environmental management and trail-based tourism.

2. Materials and Methods

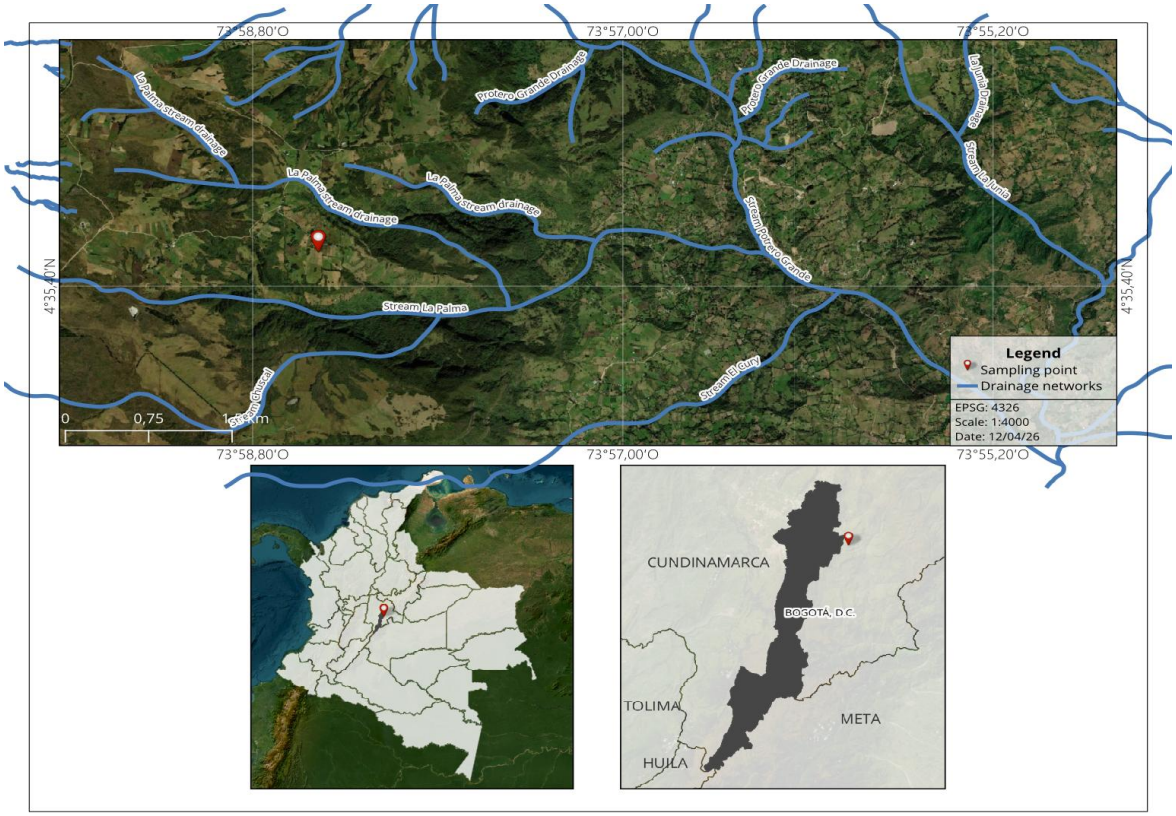
This study adopted an exploratory quantitative design to examine the organization of the dimensions of nature valuation among visitors to a single peri-urban mountain trail. The analytical approach focused on describing associations among the observed dimensions and exploring provisional respondent configurations rather than estimating population-level effects, testing causal relationships, or validating stable visitor typologies.

This study was conducted on the Kilómetro 11 trail located in the eastern hills of Bogotá, Colombia. This peri-urban ecosystem is associated with hydrological regulation, vegetation cover, landscape connectivity, and recreational and cultural experiences, making it suitable for analyzing plural valuation processes in socio-ecological contexts. Figure 1 shows the location of the study area in Bogotá and its broader territory.

Fieldwork was conducted from June to November 2025, using a non-probabilistic convenience sampling strategy. Adult visitors were approached after completing the Kilómetro 11 trail, and those who voluntarily agreed to participate completed the questionnaire individually, following a consistent administration protocol. A total of 22 visitors completed the questionnaire and constituted the final analytical sample. Because recruitment followed a non-probabilistic convenience strategy, the sample should not be considered representative of the wider population of trail visitors. The analyses were used exclusively to identify preliminary associations and exploratory valuation patterns and do not support statistical generalization, prevalence estimates, or stable population-level conclusions. Primary field data were collected directly from adult visitors using a consistent survey protocol, providing an appropriate basis for the exploratory analysis of valuation patterns within the observed sample.

Data were collected using a structured questionnaire designed to capture the perceived importance of multiple contributions of nature. The instrument included eight five-point ordinal items assessing biodiversity, hydrological regulation, air quality, landscape, ecological connectivity, recreation, cultural values, and spiritual values. Additional variables were collected to characterize the respondents, including age, gender, frequency of visit, transport mode, and visitor interests. Responses to the multiple-response visitor-interest item were grouped into three analytical domains. Environmental education and research were classified under Education; hiking, nature observation, and photography were classified under Nature; and recreation and sports were classified under Recreation. Each participant was assigned to the domain containing the largest number of selected options, which was used as the participant's dominant analytical interest category. No ties between analytical interest domains were observed in the dataset.

Figure 1. Location of the Kilómetro 11 Trail within the Eastern Hills peri-urban socioecological system of Bogotá, Colombia



Source: Authors' elaboration based on fieldwork records and spatial data from the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM), Colombia.
Note: The map shows the spatial distribution of the sampling area and drainage network within the urban–peri-urban interface of Bogotá.

Responses were coded on a five-point ordinal scale: 1 = Not at all important, 2 = Slightly important, 3 = Moderately important, 4 = Important, and 5 = Very important. Higher scores represent greater perceived importance. The English translation of the complete questionnaire is provided in Supplementary File S1. Although the instrument allowed responses across the full scale, the observed responses in this exploratory sample were concentrated between categories two and five.

Data processing and analysis were conducted using Python 3.12.3 and Google Colab as the computational environment. The main libraries used were pandas and NumPy for data management and numerical processing, scikit-learn for principal component analysis and k-means clustering, factor_analyzer for the Kaiser-Meyer-Olkin measure and Bartlett's test of sphericity, Matplotlib for data visualization, adjustText for improving label readability in figures, and openpyxl for exporting the analytical outputs. Prior to analysis, the dataset was cleaned and pre-processed, including the identification of missing values, recoding of categorical variables, and standardization of numerical variables to ensure comparability across dimensions. No missing values were identified in the eight nature valuation variables; therefore, imputation or case deletion was not required. The valuation variables were standardized prior to PCA to avoid differences in scale affecting component extraction. Because the valuation dimensions were measured using five-point ordinal items, they were treated as approximately continuous solely for the purpose of exploratory dimensional reduction after standardization. This analytical decision was intended to summarize patterns of association among the eight dimensions and should not be interpreted as assuming exact interval-level measurement or as validating a latent construct. PCA was therefore used as a descriptive exploratory technique rather than as a confirmatory factor-analytical procedure (Jolliffe and Cadima 2016; Hair *et al.* 2022). Subsequently, cluster analysis was performed using the scores of the first two principal components.

Given the small sample size, the analytical sequence was designed as a descriptive and exploratory procedure rather than a confirmatory multivariate model. PCA was used to summarize the shared variation among the eight valuation dimensions within a reduced component space, thereby limiting redundancy before clustering. Subsequently, K-means clustering was applied to the scores of the first two principal components to explore

provisional respondent configurations in that reduced space. This two-stage strategy was selected to support pattern identification in a small dataset, without interpreting the resulting components or clusters as stable population structures

To examine patterns of association among the valuation dimensions, principal component analysis (PCA) was performed. PCA is a multivariate technique that reduces dimensionality by transforming correlated variables into a smaller set of orthogonal components. The suitability of the correlation structure for exploratory PCA was examined using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The global KMO value was 0.701, suggesting adequate preliminary sampling adequacy, and Bartlett's test was statistically significant ($\chi^2 = 87.27$, $p < 0.001$), indicating that the correlation matrix differed from an identity matrix. These diagnostics supported the exploratory examination of associations among the valuation dimensions; however, they did not compensate for the limited ratio of 22 participants to eight variables or demonstrate a validated and stable component structure. Accordingly, the loadings were interpreted as provisional association patterns within the observed sample rather than as evidence of a confirmed latent structure.

The KMO measure and Bartlett's test were used as preliminary diagnostics of the correlation structure and should not be interpreted as eliminating the limitations associated with the sample size. Although these diagnostics supported exploratory PCA, the ratio of participants to variables remained limited. Accordingly, the component loadings were used to describe provisional association patterns within the observed sample and not to establish a validated factor structure.

Component retention was guided by cumulative explained variance, parsimony, and substantive interpretability, consistent with the exploratory purpose of the analysis (Jolliffe and Cadima 2016; Hair *et al.* 2022). The first two components were retained because they jointly explained 66.8% of the total observed variance and provided an interpretable two-dimensional representation of the relationships among the eight valuation dimensions. Variable loadings were examined to describe the relative contribution and position of each dimension within the reduced space. Given the small sample size, the retention of two components was treated as a descriptive analytical decision and not as confirmation of a definitive latent structure. Therefore, the resulting component solution should be assessed for stability in future studies using larger independent samples.

Subsequently, cluster analysis was conducted using the component scores derived from the PCA. The k-means clustering algorithm was applied to identify groups of respondents with similar valuation configurations. Considering the small sample size, the clustering results were interpreted as exploratory respondent groupings based on the similarity of their component scores rather than as stable visitor typologies. The number of clusters was set to $k = 3$ as an exploratory analytical decision based on the interpretability of the resulting configurations and their distribution in the space defined by the first two principal components. The selection was not based on a confirmatory classification procedure and was not treated as evidence that three clusters constituted an optimal, unique, or statistically stable solution. Given the limited number of observations, the purpose was to obtain a parsimonious descriptive representation that could support the interpretation of relative differences among respondents. Alternative cluster solutions and the reproducibility of the three-cluster configuration should be assessed in future studies using larger independent samples. No inferential comparisons among the clusters were performed because of the small, non-probabilistic sample. Therefore, the cluster-related results are reported as descriptive exploratory patterns.

K-means was selected because the retained PCA scores provided continuous coordinates suitable for exploratory partitioning according to within-group similarities (Everitt *et al.* 2011). Its use was intended to generate an interpretable descriptive segmentation of the observed respondents rather than to estimate latent classes or establish a definitive classification. Given the sample size, no claims were made regarding the optimality, reproducibility, or out-of-sample stability of the three-cluster solutions. Therefore, the resulting configurations should be understood as provisional analytical patterns that require validation using larger and more heterogeneous independent sample sizes.

The multivariate results were examined through numerical outputs and graphical representations, including a PCA loading plot and a radar chart. These outputs were used to describe the relationships among valuation dimensions and configuration-specific tendencies. Ethical considerations were addressed by ensuring voluntary participation, prior informed consent, and anonymity of respondents. No names, identification numbers, email addresses, or other direct personal identifiers were collected. Potentially identifying contextual variables were analyzed and reported only in aggregate form. The study did not involve any intervention in the ecosystem.

3. Research Results

The results are presented in four sections. First, the general characteristics of the sample and the overall valuation scores are described. Second, the structure of the valuation dimensions was examined using principal component analysis (PCA). Third, the exploratory configurations identified through cluster analysis are presented. Finally, the age group and interest distributions were described as indicative tendencies across configurations.

The sample included 22 participants in total. Women represented 59.1% of the respondents, and men represented 40.9%. Public transport was the most common means of accessing the trail (59.1%), followed by private vehicles (27.3%) and other types of motorized transport (13.6%). Most respondents reported visiting the trail for the first time (81.8%), while 13.6% described their visits as occasional, and 4.5% reported visiting the trail weekly. These results show variations in gender and transport mode, while the sample was concentrated among first-time visitors and public transport users. Table 1 summarizes the general characteristics of the visitors.

Table 1. General characteristics of visitors (n = 22)

Variable	Category	n	Percentage (%)
Gender	Women	13	59.1
	Men	9	40.9
Transport mode	Public transport	13	59.1
	Private vehicle	6	27.3
	Motorized transport	3	13.6
Visit frequency	First visit	18	81.8
	Occasional	3	13.6
	Weekly	1	4.5

Source: Authors' elaboration based on survey data.

At the aggregate level, the mean score for each valuation dimension was above the midpoint on the five-point scale. Hydrological regulation showed the highest mean value (4.727), followed by biodiversity (4.500), and air quality (4.455). Cultural values (4.318) and recreation (4.136) also had relatively high scores. Landscape (3.818), ecological connectivity (3.682), and spiritual values (3.500) showed comparatively lower values, although they were still above the midpoint. The pattern of the mean scores suggests that importance was distributed across multiple valuation dimensions rather than being concentrated in a single contribution of nature. Table 2 presents the overall mean valuation scores by dimensions.

Table 2. Overall mean valuation scores by dimension

Dimension	Mean score
Hydrological regulation	4.727
Biodiversity	4.500
Air quality	4.455
Cultural values	4.318
Recreation	4.136
Landscape	3.818
Ecological connectivity	3.682
Spiritual values	3.500

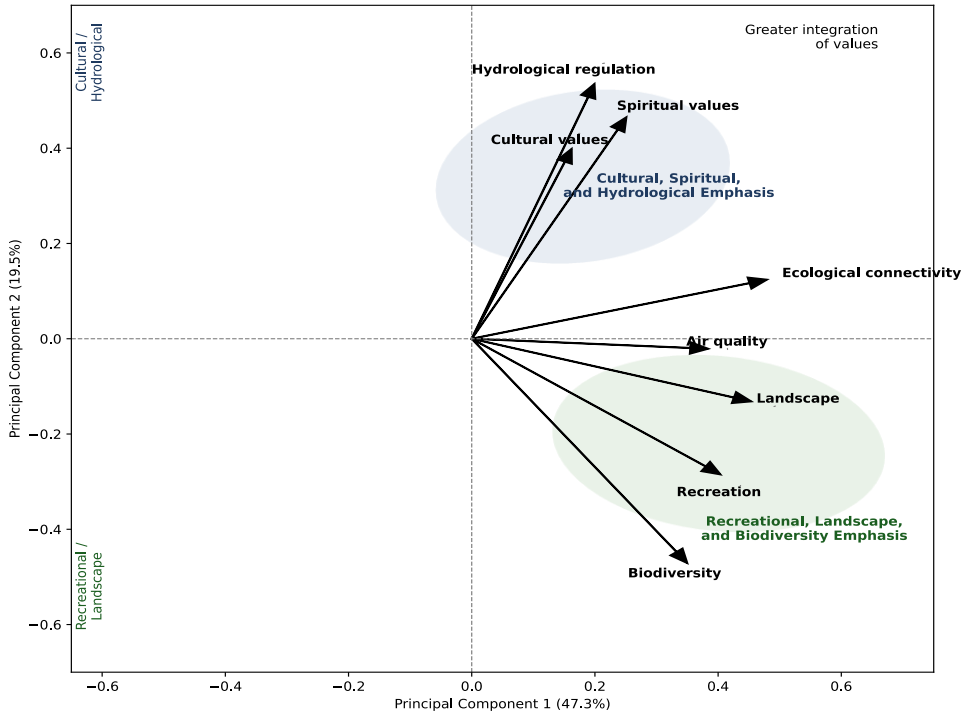
Source: Authors' elaboration based on survey data.

The first two principal components were retained for descriptive interpretation and jointly explained 66.8% of the total variance in the data. PC1 explained 47.3% of the variance, and PC2 explained 19.5%. All eight valuation dimensions loaded in the same general direction on PC1, indicating a shared pattern of association within the sample, rather than independent or opposing valuation domains.

PC2 differentiated the relative positions of the valuation dimensions. Cultural values, spiritual values, and hydrological regulation were located toward one side of the component, whereas biodiversity, recreation, landscape, and air quality were located toward the other. Ecological connectivity occupied an intermediate position.

Because the orientation of component axes is arbitrary, these positions do not represent positive and negative value judgments or statistically distinct categories. They describe relative association patterns within the observed sample and should be interpreted as provisional. Figure 2 illustrates the distribution of the valuation dimensions across the first two principal components of PCA.

Figure 2. Loading plot of nature valuation dimensions on the first two principal components



Source: Authors' elaboration based on survey data.
Note: Arrows represent the variable loadings on the first two principal components. The direction of the component axes is arbitrary; therefore, interpretation focuses on the relative position and association of the variables rather than the positive or negative sign itself. The shaded areas represent interpretative groupings derived from the loading pattern and should not be interpreted as statistically distinct factors.

To examine how these dimensions were articulated at the respondent level, cluster analysis was conducted using PCA scores. The selected three-cluster solution yielded three exploratory Configurations A, B, and C. These configurations represent provisional and partially overlapping patterns of how respondents combine valuation dimensions. Table 3 summarizes the size, mean age, and predominant interest profile of each exploratory configuration.

Table 3. Cluster size and selected visitor characteristics by configuration

Configuration	n	Mean age	Predominant interest profile
A	5	34.8	Nature-based activities
B	8	42.2	Mixed (education and recreation)
C	9	37.0	Environmental education

Source: Authors' elaboration based on survey data.

Configuration A included five respondents and showed comparatively higher scores for biodiversity (4.800) and recreation (4.400), while presenting lower scores for spiritual values (2.800) and ecological connectivity (2.800). Configuration B included eight respondents and showed higher scores for hydrological regulation (4.875) and cultural values (4.500), with comparatively lower scores for landscape (3.000), recreation (3.500), and ecological connectivity (3.125). Configuration C included nine respondents and displayed consistently high scores across most dimensions, particularly biodiversity (5.000), hydrological regulation (5.000), air quality (4.889), landscape (4.778), and ecological connectivity (4.667). These results show that Configuration C had higher mean scores across most valuation dimensions. Table 4 presents the mean valuation scores for each of the configurations.

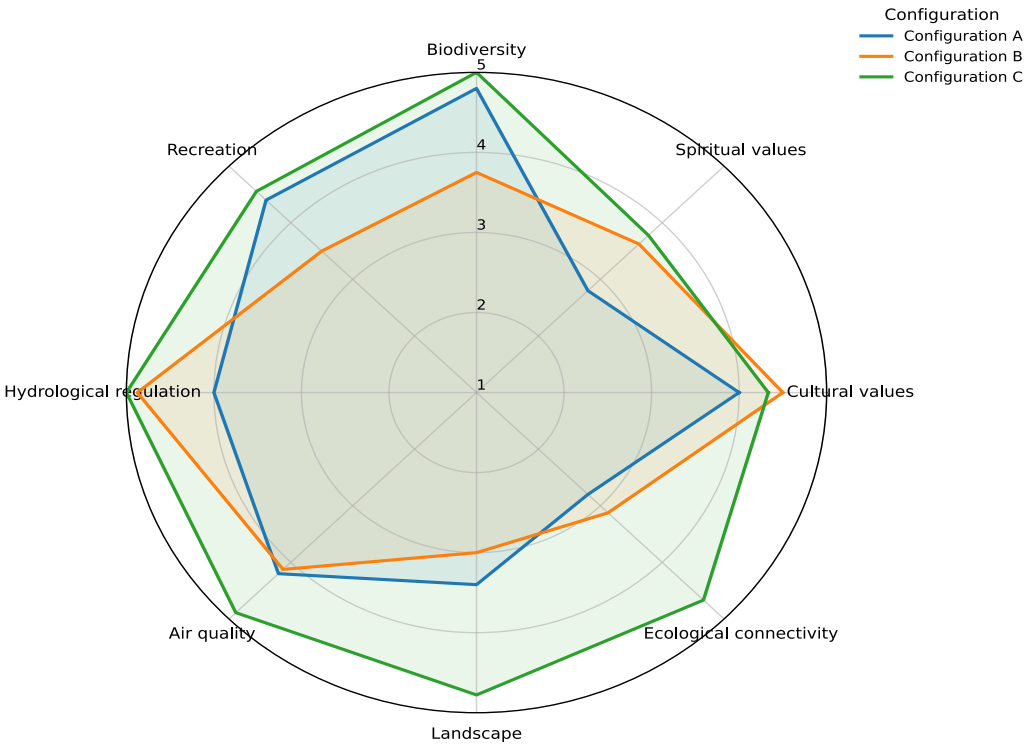
Table 4. Mean valuation scores by cluster configuration

Dimension	Configuration A	Configuration B	Configuration C
Cultural values	4.000	4.500	4.333
Spiritual values	2.800	3.625	3.778
Biodiversity	4.800	3.750	5.000
Recreation	4.400	3.500	4.556
Hydrological regulation	4.000	4.875	5.000
Air quality	4.200	4.125	4.889
Landscape	3.400	3.000	4.778
Ecological connectivity	2.800	3.125	4.667

Source: Authors' elaboration based on cluster averages.

These configurations describe the tendencies in the relative emphasis placed on the valuation dimensions rather than fixed, mutually exclusive, or population-level visitor groups. Configuration A showed comparatively greater emphasis on biodiversity and recreation, while Configuration B showed greater relative emphasis on hydrological regulation and cultural values. Configuration C obtained higher mean scores across most dimensions, representing a broader pattern of valuation within the observed sample. However, this configuration may also partly reflect a general tendency toward higher response intensity rather than a substantively distinct valuation type. Accordingly, no definitive labels or inferential distinctions were assigned to the configurations. Their partial correspondence with the differentiation observed in the second principal component is interpreted only as an exploratory pattern requiring validation with larger samples. Figure 3 visually summarizes the differences between the configurations.

Figure 3. Mean valuation profiles of the exploratory configurations



Source: Authors' elaboration based on cluster analysis.
Note: Values correspond to the mean scores of respondents assigned to each exploratory configuration on a five-point ordinal scale. The radar chart is provided only to facilitate a descriptive comparison of the relative valuation profiles observed in the sample. The configurations are not statistically validated visitor types, and differences among them should not be interpreted as being inferentially significant.

Additional cross-tabulations suggested descriptive differences in the distribution of age groups and visitor interests across configurations. Configuration A was concentrated in the 30-39 age group (80.0%), while Configuration B showed a higher proportion of respondents aged 40-49 (50.0%). Configuration C presented a more even distribution across age groups. Regarding the recoded dominant analytical interest category, Configuration A was mainly associated with Nature (60.0%), Configuration B showed the same proportion of Education and Recreation profiles (37.5% each), and Configuration C showed a higher concentration of Education profiles (66.7%). These patterns are presented as descriptive tendencies given the exploratory design and sample size. Table 5 presents the distribution of age groups and dominant interests by configuration. These cross-tabulations are reported only as descriptive tendencies and should not be interpreted as evidence of statistically significant differences among configurations. No inferential tests were applied to the differences in mean valuation scores, age distributions, or analytical interest categories across the three configurations. Given the small number of respondents within each configuration, such tests would not provide a reliable basis for population-level comparison. Accordingly, the reported percentages and cluster-specific means are presented exclusively to describe the internal composition of the exploratory solution.

Table 5. Age group and dominant interest distribution by configuration (%)

Variable	Category	Configuration A	Configuration A	Configuration A
Age group	18-29	0.0	12.5	33.3
	30-39	80.0	25.0	22.2
	40-49	20.0	50.0	22.2
	50 or more	0.0	12.5	22.2
Dominant interest	Education	20.0	37.5	66.7
	Nature	60.0	25.0	33.3
	Recreational	20.0	37.5	0.0

Source: Authors' elaboration based on cross-tabulations.

Overall, the descriptive results revealed a shared pattern of association across the eight valuation dimensions, together with differences in their relative emphasis among respondents. The PCA summarized these associations through two components, while the selected three-cluster solution provided a provisional description of respondent-level valuation profiles. The cluster-specific means and cross-tabulations were not subjected to inferential testing and should not be interpreted as evidence of statistically distinct visitor populations. Accordingly, the results describe patterns observed within the analytical sample and provide the empirical basis for the theoretical and practical interpretation developed in the Discussion.

4. Discussion

The results provide exploratory evidence that nature valuation on a peri-urban mountain trail involves both a shared multidimensional structure and differentiated relative emphases among visitors. Although all eight dimensions obtained mean scores above the midpoint of the scale, the principal contribution does not lie only in their individual levels of importance. Rather, the PCA and cluster results show how ecological, hydrological, recreational, cultural, and spiritual meanings were associated and combined within the observed sample. This distinction is important because plural valuation involves not merely recognizing the presence of multiple values but also examining how those values coexist, relate to one another, and acquire different prominence in specific socioecological contexts. Therefore, the findings are consistent with approaches that reject the reduction of nature valuation to instrumental or economic dimensions and instead emphasize relational, cultural, shared, and context-dependent meanings (Chan *et al.* 2016; IPBES 2022; Pascual *et al.* 2017; Pascual *et al.* 2023; Vatn *et al.* 2024).

All valuation variables loaded in the same direction on the first principal component, indicating a shared pattern of association across dimensions. This empirical pattern complements the IPBES plural-values framework by showing that, within the study sample, ecological, hydrological, recreational, cultural, and spiritual meanings were not expressed as isolated domains but as interconnected elements of the valuation of the trail. Whereas conventional assessments frequently examine individual ecosystem contributions or visitor preferences separately, the results suggest that multiple meanings can be simultaneously embedded in visitors' relationships with a peri-urban socioecological setting. Therefore, the contribution of this finding lies not in identifying a single dominant value, but in making visible the coexistence and mutual association of several valuation dimensions within the same multivariate structure.

The differentiation observed along PC2 adds a second analytical layer to this shared valuation pattern. Cultural values, spiritual values, and hydrological regulation were positioned on one side of the component,

whereas biodiversity, recreation, landscape, and air quality were positioned on the other. Because the orientation of the PCA axes is arbitrary, this distribution should not be interpreted as an opposition, hierarchy, or separation into statistically distinct value categories. Rather, it describes the differences in the relative association of the dimensions within the observed sample. One possible interpretation is that cultural, spiritual, and hydrological meanings were more closely connected to place-based, symbolic, and relational experiences, whereas biodiversity, recreation, landscape, and air quality were more closely associated with the directly perceived ecological and experiential attributes of the visit. This pattern complements relational-value approaches by showing that ecological processes and socially constructed meanings may coexist within the same valuation structure while acquiring different relative emphases (Arias-Arévalo *et al.* 2017; Himes and Muraca, 2018; Muradian and Pascual, 2018).

The intermediate position of ecological connectivity on PC2 also deserves attention. Unlike the other dimensions, it was not located clearly toward either of the two relative orientations observed in the component. This position may reflect its cross-cutting character in a peri-urban mountain setting, where connectivity refers both to ecological continuity among habitats and to the spatial relationships through which visitors experience the connection between the city, the mountain landscape, and broader ecological processes. Rather than constituting an isolated value, ecological connectivity may therefore operate as a bridging dimension linking biodiversity, landscape, hydrological processes, and place-based experience. This interpretation complements research showing that urban and peri-urban ecosystems depend on relationships among ecological functions, spatial continuity, and human experience (Andersson *et al.* 2014; Haase *et al.* 2014; Elmqvist *et al.* 2015). From a practical perspective, this suggests that environmental interpretation should make these often less visible territorial connections understandable to visitors, while recognizing that this interpretation remains provisional within the present sample.

The comparatively high mean assigned to hydrological regulation provides additional insight into the differences among the valuation dimensions. Within the observed sample, water-related processes received the highest average importance score, exceeding the means recorded for biodiversity, air quality, recreation, landscape, ecological connectivity and spiritual values. This result may reflect the visibility and perceived relevance of water in mountain ecosystems connected to Bogotá's urban–peri-urban interface. However, its position alongside cultural and spiritual values on PC2 suggests that hydrological regulation was not necessarily understood as a biophysical function. Water-related valuation may also incorporate place-based meanings, everyday dependencies, symbolic associations, and broader relationships between visitors and mountain territories. This interpretation is consistent with studies emphasizing that water valuation involves ecological, social, cultural, and relational dimensions that cannot be reduced to a single functional category (Ricart and Kirk, 2022; Suarez *et al.* 2022; IPBES, 2022). Although the small sample size does not allow for conclusions about the wider visitor population, the results highlight the analytical importance of examining how highly valued ecological processes may also carry cultural and relational significance.

The comparatively lower means recorded for spiritual values, ecological connectivity, and landscape should not be interpreted as evidence that these dimensions are unimportant or irrelevant. All three remained above the midpoint of the response scale, indicating that they were part of the valuation process in the sample. Their lower relative position may reflect differences in visibility, immediacy, or ease of recognition during a trail visit. Landscapes can be directly experienced, whereas ecological connectivity involves spatial and ecological relationships that may not be immediately perceptible without prior knowledge or environmental interpretation. Spiritual values may also depend more strongly on personal experience, cultural background, attachment to place, or the circumstances of a visit. These differences support the argument that valuation scores are shaped not only by the characteristics of the ecosystem but also by the ways in which visitors encounter, understand, and relate to these characteristics (Chan *et al.* 2016; Himes and Muraca, 2018; Kenter, 2016; IPBES, 2022). From a management perspective, lower relative scores may identify dimensions that require more explicit interpretation rather than those that require less attention.

It is important to distinguish the mean level of importance assigned to each dimension from its position in the multivariate structure. A comparatively high mean indicates that a dimension was rated as important by the respondents, whereas its PCA loading describes how it varied in relation to other dimensions within the observed sample. Consequently, hydrological regulation having the highest mean does not imply that it independently determines the component structure, just as the comparatively lower means of spiritual values or ecological connectivity do not imply that these dimensions are analytically irrelevant. Therefore, PCA and cluster analyses complement, rather than replace, the descriptive mean scores by showing how dimensions with different levels of importance are associated and combined across respondents (Jolliffe and Cadima 2016; Hair *et al.* 2022).

The selected three-cluster solution adds a respondent-level layer to the interpretation of the valuation structure of the data. Configuration A placed greater relative emphasis on biodiversity and recreation, suggesting a valuation pattern more closely associated with directly perceived ecological attributes and experiential trail use. Configuration B combined stronger hydrological and cultural valuation, reinforcing the possibility that water-related meanings are connected not only to ecological regulation but also to place-based and socially constructed significance. Configuration C displayed consistently high scores across most dimensions and may represent a broader or more integrated valuation pattern than the other configurations. However, because of the small sample size, this configuration may also partly reflect a general tendency toward higher response intensity, and the analysis cannot conclusively distinguish between these interpretations. Therefore, configurations should not be treated as discrete visitor typologies. Their analytical contribution lies in showing that plural valuation may be expressed through different combinations of relative emphasis rather than through mutually exclusive categories of value. This respondent-level differentiation complements studies of urban and peri-urban nature by illustrating how ecological functions, recreational experiences, and cultural meanings can coexist while acquiring different levels of prominence among visitors (Kabisch, Qureshi, and Haase 2015; Kenter 2016; IPBES 2022; Madrigal-Martínez *et al.* 2025).

The observed differences among valuation dimensions have practical implications for environmental management and trail-based tourism. A management approach centered exclusively on recreational use or biophysical monitoring may overlook the cultural, hydrological, spiritual, and relational meanings through which visitors interpret the trail. The strong valuation of hydrological regulation suggests that water-related processes could be incorporated more explicitly into environmental interpretation, visitor communication, and educational activities, not only as ecological functions but also as elements connected to place-based meanings. Similarly, the relevance of biodiversity, landscape, and ecological connectivity supports the inclusion of messages and management actions that make the trail's role within the broader peri-urban socioecological system visible.

The exploratory configurations also suggest that visitor engagement should not assume a homogeneous recreational profile. Interpretive materials, guided activities, and communication strategies could combine different entry points, including biodiversity observation, water-related narratives, landscape experience, cultural meanings, and responsible recreation. Such diversification may help environmental managers address overlapping valuation orientations while avoiding the reduction of the trail to a single function. These implications should be understood as context-specific inputs rather than prescriptive recommendations, given the limited sample and provisional character of the configurations.

This study extends previous research on urban and peri-urban ecosystems in two ways. First, existing studies have established that green and mountain spaces near cities support ecological functions, recreation, well-being, social interaction, and place-based experiences (Haase *et al.* 2014; Kabisch, Qureshi, and Haase 2015; Elmqvist *et al.* 2015; Madrigal-Martínez *et al.* 2025). The present study complements this literature by showing that these dimensions were not only simultaneously valued but were also associated with the multivariate structure observed in the sample. Second, whereas much of the existing literature identifies the presence or relative importance of individual benefits and cultural meanings, the exploratory configurations identified here illustrate how visitors may combine these meanings with different relative emphases. In this respect, the Kilómetro 11 trail can be understood not merely as an urban green space or recreational destination, but as a peri-urban socioecological setting in which water-related meanings, biodiversity, landscape, recreation, and cultural experience become interconnected within visitor valuation.

From a methodological perspective, the study illustrates the sequential exploratory use of PCA and cluster analysis to examine plural valuation in a small visitor-based sample. PCA reduced the eight interrelated valuation dimensions to two components that summarized 66.8% of the observed variance, while clustering the resulting component scores provided a descriptive representation of how respondents combined those dimensions. This sequence was analytically useful because it reduced redundancy among the original variables before exploring respondent-level configurations. However, its contribution should be understood as a methodological illustration rather than statistical validation. With only 22 observations, the estimated loadings, component scores, and cluster memberships may change substantially with the inclusion of additional participants. Therefore, the procedure offers a preliminary method of organizing plural valuation data, but it does not establish a reproducible dimensional structure or a definitive segmentation of trail visitors.

However, the statistical results require cautious interpretation. The sample was small and non-probabilistic, and the ratio between the 22 respondents and the eight valuation variables limited the stability of the correlation matrix, component loadings, and individual component scores. Although the KMO measure and Bartlett's test

supported an exploratory application of PCA, these diagnostics did not compensate for the limited number of observations or validate the resulting component structure. Additionally, the use of five-point ordinal items and the concentration of responses in the upper categories may have reduced variability and influenced the observed associations. The cluster solution is subject to further uncertainty because cluster membership can be sensitive to the composition of a small dataset and changes in the component scores used as inputs (Everitt *et al.* 2011; Jolliffe and Cadima 2016; Hair *et al.* 2022). Consequently, the three configurations should not be interpreted as stable population segments, and no inferences should be made regarding their prevalence among all trail visitors. Validation will require larger and more heterogeneous samples, replication across different periods of visitation, assessment of alternative cluster solutions, and comparisons with other peri-urban mountain trails. Therefore, the present results should be regarded as provisional analytical patterns intended to inform subsequent research rather than confirmed statistical structures.

Overall, this study makes three complementary contributions to the literature on plural valuation in peri-urban ecosystems. Empirically, it shows that visitors' valuations of the Kilómetro 11 trail were organized through interconnected ecological, hydrological, recreational, cultural, and spiritual dimensions rather than through a single dominant preference. Theoretically, it supports an understanding of plural valuation as a configuration of overlapping meanings whose relative emphasis may vary among visitors, complementing approaches that examine values as separate categories (Chan *et al.* 2016; IPBES 2022; Pascual *et al.* 2023; Vatn *et al.* 2024). Practically, it indicates that environmental interpretation and trail management may benefit from recognizing multiple ways of relating to the same peri-urban socioecological setting. These contributions remain exploratory and context-specific, but they provide a clearer basis for subsequent research on how plural values of nature are organized and expressed in visitor-based studies.

Conclusions and Further Research

This study examined how multiple dimensions of nature valuation were organized among visitors to the Kilómetro 11 trail. The findings answer the research question by indicating that these dimensions were structured through a shared pattern of association, while retaining different relative emphases among respondents. Therefore, hydrological regulation, biodiversity, air quality, cultural values, recreation, landscape, ecological connectivity, and spiritual values were not expressed as isolated preferences or as a single dominant hierarchy, but as overlapping elements of a plural valuation process. Given the exploratory design, this conclusion applies to the observed sample and should not be generalized to the broader population of trail visitors.

The principal component analysis provided exploratory evidence of two main tendencies. The first component indicated a shared pattern of association across the valuation dimensions, while the second differentiated cultural, spiritual, and hydrological meanings from recreation, landscape, biodiversity, and air quality. The selected three-cluster solution complemented this result by yielding three exploratory configurations: one more associated with biodiversity and recreation, another with hydrological and cultural valuation, and a third with a broader integrated valuation. These configurations should not be interpreted as fixed visitor categories but as indicative ways in which valuation dimensions were combined among respondents.

The practical contribution of this study lies in showing that the Kilómetro 11 trail should not be managed or communicated solely as a recreational space. Within the observed sample, water-related meanings, biodiversity, landscape, ecological connectivity, cultural significance, and recreation formed part of an interconnected valuation process. Environmental interpretation and visitor communication could therefore combine information on hydrological regulation, biodiversity conservation, landscape relationships, cultural meanings, and responsible recreational practices. Monitoring strategies could also incorporate visitor perceptions alongside ecological indicators to identify how management actions affect the multiple meanings associated with the trail. These implications are context-specific and should be treated as preliminary management inputs rather than general prescriptions.

From a methodological perspective, the sequential use of principal component and cluster analyses provided a preliminary way of summarizing the associations among the valuation dimensions and exploring respondent-level configurations. Its usefulness in this study lies in organizing a small multivariate dataset and generating hypotheses for subsequent research rather than validating a stable dimensional structure or visitor segmentation. Because the analysis was based on 22 respondents and five-point ordinal items, the component loadings, scores, and cluster memberships should be interpreted as being sample-dependent. Replication with larger independent samples is required before the analytical sequence can be considered transferable to other visitor populations or peri-urban contexts in the future.

Future research should expand the sample size and include more heterogeneous groups of visitors, as well as residents, environmental managers, local organizations, and institutional stakeholders. The stability of the component structure should be assessed with larger independent samples, and the three-cluster solution should be compared with alternative numbers of clusters and other exploratory classification procedures. Data collection across different seasons, days of the week, and stages of the visitor experience would also help determine whether the observed configurations remain consistent under changing visitation conditions. Complementary qualitative methods, including interviews, participatory mapping, and deliberative valuation exercises, could deepen the interpretation of how different actors assign meaning to water, biodiversity, landscapes, ecological connectivity, and cultural experiences. Comparative studies across other trails in Bogotá's Eastern Hills and additional peri-urban mountain ecosystems would further clarify the transferability and practical relevance of the exploratory analytical framework.

Beyond its specific empirical findings, the original contribution of this study lies in demonstrating how plural values of **n**ature can be examined as interconnected and differently emphasized configurations rather than isolated dimensions. By combining exploratory PCA with clustering based on component scores, the analysis connected the IPBES plural-value perspective with a visitor-based empirical application in a peri-urban mountain setting. The value of the case does not lie in statistical generalization or in establishing stable visitor typologies, but in providing a preliminary analytical framework for examining how ecological, hydrological, recreational, cultural, and spiritual meanings may coexist and acquire different relative prominence. This framework requires validation with larger samples and in other peri-urban socioecological contexts before its broader applicability can be established.

Declarations

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Credit Authorship Contribution Statement:

Johana Regino Vergara: Conceptualization, investigation, research design, methodology, data collection, project administration, theoretical framework, original draft writing, interpretation of results, visualization, validation, review, and editing.

Jainet Orlando Bernal Orozco: Methodology, software, formal statistical analysis, data curation, validation of quantitative procedures, interpretation of multivariate results, visualization, review and editing.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request. The dataset is not publicly deposited because the small sample size and combination of contextual variables could create a risk of indirect participant identification.

Ethics Statement: This study involved adult visitors who participated voluntarily after receiving information about the purpose of the study. Informed consent was obtained from all the participants. The survey was anonymous, and no names, identification numbers, email addresses, or other direct personal identifiers were collected from the participants. Potentially identifying contextual variables were analyzed and reported only in the aggregate form. This study did not involve any interventions in the ecosystem. Formal ethics committee approval was not required. The research was conducted as an anonymous, minimal-risk survey of adult participants.

Declaration of Competing Interest: The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this paper.

Declaration of use of generative AI and AI-assisted technologies: The authors declare that generative AI and AI-assisted technologies were used only to improve the language, readability, and editorial organization of this manuscript. The authors reviewed, edited, and validated all AI-assisted outputs and took full responsibility for the content, accuracy, interpretation, and integrity of the work.

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Supplementary File S1. Research Instrument
Visitor Characterization and Nature Valuation Questionnaire for the Kilómetro 11 Trail

Related manuscript	Plural Valuation of Nature in a Peri-Urban Mountain Trail: An Exploratory Analysis Using Principal Component and Cluster Analysis
Study location	Kilómetro 11 Trail, Eastern Hills of Bogotá, Colombia
Original language of administration	Spanish
Purpose of this file	English translation of the Spanish-language research instrument administered during the study, provided to support editorial transparency and analytical reproducibility

Document status: This supplementary file provides an English translation of the Spanish-language questionnaire used in this study. It was prepared solely for publication, editorial transparency, and methodological reproducibility; no data were collected using the English version of the questionnaire. The questionnaire was administered to adult visitors after they completed the Kilómetro 11 trail to characterize visitor profiles and assess the perceived importance assigned to multiple dimensions of nature valuation within this peri-urban mountain ecosystem.

Participant Information and Consent Procedure

Before administering the questionnaire, adult visitors were informed about the academic purpose of the study, the voluntary nature of participation, the anonymous handling of their responses, and their right to decline participation or withdraw at any time before submitting the questionnaire, without penalty or adverse consequences. No names, identification numbers, email addresses, or other direct personal identifiers were requested. Only those who voluntarily agreed to participate completed the questionnaire.

Section A. Visitor Characterization

The following items reproduce the English translation of the visitor-characterization module, which was administered in Spanish during the fieldwork. Items marked with an asterisk (*) were mandatory in the original questionnaire.

1. How many people are there in your visitor group? *

- ☐ I am visiting alone
- ☐ 2 people
- ☐ 3 people
- ☐ 4 people
- ☐ 5 people
- ☐ More than 5 people

2. How is the group composed? *

- ☐ Family
- ☐ Couple
- ☐ Friends
- ☐ Organized group
- ☐ Tourism company

3. Does anyone in your group have any of the following mobility restrictions or support needs? * *(Select all that apply)*

- ☐ Wheelchair
- ☐ Crutches
- ☐ Baby stroller
- ☐ None

4. Are you familiar with the visitor guidelines for this trail? *
- ☐ Yes
- ☐ No

5. Are you carrying any of the following items while on the trail? * *(Select all that apply)*
- ☐ Speakers, loudspeakers, or horns
- ☐ Plastic bags for waste collection
- ☐ Alcohol, cigarettes, or psychoactive substances
- ☐ Food or beverages

6. Were any of the items listed above purchased within the trail area? *
- ☐ Yes
- ☐ No

7. How many pets accompanied the group? *
- ☐ None
- ☐ One
- ☐ Two
- ☐ More than two

8. Please specify the type of pet accompanying the group: *

9. What mode of transportation did you use to reach the trail? *
- ☐ On foot
- ☐ Bicycle
- ☐ Private vehicle
- ☐ Other motorized transport
- ☐ Public transportation

10. Age *

11. Gender *
- ☐ Man
- ☐ Woman
- ☐ Other (including non-binary or gender-fluid identities)

12. Country of residence *
- ☐ Colombia
- ☐ Other

13. If other, please specify the country: *

14. Place of residence or accommodation (neighborhood or locality) *

15. Educational level *
- ☐ No formal education
- ☐ Secondary education
- ☐ Technical education
- ☐ Technological education
- ☐ University degree
- ☐ Postgraduate degree

16. Occupation or current activity *

17. Main interests during the visit * *(Select all that apply)*
- ☐ Hiking
- ☐ Nature observation
- ☐ Environmental education
- ☐ Research
- ☐ Recreation
- ☐ Photography
- ☐ Sports

18. Please indicate whether you used any of the following specialized equipment during your visit: *

Item	Yes	No
Hiking poles	○	○
Hiking boots	○	○
Water bottle or hydration pack	○	○
Crampons	○	○
Running shoes	○	○

19. How often do you visit the Kilómetro 11 trail? *

☐ First visit
☐ Occasionally
☐ Frequently (at least twice a month)
☐ Weekly

20. Approximate duration of the visit. Please specify minutes or hours*

21. How satisfied were you with your visit? *

☐ Very satisfied
☐ Satisfied
☐ Neither satisfied nor dissatisfied
☐ Dissatisfied
☐ Very dissatisfied

22. How do you perceive the safety of the trail? *

☐ Very safe
☐ Safe
☐ Neither safe nor unsafe
☐ Unsafe
☐ Very unsafe

23. How do you perceive the environmental impact generated by visitors concerning the following factors?

Item	Very high	High	Medium	Low	None
Littering	○	○	○	○	○
Damage to flora	○	○	○	○	○
Damage to fauna	○	○	○	○	○
Disturbance of wildlife	○	○	○	○	○
Consumption of trail resources	○	○	○	○	○
Fire risk	○	○	○	○	○
Use of water sources	○	○	○	○	○

Section B. Nature Valuation Dimensions

The following module was administered in Spanish during the same fieldwork process and provided the eight nature valuation variables used in the principal component analysis and the subsequent exploratory k-means cluster analysis.

For each nature valuation dimension, indicate the perceived importance of the corresponding contribution of nature to your experience at the Kilómetro 11 trail. The following five-point ordinal scale was used:

1 = Not at all important; 2 = Slightly important; 3 = Moderately important; 4 = Important; 5 = Very important.

Valuation dimension	Item assessed	1	2	3	4	5
Biodiversity	The conservation of the diversity of plants, animals, and other living organisms associated with the trail.	○	○	○	○	○
Hydrological regulation	The regulation, protection, and maintenance of water resources are associated with the trail.	○	○	○	○	○
Air quality	The maintenance or improvement of air quality in the surrounding area.	○	○	○	○	○
Landscape	The scenic quality of the trail and the opportunity to appreciate the landscape.	○	○	○	○	○
Ecological connectivity	The maintenance of ecological connections between natural areas and habitats.	○	○	○	○	○
Recreation	The availability of the trail as a space for recreation, outdoor activities, and enjoyment.	○	○	○	○	○
Cultural values	The cultural meanings, identity, learning, and shared experiences associated with the trail.	○	○	○	○	○
Spiritual values	The spiritual meanings, reflection, inspiration, and sense of connection with nature associated with the trail.	○	○	○	○	○

Supplementary Methodological Note: Coding and Analytical Use

Nature valuation dimensions	A five-point ordinal scale was coded from 1 to 5, with higher scores indicating a greater perceived importance assigned to each valuation dimension.
Multivariate analysis	Biodiversity, hydrological regulation, air quality, landscape, ecological connectivity, recreation, cultural values, and spiritual values were included in the principal component and subsequent exploratory k-means cluster analyses.
Visitor characteristics	Age, gender, visit frequency, and transport mode were used for descriptive analysis. Responses to the multiple-response visitor-interest item were grouped into the Education, Nature, and Recreation domains and used to derive a predominant analytical interest category for each participant.
Anonymity	No names, identification numbers, email addresses, or other direct personal identifiers were collected from the participants. Potentially identifying contextual variables were analyzed and reported only in aggregate form.