



How Nature Connectedness and Mindfulness Moderate University Students' Awareness of Single-Use Plastic Pollution



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ABSTRACT

Background: Anthropogenic plastic pollution poses a severe global threat; however, this study aimed to investigate the synergistic role of nature connectedness and mindfulness in shaping awareness of single-use plastic pollution among university students.

Methods: This cross-sectional questionnaire-based study assessed nature connectedness and mindfulness in 140 students in Isfahan, Iran. A Generalized Additive Model (GAM) was employed to examine nonlinear relationships. Both constructs were measured on a 5-point Likert scale and standardized to a 0-1 scale.

Results: Nature connectedness and mindfulness interacted nonlinearly ($edf > 1.00$) to predict risk perception, explaining 73.5% of the variance ($R^2 = 0.735$). Mindfulness significantly moderated the effect of nature connectedness, with nonlinear patterns showing a complex relationship. The effect of nature connectedness (mean 3.1 ± 1.4) was amplified by mindfulness (mean 3.3 ± 1.2), achieving 100% statistical power.

Conclusion: These findings underscore the synergistic role of nature connectedness and mindfulness in enhancing pollution sensitivity. Although context-specific to Isfahan, the results offer novel insights for environmental psychology. Practically, universities in Isfahan can implement nature-based interventions and mindfulness training to elevate risk perception, targeting students' moderate nature connectedness and high mindfulness to reduce plastic use, directly shaping campus sustainability policies and curbing single-use plastic waste in Iran's urban context.

1. Introduction

Environmental pollution represents one of the most pressing global challenges of the 21st century, threatening ecosystems, human health, and economic stability (Edo et al., 2024; Shetty et al., 2023). Among the myriad forms of pollution, anthropogenic sources, those driven by human activity, have garnered increasing attention due to their widespread and persistent impact (Babuji et al., 2023). In particular, single-use plastics epitomize this issue, characterized by their ubiquity in daily life (Veidis et al., 2021), slow degradation (Dey et al., 2021), and devastating effects on marine and terrestrial environments, as well as public health (Smith et al., 2023) and local economies (Herberz et al., 2020). These plastics, often discarded after a

single use, contribute significantly to global waste streams, with estimates suggesting 400 million tons enter the environment annually, harming biodiversity and releasing microplastics into food chains (Barone et al., 2025). Addressing this crisis requires not only technological and policy interventions but also a deep understanding of human perceptions and behaviors, as awareness of pollution risks is a critical precursor to behavioral change (Borg et al., 2022).

Within the realm of environmental science, psychological factors play a pivotal role in shaping how individuals perceive and respond to pollution (Soares et al., 2021). Environmental psychology highlights that human-nature relationships, such as nature connectedness (the emotional, cognitive, and psychological bond individuals feel with the natural world), can foster pro-environmental attitudes and



behaviors (Wilkie & Trotter, 2022; Wyss et al., 2022). Similarly, mindfulness is defined as present-moment awareness and non-judgmental attention to one's thoughts and surroundings (Simione & Saldarini, 2023), entailing a deliberate, open-hearted orientation to one's experience. This process disrupts automatic, habitual behaviors (such as the unconscious use of single-use plastics) by creating cognitive space for more intentional, value-congruent choices (Monteiro et al., 2019). In an environmental context, mindfulness cultivates ecological noticing, enhancing the ability to perceive the interconnectedness between personal actions and broader environmental systems. It thereby fosters greater reflection on environmental consequences and reduces unsustainable consumption patterns (Apaolaza et al., 2022). These psychological dimensions are particularly relevant in urban settings, where exposure to nature may be limited, yet pollution pressures, including single-use plastics, are acute (Shin et al., 2024).

A substantial body of research has explored the role of nature connectedness in promoting environmental awareness and behavior. The Biophilia Hypothesis, proposed by Mayer and Frantz (2004), suggests that humans possess an innate affinity for nature, which can cultivate environmental concern and motivate actions against pollution, such as reducing plastic use. Studies like those by Wolsko and Lindberg (2013) have demonstrated that nature connectedness is a multifaceted construct, encompassing emotional, cognitive, and psychological well-being, and is strongly linked to heightened sensitivity to environmental threats, including single-use plastics. For instance, White et al. (2021) and Thomson and Roach (2023) found that individuals with greater nature connectedness exhibit increased concern for ecological issues, which may translate into greater awareness of pollution risks. However, these studies often report modest effect sizes and typically rely on linear models (Yan et al., 2024), potentially overlooking the complex, nonlinear patterns that may characterize these relationships among diverse populations.

Mindfulness, on the other hand, has gained attention as a psychological tool for enhancing environmental sensitivity. Apaolaza et al. (2022) and Trötschel and Sheate (2022) argue that mindfulness fosters present-moment awareness and reflection, enabling individuals to engage more deeply with environmental challenges. This reflective capacity can heighten awareness of pollution, including single-use plastics, by reducing distractions and promoting thoughtful consideration of ecological consequences. Research by Stewart and Hagg (2018) and Liu et al. (2020) further suggests that mindfulness may enhance psychological well-being, which could amplify its effects on nature connectedness, leading to greater environmental concern. However, the interaction between mindfulness and nature connectedness remains underexplored, particularly in the context of specific pollutants like single-use plastics.

Despite these advances, significant gaps persist in the literature concerning single-use plastic pollution awareness, especially among university students in non-Western urban settings like Isfahan, Iran. Few studies have examined the

nonlinear and interactive effects of nature connectedness and mindfulness on pollution awareness, limiting our understanding of how these psychological factors might operate in complex, threshold-based ways. Moreover, research on young, educated populations in regions like Isfahan is scarce, leaving uncertainty about cultural, educational, or regional influences on these relationships. Moreover, while awareness is a crucial first step, the literature largely neglects the transition from awareness to behavior change, such as reducing plastic use, and overlooks the potential moderating role of mindfulness in amplifying nature connectedness's impact.

Therefore, understanding the logical drivers behind these perceptions, such as nature connectedness and mindfulness, could offer a reasoned approach to explaining why awareness varies and how it can be strengthened to address the escalating threat of single-use plastics. To address these gaps, this study aims to investigate whether nature connectedness and mindfulness, and their interaction, predict awareness of single-use plastic pollution among university students in Isfahan. Universities, as hubs of young, educated individuals, offer a unique context to explore these dynamics given students' potential to influence broader societal change through awareness and action. Specifically, we hypothesize that nature connectedness positively influences awareness, and this effect is moderated by mindfulness, potentially revealing nonlinear patterns due to psychological and environmental complexities. This study aims to investigate whether nature connectedness and mindfulness, and their interaction, predict awareness of single-use plastic pollution among university students in Isfahan.

2. Materials and Methods

2.1 Study design

This cross-sectional study was conducted in Isfahan, Iran, during the 2023-2024 academic year.

2.2 Participants and sampling

This study involved 140 university students recruited via convenience sampling. Inclusion criteria were: being a university student in Isfahan, aged 18-25, and enrolled in a non-environmental, non-psychological discipline (e.g., excluding agriculture, environmental studies, and psychology). The sample was evenly split by gender, with 70 male and 70 female participants. The majority of participants fell within the 18 to 25-year age range, reflecting a young adult population. All volunteers resided in Isfahan, Iran. This sampling approach aimed to minimize the influence of academic backgrounds related to the study's focus and ensure participants were unaware of the research objectives, we selected volunteers from academic disciplines outside of agriculture, environmental studies, and psychology, thereby reducing potential bias from prior knowledge or training in these areas.

2.2.1 Statistical Power Analysis

To assess the adequacy of the sample size for detecting potential relationships measured by the questionnaire, a post-hoc power analysis was conducted using G*Power software. This analysis was based on a multiple regression framework, assuming three predictors (NaCo, Mind, and their interaction). The effect size (f^2 – Eq. 1) was calculated from the observed coefficient of determination of the fitted model, representing the proportion of variance in the dependent variable (PR-SUP) explained by the predictors relative to the unexplained variance. The analysis required inputs including the effect size, the significance level (α , set at 0.05), the total sample size ($N = 140$), and the number of predictors (3). This approach was used to evaluate the statistical power ($1 - \beta$), providing an estimate of the study's sensitivity to detect the relationships identified in the model.

$$f^2 = \frac{R^2}{1 - R^2} \quad \text{Eq. 1}$$

2.3 Data collection

2.3.1 Questionnaire Design

Data were collected using a self-report questionnaire comprising three main constructs, mindfulness, perception of risks from single-use plastics, and nature connectedness, each assessed with items on a 5-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5). Mindfulness (Mind) was evaluated through 5 items (M-1 to M-5, listed in Appendix A), categorized into distinct dimensions based on the framework by Apaolaza et al. (2022). These dimensions included awareness of sensations, emotional awareness and expression, focus and distraction, verbal expression and thought clarity, and self-perception of thoughts. Perception of risks from single-use plastics (PR-SUP) was assessed using four items designed to cover environmental (PR-1 and PR-2), health (PR-3), and economic dimensions (PR-4). Nature connectedness (NC-1 to NC-4, Appendix A) was estimated with seven items, assessing the emotional, psychological, and cognitive dimensions of an individual's relationship with the natural world. These included unity and oneness with nature, interconnectedness, belonging to nature, closeness with animals and plants, personal well-being and nature's well-being, and feeling disconnected. Responses were all measured on the 5-point Likert scale. Content validity was evaluated through expert review by a panel of three university faculty members specializing in environmental psychology, behavioral sciences, and environmental education. These experts examined each item for clarity, relevance to the intended construct, and alignment with established theoretical dimensions, and minor wording adjustments were made based on their recommendations. The questionnaire's reliability was confirmed with Cronbach's alpha values > 0.7 . For each construct (Mind, PR-SUP, and NaCo), item responses were averaged to create composite scores, reflecting participants' overall levels on each dimension. These

averaged scores were then standardized to a 0-1 scale using the min-max standardization method to facilitate comparison and analysis across variables, ensuring consistency in the range of values for subsequent statistical evaluations.

2.4 Statistical Modeling

To investigate the nonlinear relationships between PR-SUP and the predictors, a GAM was employed. GAMs are particularly valuable in this context because they allow for flexible, nonparametric modeling of nonlinear effects and interactions, making them well-suited for capturing complex psychological and environmental relationships. The GAM analysis was conducted using the mgcv package (Wood, 2017) in R, with additional support from the nlme package for handling mixed-effects models if needed for robustness checks. The model fitting utilized the Restricted Maximum Likelihood (REML) method, which optimizes parameter estimation by balancing model fit and complexity, reducing bias in variance component estimation and improving the reliability of smooth term coefficients (Wood, 2017). The model was specified as Eq. 2. The variables were derived from averaged composite scores that were subsequently standardized using min-max normalization. For each construct, the minimum observed value was subtracted from each composite score and divided by the range of that construct, resulting in standardized values between 0 and 1 to ensure consistent scaling across predictors and the response prior to nonlinear modeling. The model's goodness-of-fit was evaluated using the adjusted coefficient of determination ($\text{Adj. } R^2$), which quantifies the proportion of variance in PR-SUP explained by the predictors. Residual diagnostics were conducted to assess model assumptions, including tests for normality using the Shapiro-Wilk test and for autocorrelation using the Durbin-Watson test, ensuring the residuals were approximately normally distributed and free of systematic patterns, respectively.

$$\text{model} < - \text{gam}(\text{PRSUP} \sim \text{s}(\text{NaCo}) + \text{s}(\text{Mind}) + \text{ti}(\text{NaCo}, \text{Mind})) \quad \text{Eq. 2}$$

Where PRSUP represents the standardized composite score of participants' perception of risks from single-use plastics, NaCo denotes the standardized composite score of nature connectedness, and Mind represents the standardized composite score of mindfulness.

3. Results and Discussion

3.1 Descriptive Statistics and Preliminary Analysis

A total of 140 participants met the inclusion criteria and were included in the final analyses. The distribution of academic semesters and major groups is presented in Table 1. Most students (67.1%) were in the first or second academic semester, reflecting the predominance of early-stage undergraduates in the sample. Moreover, students from engineering and technical disciplines formed the largest group (41.4%), followed by those in the humanities (35.0%),

with the smallest proportion coming from basic sciences and other majors (23.6%)

Table 1. Frequency and percentage distribution of demographic variables in the sample

Variable	Category	Frequency	Percentage
Gender	Male	70	50%
	Female	70	50%
Age	18–21 years	82	58.60%
	22–25 years	58	41.40%
Academic Semester	Semester 1–2	94	67.10%
	Semester 3–6	46	32.90%
Field of Study	Engineering and Technical Sciences	58	41.40%
	Humanities	49	35.00%
	Basic Sciences and Others	33	23.60%

A post-hoc power analysis using G*Power assessed the study's statistical power with a sample size of 140 and three predictors. The effect size was calculated as $f^2 = 0.735 / (1 - 0.735) \approx 2.7736$ and yielded an estimated power of 1.000 at $\alpha = 0.05$. Because post-hoc power is derived from observed data, this value should be interpreted cautiously and viewed primarily as an indicator of the model's sensitivity rather than as evidence of guaranteed detectability. The large observed effect size, together with the sample size, suggests that the study had sufficient capacity to detect the relationships identified in the analysis. The descriptive statistics for the variables in this study are presented in Table 2. The multicollinearity between nature connectedness and mindfulness was found to be moderate ($VIF = 2.41$) which may slightly inflate the standard errors of the regression coefficients but remains within acceptable limits (typically < 5), supporting the reliability of the model's conclusions.

Table 2. Descriptive statistics and multicollinearity assessment for perception of risks from single-use plastics (PR-SUP), nature connectedness, and mindfulness among university students

Variable	Descriptive statistics					VIF
	Mean	SD	Min	Max	N	
PR-SUP	3.8	0.9	1	5	140	-
Nature Connectedness	3.1	1.4	1	5	140	2.41
Mindfulness	3.3	1.2	1	5	140	2.41

To explore the distribution and relationships among these variables, all values were standardized to a 0-1 scale. Figure 1 presents a histogram of standardized PR-SUP, showing its frequency distribution with a peak around 0.7-0.9, indicating right skewness where most students reported high awareness of single-use plastic pollution. It also illustrates the scatterplot associations between PR-SUP and standardized NaCo, Mind, and their interaction (NaCo \times Mind). The PR-SUP-NaCo association reveals a positive trend, suggesting that higher nature connectedness is associated with greater awareness, though with some dispersion. A

similar positive association is also present between PR-SUP and Mind with awareness increasing as mindfulness rises, albeit with wider variability at higher mindfulness levels. The PR-SUP versus NaCo \times Mind also indicates a potential interaction, with awareness appearing to increase more steeply at higher combined values of nature connectedness and mindfulness, supporting the hypothesis of moderation.

3.2 Nonlinear Modeling of Psychological Drivers and Their Synergy

The GAM model was employed to examine the nonlinear relationships between NaCo, Mind, and their interaction in predicting PR-SUP. The GAM explained 73.5% of the variance in awareness ($Adj. R^2 = 0.735$ -Table 3), indicating a very large effect size ($f^2 \approx 2.7736$). The model included an intercept estimate of 0.527 ($t = 57.860, p < 0.001$), establishing the baseline for PR-SUP. Smooth terms for NaCo, Mind, and their interaction (NaCo \times Mind) were statistically significant, revealing complex nonlinear patterns in their effects on PR-SUP. The perception of risks associated with various types of plastics is a fundamental driver of environmental behavior and a critical component in crafting effective strategies to mitigate pollution, particularly in urban settings where anthropogenic pressures are pronounced. As emphasized by Genovese et al. (2023), addressing this pollution effectively hinges on enhancing perception and awareness, as these are essential for cultivating pro-environmental attitudes and behaviors. Our research reveals that nature connectedness and mindfulness significantly bolster awareness of single-use plastic pollution among university students, with mindfulness amplifying the impact of nature connectedness. This finding aligns with prior research indicating that consumer perception ultimately shapes the extent of single-use plastic pollution (De Kock et al., 2020) and behavior change programs aimed at increasing awareness, particularly among young adults, represent a rapid and cost-effective complement to traditional environmental policy in addressing plastic pollution (Oturai et al., 2022). Consequently, elucidating the underlying drivers of these perceptions, such as nature connectedness and mindfulness, provides a rational framework for explaining variance in awareness and for developing targeted interventions to mitigate the escalating threat of single-use plastics.

The approximate significance of the smooth term for NaCo demonstrated the most complex relationship ($edf = 4.893, F = 2.328, p = 0.046$), characterized by multiple peaks and troughs across its 0-1 range, as shown in Figure 2, suggesting a highly nuanced association with PR-SUP with the most intricate nonlinear pattern. The smooth term for Mind ($edf = 3.351, F = 3.367, p = 0.012$) exhibited a less complex but still nonlinear trend, with a generally increasing effect on PR-SUP, peaking toward higher mindfulness levels. The interaction term (NaCo \times Mind, $edf = 2.091, F = 8.991, p < 0.001$) indicated that mindfulness moderates the relationship between nature connectedness and PR-SUP, with the effect varying across levels of mindfulness, showing a simpler but significant moderating pattern (Figure 2).

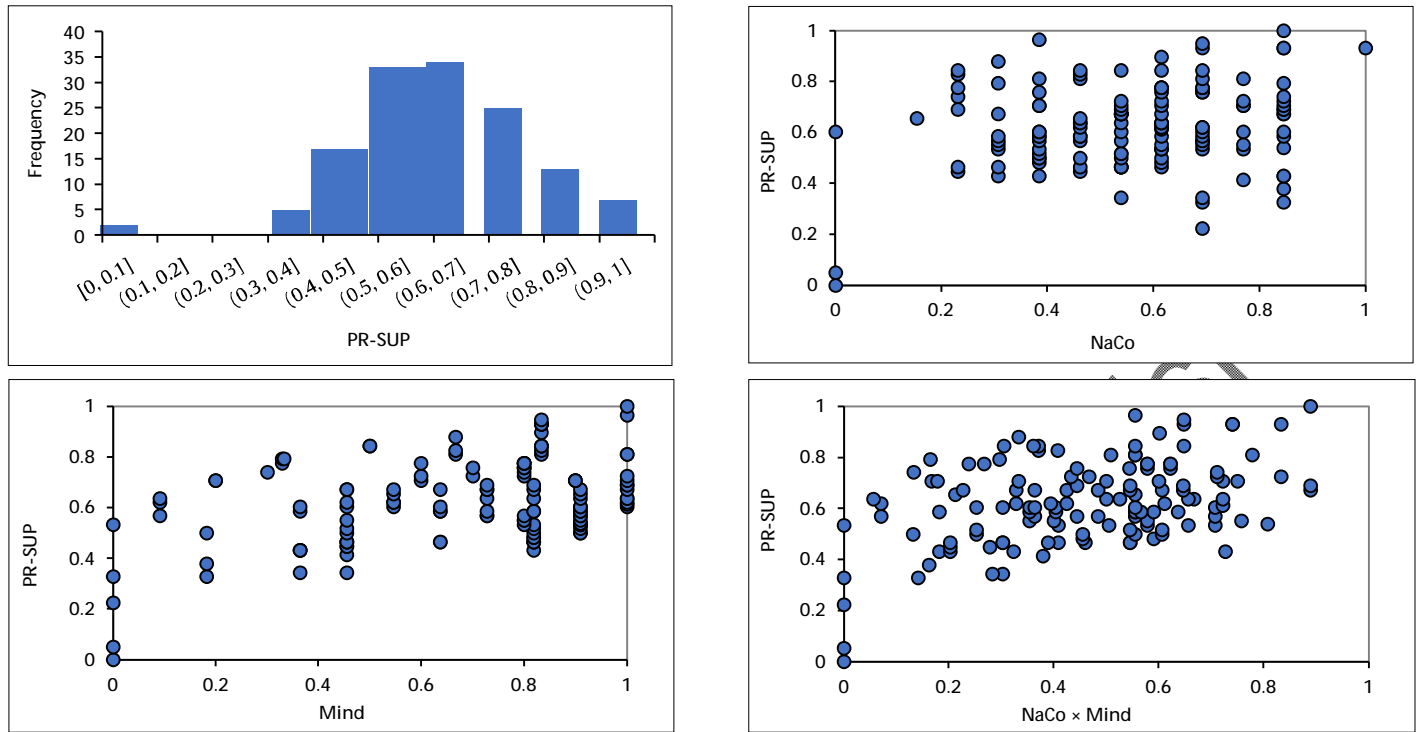


Figure 1. Distribution and relationships of standardized variables: perception of risks from single-use plastics (PR-SUP), nature connectedness, and mindfulness among university students

Table 3. Approximate significance of smooth terms and parametric coefficients of the GAM model

Smooth terms	Approximate significance				R ²	Intercept	
	edf	Ref.df	F	p-value		Estimate	t (p)
s (NaCo)	4.893	5.974	2.328	0.046	0.735	0.527	57.860 (0.000)
s (Mind)	3.351	4.172	3.367	0.012			
s (NaCo × Mind)	2.091	2.661	8.991	0.000			

The GAM model uncovered intricate nonlinear patterns in the relationships between predictors and awareness of single-use plastic pollution. Nature connectedness displayed the most complex pattern, suggesting a highly variable influence on awareness that contrasts with the smoother, yet still nonlinear, trend observed for mindfulness. This difference in complexity may reflect the multifaceted nature of nature connectedness, encompassing emotional,

cognitive, and psychological dimensions, as opposed to mindfulness's more focused role in present-moment awareness. This conclusion has been made in previous studies like Wolsko and Lindberg (2013) who ranked nature connectedness as a factor rooted to a large number of hedonic and eudaimonic aspects of psychological well-being. However, in contrast, present-moment awareness is often referred to as a singularity of mindfulness (Bullen, 2024).

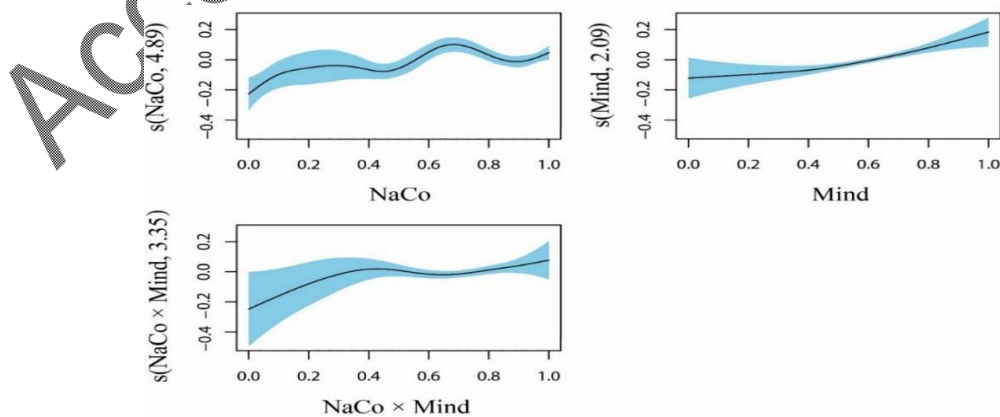


Figure 2. Nonlinear smooth term effects from the GAM model to predict perception of risks from single-use plastics (PR-SUP), nature connectedness (NaCo), and mindfulness (Mind)

The standardized PR-SUP values were observed to increase markedly at higher levels of both nature connectedness and mindfulness, underscoring mindfulness's role in amplifying nature connectedness's effect on awareness. This pattern aligns with prior research indicating that psychological traits interact to enhance environmental concern, as encapsulated in Tang and Chooi (2023) concept of "from concern to action," which highlights the progression from heightened awareness to behavioral change. The robustness of these relationships is further supported by the exceptionally strong statistical evidence, particularly for the interaction term (NaCo \times Mind), which demonstrated the most significant moderating effect, revealing that the influence of nature connectedness on awareness varies across different levels of mindfulness. Logically, this moderation may arise from mindfulness enhancing psychological well-being, as evidenced by Stewart and Haaga (2018), and fostering reflective engagement with nature, as demonstrated by Apaolaza et al. (2022) and Liu et al. (2020). These findings suggest that individuals with higher mindfulness levels may

be more attuned to their natural surroundings, leading to a deeper appreciation of environmental issues and, consequently, greater awareness of single-use plastic pollution.

Model fit was further assessed through predicted-vs-observed and residual plots (Figure 3). It demonstrates a strong alignment between predicted and observed PR-SUP values, with points clustering closely around the diagonal line, indicating that the model effectively captures the variability in awareness of single-use plastic pollution (Figure 3, left panel). The residual plot also showed its values to be scattered randomly around zero, with no discernible patterns, suggesting no significant violations of model assumptions (Figure 3, right panel). Residual diagnostics confirmed this, with residuals exhibiting approximate normality (Shapiro-Wilk = 0.969, $p = 0.077$) and no significant autocorrelation (Durbin-Watson = 1.901, $p = 0.120$), reinforcing the robustness of the GAM in modeling the nonlinear relationships between nature connectedness, mindfulness, and perception of risks from single-use plastics.

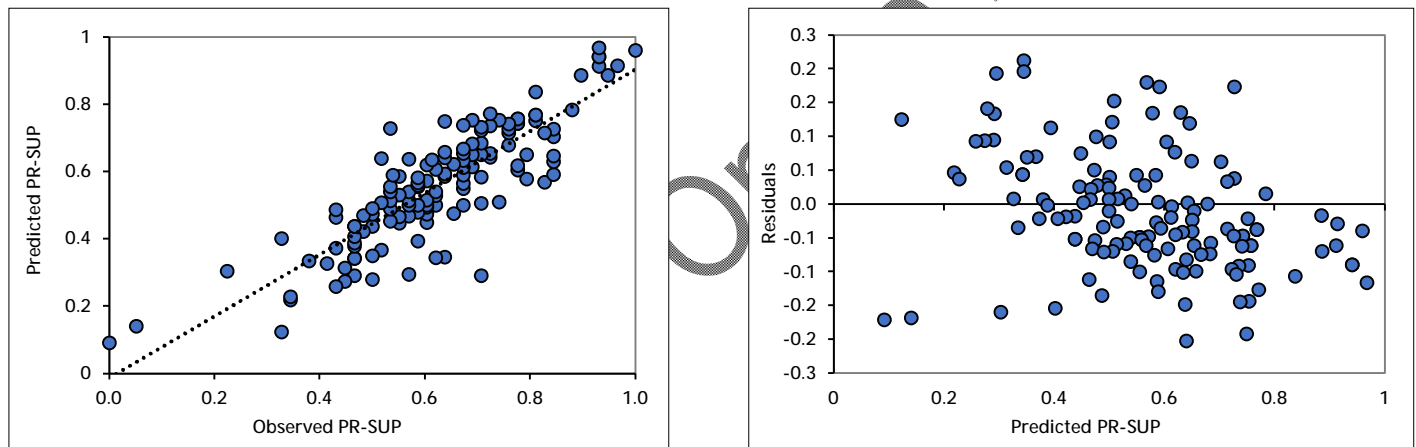


Figure 3. Model fit assessment for standardized awareness of single-use plastic pollution

The robust association between nature connectedness and awareness resonates with the Biophilia Hypothesis (Mayer & Frantz, 2004), which suggests that humans possess an innate affinity for nature that fosters environmental concern. Our results indicate that this affinity may translate into heightened awareness of anthropogenic pollution, such as single-use plastics, among Isfahan university students, aligning with logical expectations that a deeper connection to nature could heighten sensitivity to environmental threats. The moderating influence of mindfulness, as it is known an acceptable notion (Apaolaza et al., 2022), demonstrates that mindfulness enhances pro-environmental attitudes by encouraging present-moment awareness and reflection, potentially amplifying attention to environmental issues. However, the interaction between nature connectedness and mindfulness, where mindfulness appears to strengthen the impact of nature connectedness on awareness, represents a novel contribution, distinguishing our study from similar research. This distinctive finding may

stem from the unique cultural or educational context of Isfahan students, where mindfulness practices might align closely with nature-based values, or from the salience of single-use plastics as a pressing local pollution concern, as suggested by prior studies on regional environmental priorities (Chen et al., 2021).

Practically, these findings provide valuable, actionable insights for addressing single-use plastic pollution within university settings. Universities in Isfahan could introduce nature-based interventions, such as creating campus green spaces or organizing outdoor activities, to cultivate nature connectedness, particularly among students who exhibit moderate engagement. Complementing these efforts with mindfulness training, such as meditation workshops or mindfulness-based stress reduction programs, could enhance awareness by capitalizing on the interaction between nature connectedness and mindfulness. Future campus initiatives should also prioritize tracking behavioral outcomes, assessing whether heightened awareness

translates into tangible actions against anthropogenic pollution, as recommended by longitudinal research on environmental behavior change (Oturai et al., 2022).

3.3 Limitations and future directions

This study is subject to several limitations. The sample used in this study was limited, comprising Isfahan University students aged 18-25 and specifically excluding those majoring in environmental science or psychology, which restricts the generalizability of the findings to other populations. The results from Isfahan university students are not sufficient to generalize to the wider urban context of Iran. The study also focused on awareness as a critical precursor and did not assess actual pro-environmental behavior. Moreover, while gender was balanced, other demographic factors were not analyzed, leaving uncertainty about whether increased awareness of single-use plastic pollution translates into reduced plastic use. Future research could investigate these findings across more diverse populations, including non-students, older adults, or individuals from different cultural or geographic settings, to assess their broader applicability and build on the need for comparative analysis. Longitudinal studies could also explore whether nature connectedness and mindfulness predict actual reductions in single-use plastic consumption. Furthermore, examining additional psychological moderators, such as environmental knowledge or social norms, and mediators, such as eco-anxiety or attitudes, could enrich the model. Larger sample sizes or mixed-methods approaches, including qualitative interviews, could further validate the nonlinear patterns observed and clarify the influence of cultural and environmental factors on plastic pollution awareness.

4. Conclusion

This study demonstrates that nature connectedness and mindfulness significantly enhance awareness of single-use plastic pollution among university students, with mindfulness amplifying the effect of nature connectedness which offers a powerful approach to understanding psychological drivers of anthropogenic environmental harm. These findings, observed among Isfahan university students, highlight the potential of integrating nature-based engagement with mindful practices (NaCo × Mind) to heighten sensitivity to pollution risks which is a critical step toward sustainable behaviors. Practically, universities in Isfahan and beyond could implement campus green spaces and mindfulness training to leverage these insights, thus informing broader sustainability policies in Iran to address the environmental, health, and economic challenges of single-use plastics. Theoretically, the study advances environmental psychology by revealing the synergistic role of these factors, challenging linear models and suggesting complex patterns for future exploration. By bridging psychological insights with pollution mitigation, this research lays the foundation for innovative interventions,

paving the way for a more sustainable future in combating single-use plastic pollution globally.

Authors' Contributions

Mana Tanhayi: Conceptualization; Methodology; Supervision; Writing-review & editing. **Atefeh Chamani:** Formal analysis; Investigation; Software; Validation; Visualization. **Saeed Mohammadi:** Data curation; Resources; Project administration; Writing-review & editing.

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Conflicts of Interest

The authors have declared no competing interests.

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Ethical Considerations

The proposal for the present study was reviewed and approved by the Research Committee of Isfahan (Khorasgan) Branch, Islamic Azad University. (Research code: 162695065).

Using Artificial Intelligence

The authors utilized the DeepSeek Chat (free online platform) to refine grammar and enhance language clarity using the prompt: "Check grammar and improve language."

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