



Sustainable Household Waste Management: Synergy of Environmental Fiqh and Separate Waste Bin Training

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Abstract:

This study aims to analyze the effectiveness of sustainable household waste management by integrating environmental fiqh values with training in using waste separation bins. This study employed a qualitative approach with a case study design. Data were collected through in-depth interviews, participatory observation, and documentation involving village officials, religious leaders, environmental cadres, and community members. The data were analyzed thematically, using triangulation to ensure the validity and credibility of the findings. The results indicate that integrating environmental fiqh principles into practical waste-sorting training enhances community ecological awareness, waste management skills, and environmentally responsible behaviors. Participatory training with hands-on practice and ongoing mentoring encouraged community members to separate household waste by type consistently. These practices improved environmental cleanliness, reduced waste accumulation, and improved environmental health conditions. The findings suggest that combining religious values with practical environmental education can provide a contextual, sustainable strategy for strengthening community participation in household waste management. This approach also demonstrates the potential of environmental fiqh as a value-based framework for fostering long-term ecological responsibility and supporting sustainable community-based environmental practices.

INTRODUCTION

Household waste management has become an increasingly important environmental concern as population growth, urbanization, and changing consumption patterns (Agboola et al., 2025; Voukkali et al., 2024; Wadi et al., 2023). Effective waste management is essential because unmanaged household waste can contribute to soil and water pollution, environmental degradation, and public health problems (Abubakar et al., 2022; Kumar et al., 2024). Beyond its technical dimensions, waste management is also closely related to community awareness, responsibility, and everyday behavior. Therefore, addressing household waste requires approaches that can encourage people to understand the environmental consequences of their actions and consistently adopt sustainable practices (Etim, 2024; Nguyen et al., 2023). Community-based waste management is particularly important because households are the primary source of domestic waste and the first level at which waste can be reduced and separated. Strengthening community participation can consequently improve environmental quality

while fostering collective responsibility. Thus, developing sustainable household waste management strategies that integrate practical skills, environmental awareness, and community values is important for creating healthier, cleaner, and more resilient communities.

Despite the growing importance of sustainable waste management, many communities still struggle to implement proper household waste practices. A major problem is the persistence of mixed waste disposal, in which organic and inorganic materials are discarded together without prior separation. This practice increases the volume of waste transported to disposal sites, reduces recycling opportunities, and makes organic waste processing more difficult (Meena et al., 2023; Rashid & Shahzad, 2021). Inadequate waste management can subsequently create unpleasant odors, attract disease-carrying organisms, and contribute to environmental pollution. The problem is not solely caused by limited infrastructure; it is also linked to insufficient knowledge, skills, awareness, and consistency among community members. Although waste separation facilities can be provided, their effectiveness depends on whether households understand how and why to separate waste. Behavioral change therefore becomes a fundamental component of sustainable waste management because technical facilities alone cannot guarantee responsible environmental practices. Addressing this problem requires interventions that combine practical training with approaches that strengthen long-term community commitment.

The field phenomenon demonstrates that household waste management remains a relevant social and environmental issue because waste separation has not yet become a consistent part of everyday household behavior. Communities may understand the importance of cleanliness but still dispose of different types of waste together because of limited practical knowledge, poor habits, or a lack of ongoing support. This situation illustrates a gap between conceptual environmental awareness and its implementation in daily practice. In Muslim communities, this gap can be addressed by linking environmental responsibility to religious values. Environmental fiqh emphasizes humans' responsibility to preserve nature, prevent environmental damage (*fasād*), and realize benefits (*maṣlaḥah*) for humans and the environment. Values such as cleanliness (*ṭahārah*), balance (*mīzān*), harm avoidance, and collective responsibility (*farḍ kifāyah*) are highly relevant to responsible waste management. Integrating these values into practical waste-sorting activities can therefore make environmental education more meaningful and potentially strengthen behavioral commitment within the community.

Previous research has shown that sustainable waste management requires source separation, applying the reduce, reuse, and recycle (3R) principles, and active community participation. (Leknoi et al., 2024), For example, Leknoi et al. (2024) emphasized the importance of separating waste at its source and strengthening community involvement to establish sustainable waste management systems. Similarly, training on using separate waste bins has been shown to improve community knowledge and skills in distinguishing organic and inorganic waste. These findings confirm that practical education and community participation are important components of waste management interventions. However, existing approaches tend to emphasize technical skills and behavioral dimensions without sufficiently considering the normative and ethical values that influence people's long-term commitment. Consequently, improvements in knowledge and skills may not always translate into consistent household practices. This limitation indicates the need for an approach that not only teaches communities how to

separate waste but also explains why environmental responsibility should become part of their moral and social obligations. Such integration is important for strengthening the sustainability of community-based waste management.

The literature also indicates that environmental values have increasingly been recognized as important foundations for sustainable behavior, yet their integration with practical waste management education remains limited (Debrah et al., 2021; Nisa et al., 2025). Environmental fiqh provides a religious framework that positions humans as responsible stewards of the Earth and emphasizes preventing environmental harm. Islamic environmental principles, including cleanliness, balance, collective responsibility, and the prohibition of causing harm, can provide a meaningful normative foundation for waste management practices (Shompa et al., 2025; Derysmono, 2025; Shabila et al., 2026). Nevertheless, these values have not always been internalized into concrete environmental behaviors, creating a gap between religious understanding and practical implementation. Existing studies on waste-sorting training generally focus on improving knowledge and technical skills, while research on environmental fiqh often remains conceptual or normative. This study contributes by connecting these two dimensions through an integrated approach that combines environmental fiqh with practical training in using separate waste bins (Basar et al., 2026; Hermawansyah, 2025). This approach addresses an important research gap by positioning religious values as an educational foundation for sustainable environmental behavior.

Based on the identified problems and research gap, this study addresses how communities can develop consistent, sustainable household waste management practices by integrating religious values with practical waste-sorting skills. The problem involves not only the limited practice of separating organic and inorganic waste but also the challenge of transforming environmental knowledge into habitual behavior. Previous technical interventions have shown the benefits of waste-sorting training, but their sustainability may be limited when communities lack strong value-based motivation. At the same time, although environmental fiqh provides ethical principles for environmental protection, these principles require practical translation into everyday community activities. Therefore, the central problem is the lack of an integrated mechanism that connects environmental ethics, technical competence, and continuous community participation. Addressing this problem matters because effective household waste management can reduce pollution, improve community cleanliness, and strengthen collective responsibility. The study therefore examines whether integrating environmental fiqh values with separate-bin training can support meaningful, sustainable changes in community waste management behavior.

This study aims to analyze the effectiveness of integrating environmental fiqh values with practical training on using separate waste bins to strengthen sustainable household waste management. The study examines how religious values can translate into practical environmental behaviors, particularly through household-level waste separation. It also examines changes in ecological awareness, waste management skills, participation, and behavioral consistency following participatory training and ongoing assistance. The study includes community members and relevant local actors involved in environmental management, with attention to the relationship between religious understanding and practical waste management. By combining normative education with hands-on practice, the study seeks to develop an approach that is contextually relevant, socially participatory, and sustainable. The expected contribution extends beyond

improving waste-sorting skills, as the approach aims to strengthen environmental responsibility as part of everyday community life. In this regard, the study supports broader sustainable development goals by promoting cleaner environments, healthier communities, responsible consumption practices, and stronger community participation in environmental protection.

RESEARCH METHODS

This community service activity employed a Participatory Action Research (PAR) approach, which emphasizes active community involvement in identifying problems, implementing solutions, reflecting on outcomes, and developing sustainable practices (Cornish et al., 2023; De Oliveira, 2023). The approach was selected because the activity went beyond observing household waste management problems; it focused on empowering community members through environmental fiqh education, separate waste-bin training, direct practice, and ongoing mentoring. PAR enables the community to become active participants rather than mere recipients of the program, strengthening ownership and the intervention's sustainability. The activity was implemented through several interconnected stages: identifying household waste management problems, introducing environmental fiqh values, training on waste separation, hands-on practice using separate waste bins, mentoring, and evaluating behavioral changes. This approach aligns with community-based empowerment principles, in which the community develops knowledge and solves problems collaboratively.

The activity was conducted in Deram Village, which was purposively selected because of household waste management problems and the community's strong religious and social characteristics. The location was considered appropriate because mixed waste disposal remained common, while environmental management had not yet been optimally integrated with religious values. In addition, the community's social cohesion and involvement of religious and community leaders provided a supportive context for implementing environmental fiqh-based education. Participants included village officials, religious leaders, community leaders, environmental cadres, and residents who participated directly in the training and mentoring activities. These groups were involved to disseminate knowledge, strengthen community participation, and encourage the continuation of waste management practices after the program ended.

Data collection used participatory observation, interviews, documentation, and activity evaluation. The researchers used participatory observation throughout the training and mentoring processes to assess participants' involvement, understanding, practical skills, and consistency in separating household waste (Salmona & Kaczynski, 2024). The researchers interviewed selected participants, community leaders, religious figures, and environmental cadres to explore their perceptions of environmental fiqh, training experiences, and changes in waste management practices. Documentation included photographs, activity records, training materials, and community waste management documentation. In addition, pre-activity and post-activity evaluations were used to identify changes in participants' knowledge and understanding of waste separation and environmental responsibility. Together, these techniques provided complementary information on both the implementation process and the outcomes of the community service activity.

Data were analyzed descriptively and thematically by organizing information obtained from observations, interviews, documentation, and activity evaluations into

several relevant categories. The analysis focused on four main aspects: community understanding of environmental fiqh, improvements in waste-sorting knowledge and skills, changes in household waste management behavior, and factors that supported or inhibited program sustainability. The analysis used data reduction, categorization, interpretation, and conclusion drawing. The study also examined changes between the conditions before and after the intervention descriptively to identify improvements in participants' awareness, skills, and participation. The results were interpreted by linking the observed behavioral changes to the implementation of environmental fiqh-based education, practical waste-sorting training, and continuous mentoring. This analytical process was intended to determine the extent to which the community service intervention contributed to sustainable household waste management practices.

The validity of the activity findings was ensured through source and technique triangulation. Source triangulation involved comparing information from residents, environmental cadres, religious leaders, community leaders, and village officials. Technique triangulation involved comparing findings from participatory observations, interviews, documentation, and activity evaluations. The researchers also confirmed member confirmation by discussing the main findings with several key participants to ensure their interpretations reflected the community's actual experiences and conditions. These procedures strengthened the findings' credibility and consistency. In addition, the activity upheld ethical principles by obtaining participants' consent, protecting the confidentiality of personal information, and respecting the community's religious, cultural, and social values. Through this methodology, the community service activity was designed not only to transfer technical knowledge but also to support active participation, behavior change, and the development of sustainable household waste management practices grounded in environmental and religious values.

RESULTS AND DISCUSSION

Results

Process and Forms of Training on the Use of Separate Trash Bins

The community service activity was carried out through a participatory training program involving village officials, religious leaders, environmental cadres, and community members. The activity began with a socialization session introducing the types and characteristics of household waste, particularly organic and inorganic waste, followed by an explanation of the importance of waste separation at the source. The socialization incorporated environmental fiqh values to strengthen participants' understanding that maintaining cleanliness and preventing environmental damage are not merely technical responsibilities but also moral and religious responsibilities. Before the training, participants completed a pretest to measure their initial knowledge of household waste management, waste classification, and environmental responsibility. The pretest results showed that the participants' initial understanding was still limited, particularly regarding proper waste classification and the practical procedures for separating household waste. The average pretest score was 58.50, indicating a need for practical, value-based environmental education.

The training continued with hands-on practice using separate trash bins for organic and inorganic waste. The bins were labeled and marked to support identification and reduce confusion during sorting. Participants directly identified various types of household waste and placed them in the appropriate containers. This participatory

method enabled participants to apply the knowledge introduced during the socialization session immediately. After the practical session, participants completed a posttest to measure changes in their understanding. The average posttest score increased to 82.50, representing an increase of 41.03% compared with the pretest results. This increase indicates that the combination of explanation, practical demonstration, and direct participation effectively improved participants' understanding of household waste separation and environmental responsibility.

The training was followed by continuous mentoring conducted by environmental cadres and village officials. The mentoring focused on ensuring participants could apply waste separation consistently at home, rather than treating the training as a one-time activity. During mentoring, cadres observed the use of separate bins, corrected incorrect classifications, and encouraged residents to maintain the practice. A Village Official explained, "We designed this separate trash bin training not only to teach people how to dispose of waste, but also to instill the awareness that taking care of the environment is part of religious responsibility. Therefore, we involve religious leaders so that the community feels that this activity is not just a village program, but also part of the values they believe in." This statement demonstrates that the training was deliberately designed to connect technical waste management with values that were familiar and meaningful to the community.

Environmental Cadres also emphasized the importance of direct practice and follow-up assistance. One cadre stated, "If it is just explained, people usually forget quickly. However, when we directly practiced separating organic and inorganic waste using different bins, they understood it better. After that, we also regularly accompanied them, so that the habit of sorting waste is really applied in each of their homes." Residents similarly reported changes in their household practices. One resident stated, "In the past, we used to just mix our trash. After attending the training and learning about it from a religious perspective, we realized that cleanliness is important. Now at home, we are used to separating waste, and the environment also feels cleaner than before." These findings indicate that the training process involved three mutually reinforcing components: value-based socialization, hands-on practice, and continuous mentoring.



Figure 1. Socialization and community works in managing organic and inorganic waste

Figure 1 illustrates the implementation of community-based waste management through socialization and direct community practice. The activities show participants receiving information on classifying and managing organic and inorganic waste, followed by hands-on practice separating waste using different bins. These activities demonstrate

that the program combined knowledge transfer with hands-on practice to help participants understand and apply proper waste-sorting procedures in their daily lives. The involvement of village officials, environmental cadres, religious leaders, and community members also reflects the program's participatory nature. Thus, the figure demonstrates how environmental education was translated into practical community action by integrating technical waste-management practices with collective awareness and environmental responsibility.

Environmental Fiqh and Waste Management Training Effectiveness

The program's effectiveness was assessed by comparing participants' knowledge before and after the training through pretest and posttest measurements. The pretest was administered before the environmental fiqh socialization and technical waste-sorting training, while the posttest was administered after the training and practical activities. The results showed an increase in participants' average scores from 58.50 on the pretest to 82.50 on the posttest. The increase of 24.00 points, or approximately 41.03%, indicates an improvement in participants' understanding of waste classification, waste separation procedures, and environmental responsibility. The findings suggest that the training not only transferred technical information but also strengthened participants' understanding of the relationship between environmental protection and religious responsibility.

Integrating environmental fiqh provided a normative foundation for the technical waste management practices introduced during the activity. Participants were encouraged to understand cleanliness, prevention of environmental damage, balance, and collective responsibility as values they could translate into concrete household practices. Village Apparatus explained, "We designed this waste management program not only to focus on the technical aspects but also to strengthen the understanding of environmental fiqh. We want the community to understand that managing waste is not just a village regulation, but part of religious responsibility. Therefore, we always involve religious leaders in every activity so that the message conveyed is more easily accepted." This statement shows that environmental fiqh served as a motivational and educational foundation, while technical training gave participants the practical means to implement these values.

Direct practice and mentoring also shaped participants' waste-sorting behavior. Environmental Cadres stated, "If it is only socialized through lectures, people usually forget quickly. However, when we practice sorting and managing waste directly, they understand better. Especially since we also regularly assist residents after the training, the habit of sorting waste gradually forms in each household." This finding indicates that repeated practice, rather than information delivery alone, supported behavioral change. The posttest improvement, combined with observations during mentoring, suggests that participants developed both cognitive understanding and practical competence. Cadres and community leaders further strengthened program continuity by providing local support and reminders after formal training ended.

Residents also reported that integrating religious values helped them reinterpret waste management as part of their daily responsibility. One resident stated, "Previously, we just threw away trash mixed. After attending the training and being explained from a religious perspective as well, we realized that maintaining cleanliness is part of worship. Now at home, we are used to separating waste, and the surrounding environment also feels cleaner." This statement aligns with the observed changes in household waste-

sorting practices. Therefore, the program's effectiveness can be understood not only from increases in pretest and posttest scores but also from changes in participants' practical engagement and reported behavior. The combination of environmental fiqh, technical training, hands-on practice, and mentoring created a more comprehensive intervention for encouraging sustainable household waste management.

Household Waste Management and Environmental Health

Implementing household waste management practices produced observable improvements in environmental cleanliness. After the training and mentoring activities, waste accumulation in residential areas and public spaces decreased, and using separate bins made household waste management more organized. Participants could identify and handle organic and inorganic waste separately, creating more opportunities for further processing and reducing mixed waste. Observations during the mentoring period and participants' accounts of household practices supported these changes. The improvement was particularly visible in areas where residents consistently separated waste. The results indicate that strengthening household-level waste management can contribute to broader environmental improvements because waste reduction begins with source-level behavioral practices.

Village Apparatus reported, "Since this household waste management program started, we have seen the village environment become much cleaner and more organized. Garbage no longer piles up in the drains or yards. We indeed encourage this program to become a community habit, because its impact is not only on cleanliness but also on the overall environmental health." Environmental Cadres similarly explained, "In the past, many drainage channels were clogged with household waste. Now, after residents started sorting and managing their waste, the ditches are cleaner and water rarely pools. This also makes the environment feel healthier and less prone to odor." These statements reinforce the observational findings that changes in household waste practices were accompanied by improvements in the physical environment, particularly regarding waste accumulation, drainage cleanliness, unpleasant odors, and standing water.

Residents also reported improved comfort and cleanliness in their immediate surroundings. One resident stated, "Compared to before, now the area around our house is cleaner and more comfortable. Trash no longer litters the place, and we are also more mindful of cleanliness. The children rarely get sick, and there are not as many mosquitoes as before." The statement reflects residents' perception that improved waste management contributed to a more comfortable living environment. However, the reported reduction in illness should be interpreted as a community perception rather than as evidence of a direct medical effect because the activity did not involve clinical health measurements. The findings instead demonstrate that improved waste management was associated with perceived improvements in sanitation, cleanliness, and environmental comfort.

Documentation from the training and community activities further supported the observations and interview findings. The combination of separate waste bins, direct sorting practices, community participation, and continued mentoring demonstrated that waste management practices were gradually becoming integrated into daily household activities. The environmental improvements observed after the intervention indicate that community empowerment can generate effects beyond knowledge acquisition by

encouraging collective action and environmental responsibility. Nevertheless, sustaining these outcomes requires continued monitoring, reinforcement by environmental cadres and village officials, and consistent household participation. Thus, the program's impact should be understood as an ongoing process of behavioral and environmental improvement rather than as a one-time outcome of the training activity.

Overall, the findings show that integrating environmental fiqh with technical waste management training produced complementary effects on knowledge, skills, awareness, and community practices. The increase between the pretest and posttest scores indicates that participants' understanding improved after receiving value-based socialization and practical training. At the same time, observations and interviews suggest that changes in household waste-sorting behavior accompanied this cognitive improvement. Environmental fiqh strengthened moral and religious motivation to maintain cleanliness and prevent environmental harm, while hands-on training translated these values into concrete waste-management skills. Continuous mentoring then supported the formation of more consistent habits. The observed reduction in waste accumulation and improvement in environmental cleanliness further indicate that household-level behavioral changes can contribute to broader community environmental conditions. These findings imply that community service programs addressing environmental problems should not rely solely on technical instruction but should use local social and cultural values to strengthen participation and sustainability. The synergy between religious values, practical competence, and community-based mentoring therefore represents a contextual empowerment strategy for promoting sustainable household waste management.

Discussion

The findings from this community service activity show that integrating environmental fiqh with technical training on separate waste bins can strengthen the community's capacity for household waste management. The participatory implementation involving village officials, religious leaders, environmental cadres, and community members aligns with the principles of community-based waste management, which emphasize active community participation as an essential to sustainable environmental management. Improvements in participants' understanding, reflected in the pretest and posttest results, along with observations of increased participation during practical activities, indicate that the program moved beyond one-way knowledge transfer toward active community empowerment. This finding is consistent with previous research emphasizing the importance of community involvement in developing sustainable waste management practices (Alimoradiyan et al., 2024; Leknoi et al., 2024). However, this program extends this approach by grounding it in environmental fiqh as a value-based foundation, positioning community participation not only as a practical mechanism but also as a form of social and moral responsibility.

The hands-on practice of separating organic and inorganic waste also supports previous findings that experiential learning can be more effective in developing practical understanding and encouraging behavioral change than passive socialization or lecture-based approaches. Participants could directly identify different types of household waste, use separate bins, and apply the sorting process to situations they encounter in daily life. The improvement between pretest and posttest results provides additional evidence that practical activities contributed to improved understanding. Nevertheless, the program

differs from conventional technical waste-sorting training because environmental cadres and village officials reinforced practical skills through continuous mentoring (Herzanita et al., 2025; Muhammad et al., 2026). This combination allowed participants to receive repeated guidance after the formal training had ended. Therefore, the findings suggest that experiential learning becomes more meaningful when followed by sustained assistance, particularly when the intended outcome is not merely increased knowledge but the formation of consistent household waste management habits.

A distinctive contribution of the program is its integration of environmental fiqh into practical environmental education. Previous research has highlighted the strategic role of religious values in developing environmental ethics and ecological awareness. The present findings support this perspective by demonstrating that concepts such as human responsibility as stewards of the Earth, maintaining cleanliness, and preventing environmental damage can be translated into concrete household waste management practices. Rather than presenting environmental fiqh solely as a theoretical or normative discourse, the program transformed these principles into practical motivation for separating and managing household waste (Aminah & Muslim, 2026; Shompa & Mohadis, 2022). Theoretically, this finding strengthens the view that value-based frameworks rooted in local religious and social contexts can influence environmental behavior. Practically, this integration gives community facilitators an alternative strategy for communicating environmental messages in a culturally meaningful way that connects more closely to participants' everyday values and beliefs.

The synergy between environmental fiqh and technical waste management training further supports the argument that sustainable behavioral change requires both practical competence and internal motivation. This finding aligns with Baba-Nalikant et al. (2023), who emphasized that environmental behavioral change is more sustainable when technical knowledge is paired with value strengthening. The program's technical component provided participants with the knowledge and skills needed to separate household waste correctly. At the same time, environmental fiqh strengthened their motivation to maintain the practice as part of their broader responsibility toward the environment. The continued waste-sorting observed during the mentoring period indicates that the intervention had effects beyond the training session itself. From a practical perspective, this suggests that community service programs should combine technical training, contextual value education, and follow-up mentoring rather than relying exclusively on short-term socialization. Such a model can increase the possibility that newly acquired practices will become embedded in household routines.

The environmental improvements observed after implementing waste management practices are also consistent with previous studies showing that waste separation at the source and organic waste management can reduce waste accumulation, unpleasant odors, and potential breeding sites for disease vectors such as mosquitoes and flies. Cleaner residential surroundings, improved drainage conditions, and reduced standing water observed during the activity indicate that household-level waste management can generate wider environmental benefits. These findings also support Br (2026), who argues that environmental programs should be assessed not only by physical changes but also by the development of collective awareness and a culture of environmental responsibility. Theoretically, this reinforces a multidimensional understanding of environmental empowerment in which knowledge, values, behavior, participation, and environmental conditions are interconnected. Practically, the findings show that relatively simple interventions, such as separate-bin training combined with

mentoring, can drive visible improvements in community environmental conditions when residents are actively involved.

Overall, this community service activity contributes by developing an integrated empowerment model that connects religious values, technical environmental skills, participatory learning, and ongoing community support. The program shows that environmental fiqh can serve not only as a normative framework but also as an educational tool for strengthening motivation and collective responsibility in household waste management. Together, these elements offer a contextual alternative to conventional waste management programs that primarily emphasize infrastructure or technical knowledge. Theoretically, the activity strengthens the connection between religion-based environmental ethics and community-based environmental management. Practically, it offers a replicable approach for community organizations, village authorities, environmental cadres, and religious leaders seeking to promote sustainable waste management through locally relevant strategies. However, the model's long-term effectiveness depends on continued mentoring, community participation, and institutional support to sustain waste-sorting practices and develop them into a lasting environmental culture.

CONCLUSION

This study concludes that integrating environmental fiqh values with practical training on waste segregation can improve community awareness, knowledge, skills, and household waste management practices. Participatory learning, hands-on activities, and ongoing mentoring encouraged residents to consistently separate organic and inorganic waste, improving environmental cleanliness, sanitation, and community comfort. The findings highlight that value-based environmental education can complement technical waste management approaches and provide an adaptable model for communities with similar social and religious characteristics. Future research should include broader participants and locations, use quantitative measures of knowledge and behavioral change, and conduct longitudinal evaluations to assess the sustainability of waste segregation practices and their environmental impacts. This study suggests that integrating religion-based environmental values into community empowerment programs can strategically foster sustainable waste management behavior and support the development of contextual environmental policies and initiatives.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

While preparing this manuscript, the authors used AI tools only for language editing and stylistic improvements. The authors conducted all scientific analyses, interpretations, and final assertions independently and accept full accountability for the published work.

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