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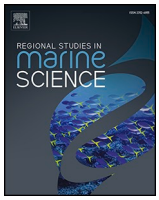

Exploratory factors in community-based adaptation strategies for managing marine microplastics

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ABSTRACT

The growing issue of marine microplastics poses significant environmental challenges, necessitating effective control strategies informed by community engagement. Conducted in Jakarta, Indonesia, this research employs exploratory factor analysis, cluster analysis, and logistic regression to identify key factors influencing public willingness to engage in microplastic control initiatives. The study identifies five main determinants: asset integration, responsive flexibility, coordinated systems, empowerment through knowledge, and stakeholder activation. Notably, asset integration ($p = 0.004$), responsive flexibility ($p = 0.01$), and coordinated systems ($p < 0.001$) significantly enhance public participation, suggesting that practical and adaptable infrastructure is crucial for increasing community engagement. However, empowerment through knowledge, while positively trending, does not show statistical significance ($p = 0.422$), indicating that awareness alone may not be sufficient to motivate community action. Stakeholder activation is identified as a particularly critical factor ($p < 0.001$), substantially boosting participation levels. Cluster analysis further divides participants into two groups: 'Proactive Participants' ($n = 328$), demonstrating high engagement, and 'Skeptical Observers' ($n = 117$), showing lesser willingness. Additionally, the study reveals that age significantly impacts engagement, with younger individuals (20–29 years) demonstrating significantly lower willingness ($p = 0.002$). These findings highlight the necessity for targeted policies and community-driven actions to effectively mitigate marine microplastic pollution. They underscore the need for integrated strategies that combine rigorous scientific research with robust community involvement to develop sustainable solutions for controlling marine microplastics.

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1. Introduction

The increasing prevalence of microplastics in marine environments has become a pivotal environmental issue (Gallo et al., 2018; Shukla et al., 2024; Wootton et al., 2024), eliciting significant concern due to their persistent and pervasive nature. Defined as small plastic particles under five millimeters in diameter, these microplastics originate from various sources, including the breakdown of larger plastic debris and microbeads from health and beauty products (Díaz-Mendoza et al., 2020; Shamskhany et al., 2021; Zhao et al., 2022). Once they enter marine ecosystems, microplastics are particularly challenging to remove and have been detected in oceans and seas globally, adversely affecting water quality, marine life, and human health (Elgarahy et al., 2021; Mishra et al., 2021; Vivekanand et al., 2021). In Africa, significant research efforts have focused on developing effective policies, legislation, and regulatory frameworks to manage microplastic pollution. These efforts have led to the creation of a sustainable, harmonized approach for microplastic management, integrating various best practices from around the continent (Deme et al., 2022). In Asia, studies have highlighted the ecological and toxicological impacts of microplastics across various freshwater and marine environments. Notably, the prevalence of microplastics in Asian water bodies often follows a gradient, with higher concentrations observed from China to Bangladesh, underscoring the urgent need for region-specific research and interventions (Sadia et al., 2024). The situation in Vietnam exemplifies regional responses to microplastic pollution, where adapted methodologies have been widely adopted by researchers to monitor microplastics in sediments and surface waters across diverse ecological settings, including rivers, lakes, bays, and beaches (Strady et al., 2021). These efforts reveal significant microplastic accumulation, impacting aquatic organisms across multiple trophic levels (Phuong et al., 2022). In Vietnam, an adapted methodology has been widely adopted by local researchers to monitor microplastics in the sediments and surface waters across 21 environments, including rivers, lakes, bays, and beaches, which underscores the widespread presence of microplastics in these settings (Strady et al., 2021). In Indonesia, the focus intensifies on Jakarta due to its unique geographic and socio-economic position, making it a pivotal case study for understanding the dynamics of marine microplastics (Cordova et al., 2024; Diansyah et al., 2024). Despite over 250 studies conducted over the last decade, including reviews and original research, there remains a gap in comprehensive understanding and management of microplastic distribution within the region (Isfarin et al., 2024). Local regulations aimed at limiting plastic usage have been supported by effective monitoring, sanctioning, and public education initiatives, yet these measures require further enhancement and coordination (Isfarin et al., 2024).

The challenge posed by marine microplastics is multidimensional, involving complex interactions between natural processes and human activities (Nguyen et al., 2023; Hu et al., 2024). Microplastics are not only a direct result of human waste management practices but are also influenced by factors such as urban development, population density, and local governance. Their small size allows them to be ingested by marine organisms, leading to bioaccumulation and biomagnification of toxic substances within the marine food chain (Miller et al., 2020, 2023; Gola et al., 2021), which not only impacts marine biodiversity but also poses health risks to humans consuming contaminated seafood. Despite the recognition of these problems, current strategies for managing microplastic pollution are fragmented and often ineffective (Vaid et al., 2021; Hettiarachchi and Meegoda, 2023). Research into the sources, distribution, and impacts of microplastics has been hampered by methodological discrepancies and a lack of standardized analysis techniques (Rai et al., 2021; Adhikari et al., 2022). Furthermore, public awareness and engagement in controlling marine microplastic pollution remain low (Garcia-Vazquez and Garcia-Ael, 2021; Dowarah et al., 2022), partly due to insufficient dissemination of information and lack of visible immediate impact to individual actions.

The necessity for a comprehensive approach to tackle marine microplastics is evident (Hasan Anik et al., 2021; Onyena et al., 2022; Mubin et al., 2023). Such an approach requires integrating scientific research, which can provide a detailed understanding of the problem's scope and nuances, with public policy and community-based strategies. These strategies should aim not only to mitigate the existing pollution but also to prevent future contributions to microplastic waste. Effective management practices need to be bolstered by robust regulatory frameworks that encourage reduction, reuse, and recycling of plastic materials (Mateo et al., 2022; Beena and Muringayil, 2024). Additionally, fostering public awareness and active participation in pollution reduction can significantly enhance the effectiveness of these strategies (Oh and Hettiarachchi, 2020; Zhang et al., 2020; Yadav et al., 2022).

There is a notable disparity in the methodologies used across different studies, leading to challenges in comparing and synthesizing data on marine microplastics (Alimi et al., 2021; Montoto-Martínez et al., 2022; Lin et al., 2024). This inconsistency extends to the methods for sampling, identifying, and quantifying microplastics, complicating efforts to assess the true scale of pollution and its impacts. Standardizing these methodologies is crucial for developing a clear, global understanding of microplastic distribution and its ecological consequences (Provencher et al., 2020; Pérez-Guevara et al., 2022). While there is growing literature on the ecological and health impacts of marine microplastics (Ajith et al., 2020; Sana et al., 2020; Khalid et al., 2021; Prata et al., 2021; Yang et al., 2022; Yuan et al., 2022), there is less focus on the socio-economic dimensions, particularly regarding how public perceptions and behaviors affect and are affected by microplastic pollution. Understanding these human dimensions is essential for designing effective interventions that not only mitigate existing pollution but also prevent future contributions. Despite the severity of the microplastic pollution problem, public awareness and active participation in mitigation strategies are not at the level required to effect substantial environmental change. This gap in engagement may stem from the lack of visible, immediate impacts of microplastics compared to other environmental issues, which can dilute public perception of the urgency of the problem. Addressing these gaps requires a multidisciplinary approach that combines rigorous scientific research, enhanced public education, community involvement, and robust policymaking. By bridging these gaps, the study aims to contribute to the development of more effective, sustainable, and community-supported marine microplastic management strategies, particularly in densely populated and environmentally critical areas like Jakarta.

The present study in Jakarta aims to fill the gaps in our understanding by examining how different factors influence public willingness to engage in marine microplastic management strategies. By identifying key determinants of public engagement and understanding demographic variations in environmental activism, this research seeks to contribute valuable insights that could guide policymaking and community initiatives aimed at controlling and mitigating the impact of marine microplastics. This comprehensive analysis is expected to provide a solid foundation for developing targeted, effective, and sustainable interventions to address one of the most pressing environmental issues of our time.

2. Hypothesis development

The Jakarta microplastic management study endeavors to elucidate the multifaceted influences on individuals' willingness to participate in initiatives aimed at controlling and reducing microplastic pollution. This exploration is rooted in the integration of various theoretical models and empirical findings from environmental psychology and management sciences, forming a cohesive framework that guides the empirical investigation.Figs. 1 and 2

H1. Asset integration

The first hypothesis posits that the integration of tangible

environmental assets such as public-accessible recycling facilities and visible anti-pollution measures directly influences the willingness of the public to engage in microplastic management (Antohi et al. 2023; Stoett et al. 2024). This hypothesis stems from the resource mobilization theory, which suggests that the availability of resources significantly enhances individual and collective action towards a common goal (Farjam et al. 2020; Ntamu et al. 2023). Asset integration in the context of microplastic management refers to the physical and logistic infrastructure that facilitates effective waste management and pollution control (Mahmud et al. 2022; Hettiarachchi and Meegoda, 2023; Thacharodi et al. 2024). The presence of these assets makes it feasible and convenient for individuals to participate in microplastic management practices, thus potentially increasing their willingness to engage in such activities.

H2. Responsive flexibility

The second hypothesis asserts that responsive flexibility in policy and operational frameworks can positively affect public engagement in microplastic management. This flexibility might include adaptive policies that respond to emergent research findings about microplastics and their impacts (Tu et al. 2022; Hassan et al. 2024; Yang et al. 2024), or operational practices that adjust to seasonal variations in waste volumes (Jiang et al. 2020; Roufou et al. 2021). The concept of responsive flexibility is derived from the adaptive management literature (Zhang et al. 2021; Szemző et al. 2022; van Assche et al. 2022), which highlights the importance of being able to change strategies in response to new information or changing conditions. This adaptability is crucial in managing environmental issues like microplastics (Senathirajah and Palanisami, 2023), where new research can frequently shift the understanding of impacts and mitigation strategies.

H3. Coordinated systems

The third hypothesis is that well-coordinated environmental management systems, which include integration between various governmental and non-governmental bodies (Yang et al. 2021; Hung et al. 2022; Kurniawan et al. 2024), significantly encourage public participation in microplastic management. The effectiveness of environmental governance systems often hinges on their capacity to coordinate actions across different sectors and scales (Hamilton et al. 2020; Hedlund et al. 2023). Effective coordination ensures that initiatives are synergistic and that resources are used efficiently (Arputharaj et al. 2024), which can enhance public trust and willingness to participate in proposed solutions.

H4. Empowerment through knowledge

This hypothesis suggests that educational outreach and awareness campaigns significantly impact public willingness to engage in microplastic management by empowering individuals with knowledge about the environmental, health, and societal impacts of microplastics. Education increases awareness and understanding, which are critical components of behavioral change theories such as the Theory of Planned Behavior, where knowledge is a key determinant of behavioral intentions (Al Mamun et al. 2020; Hao et al. 2020; Khaliqi et al. 2023).

H5. Stakeholder activation

Stakeholder activation, involving the active participation of local communities, industries, and policymakers, is hypothesized to enhance public engagement in microplastic management. This approach is grounded in stakeholder theory, which posits that organizations are more successful when they actively involve their stakeholders in decision-making processes (Tian and Wang 2024a; Ghezal, 2024). In environmental management, engaging stakeholders not only helps in garnering broad support for initiatives but also in tapping into local knowledge and resources (Chanza and Musakwa, 2021; Lukman et al. 2023; Picavet et al. 2023; Kurniawan et al. 2024), which can lead to more effective and culturally appropriate solutions.

H6. Age group

Finally, the influence of demographic factors on environmental behavior is captured in the sixth hypothesis, which suggests that age significantly affects willingness to participate in microplastic management. Different age groups may have varying perceptions of environmental risks and responsibilities (Díaz et al. 2020; Calculli et al. 2021; Lorenzini et al. 2021), which can influence their engagement levels. Research in environmental psychology often highlights age as a predictor of environmental concern and action (Wallis and Loy, 2021; Suryawan and Lee, 2023), with findings suggesting that younger individuals are more likely to engage in pro-environmental behaviors due to higher levels of environmental awareness and education. The theoretical underpinning of these hypotheses integrates the resource-based view, stakeholder theory, and behavioral change theories to create a robust framework for analyzing how various factors influence public willingness to participate in microplastic management. This comprehensive approach not only provides a deep understanding of the factors driving public engagement in Jakarta but also contributes to the broader discourse on sustainable environmental practices. By exploring these hypotheses, the study aims to offer actionable insights that can guide policy development, enhance public engagement strategies, and ultimately contribute to effective microplastic management in urban environments.

3. Method

3.1. Study design

The research on microplastic management in Jakarta aimed to dissect the multifaceted factors influencing effective strategies in microplastic pollution control by closely examining the perceptions and behaviors of a cross-section of the city's residents. The study was crafted to gather insights into how individuals perceive microplastic issues and what actions they are taking or are willing to take to mitigate these environmental challenges. Understanding these perceptions and behaviors is crucial for developing targeted and efficient microplastic management policies and interventions tailored to the specific needs and realities of Jakarta's diverse population. To achieve this, the study employed an Exploratory Factor Analysis (EFA), a statistical approach used extensively in environmental research to uncover latent

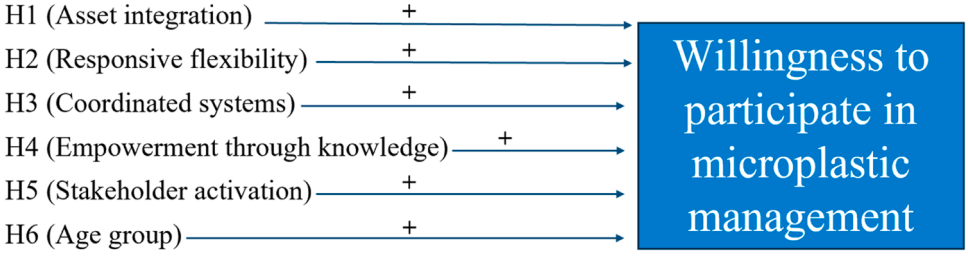

Fig. 1. Conceptual framework for microplastic management adaptation.

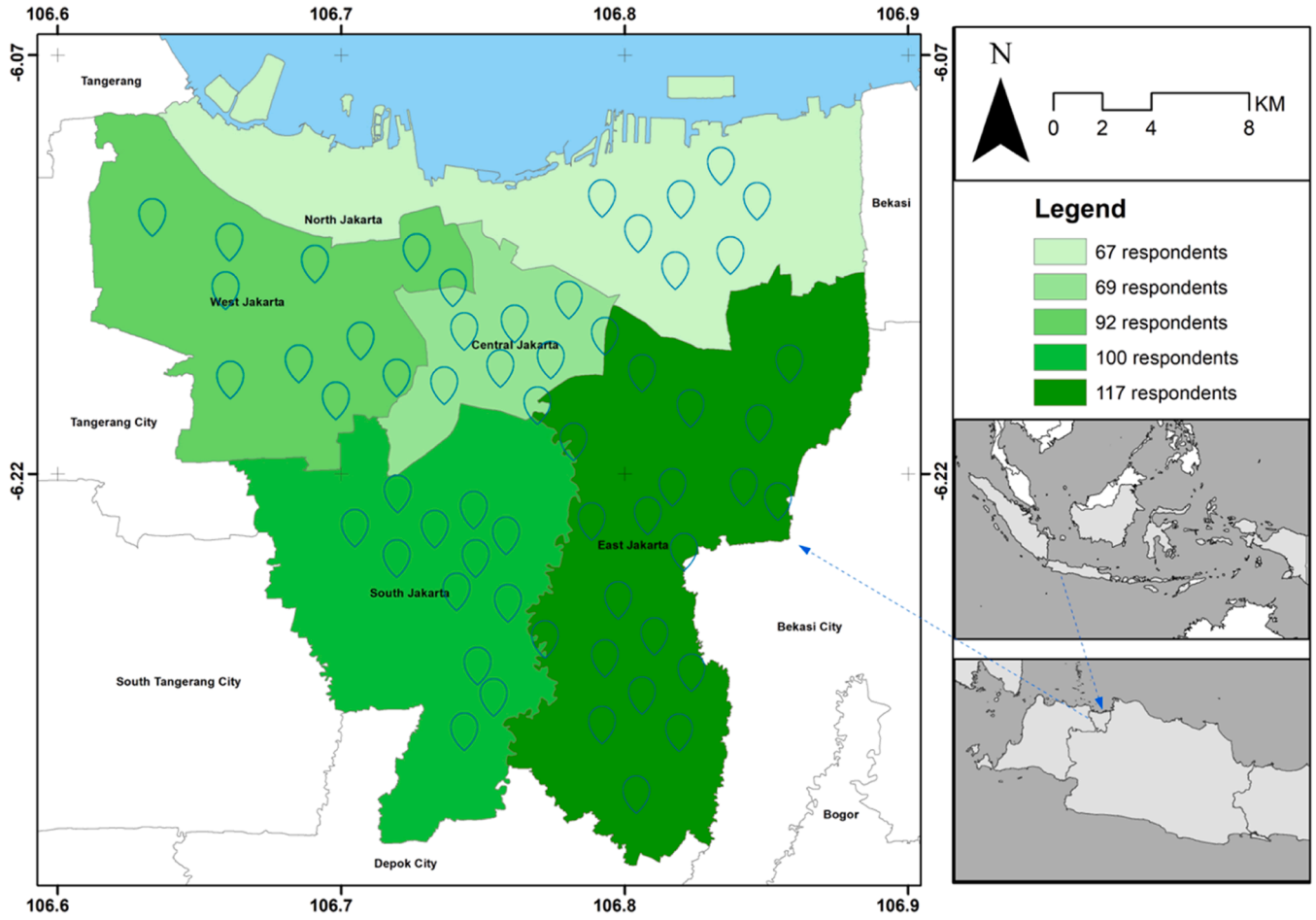

Fig. 2. Map of Jakarta highlighting study locations for microplastic management research.

relationships within complex, multidimensional data sets. The EFA was chosen for its robustness in identifying not obvious or latent constructs that influence environmental behavior and perceptions among populations. It aimed to reduce the extensive data collected through surveys into simpler, interpretable underlying factors that represent the different dimensions of how residents relate to and manage microplastic pollution.

A sample size of 445 residents was determined to be statistically adequate for factor analysis, ensuring that the results would be both reliable and generalizable across the urban setting of Jakarta. This sample size was based on guidelines that suggest a participant-to-variable ratio of at least 10:1, which is considered sufficient to achieve stable and meaningful results in an EFA. The study's sample was carefully compiled to encompass a broad demographic spectrum, including varied age groups, genders, educational backgrounds, and socioeconomic statuses, providing a comprehensive overview of the community's attitudes and practices regarding microplastic management. The survey instrument used in the study was meticulously developed to cover a wide range of questions related to microplastic awareness, attitudes towards microplastic pollution, personal behaviors concerning plastic use and disposal, and support for potential microplastic management policies. The survey questions were designed to be answered on a Likert scale, providing a quantitative measure of residents' attitudes and perceptions which are particularly amenable to analysis via EFA. This scale approach allows for a nuanced capture of the degrees of agreement or disagreement with the presented statements, facilitating a more detailed analysis of the subtleties in participants' responses.

Before the main survey was administered, a pilot test with 55 respondent was conducted with a smaller subset of the population. This preliminary phase was crucial for validating the questionnaire's effectiveness in capturing the intended data and for ensuring that the questions were comprehensible and culturally appropriate for the Jakarta context. Feedback from the pilot test led to refinements in the survey design, ensuring that the language and framing of questions were clear and that the survey as a whole was well-structured and unbiased.

3.2. *Sampling procedure*

The study on microplastic management in Jakarta was meticulously designed to capture a broad spectrum of data reflecting the city's diverse socio-demographic landscape. Given Jakarta's complex urban environment, which includes a wide range of economic and cultural backgrounds, a stratified random sampling technique was employed to accurately gather diverse perspectives on microplastic pollution across different community sectors. The city was divided into its five administrative regions each offering distinct environmental challenges and community profiles critical for understanding varied attitudes and behaviors towards microplastic management. Within these regions, neighborhoods were randomly selected to avoid biases such as selecting areas based on visible pollution levels or public awareness of environmental issues. This randomness ensured that both highly polluted areas and those less visibly affected were included, providing a comprehensive overview of the city's microplastic management issues. Households within these neighborhoods were then randomly chosen using updated residential lists from local community offices. A computer-generated sequence selected the households, which were surveyed based on a proportional allocation method considering each region's population size. This approach maintained the statistical power of the study across

varying urban settings and population densities.

To engage participants effectively, they were given a clear explanation of the study's goals and methods, and informed consent was obtained. This ethical approach respected participants' rights and enhanced data quality, as well-informed participants are more likely to provide honest and thoughtful responses. Significant educational initiatives were also implemented to boost public understanding and engagement. The community was educated on various microplastic sampling techniques, highlighting the importance of standardized procedures for reliable data collection. Moreover, interviewers received specialized training to effectively communicate complex information about microplastic pollution, its sources, impacts, and the global efforts required for its control. The study targeted respondents who had either a background understanding of microplastics or expressed a genuine interest in environmental issues, ensuring that the data collected was insightful and meaningful. These educational efforts were pivotal in enhancing community engagement and the success of the microplastic management efforts. By raising awareness and fostering a better understanding through targeted education and trained communicators, the study nurtured a well-informed community ready to support and participate in ongoing and future environmental conservation projects. This structured approach not only informed the public about the technical aspects of microplastic management but also empowered them to actively contribute to discussions and initiatives aimed at reducing microplastic pollution.

In conducting the study on microplastic management in Jakarta, the selection of the city was informed by its diverse geographical layout, which includes varied socio-economic backgrounds and different levels of engagement in previous plastic management initiatives. This diversity was crucial to capture a comprehensive range of data on community behaviors and attitudes toward microplastic pollution. To analyze this data effectively, the study applied k-means clustering a statistical method that sorts data into clusters based on similarities in survey responses specifically related to adaptive capacity in managing microplastics (Sianipar et al., 2024; Suhardono et al., 2024; Suryawan et al., 2024, 2025a; Yang et al., 2025). This clustering helped identify distinct groups within the population that shared common characteristics regarding their ability and readiness to tackle microplastic issues. After forming these clusters, an Analysis of Variance (ANOVA) was conducted to test the significance of the differences between these clusters in terms of their adaptive capacity factors. This step was critical to ensure that the clusters identified were not only statistically distinct but also meaningfully different in ways that could inform targeted policy interventions. The combination of geographic and socio-economic sampling with sophisticated statistical analysis allowed the study to generate nuanced insights into how different sectors of Jakarta's population perceive and respond to microplastic challenges. This approach aimed to enhance the effectiveness of future microplastic management strategies by tailoring them to the specific needs and capacities of each identified cluster within the city's diverse urban environment.

3.3. Data collection and questionnaire

To ensure a high response rate and accurate data collection, the survey was administered in two modes: in-person interviews and online submissions. In-person interviews were conducted by trained field researchers who visited selected households. This method was particularly important in areas with limited internet access or among demographics less comfortable with technology. It also allowed for any questions or clarifications that the participants might have about the survey, ensuring the accuracy and completeness of the responses. For participants comfortable with digital tools, an online version of the survey was made available. This was distributed via email to those who opted for digital communication, along with clear instructions on how to complete and submit the survey electronically. The online method provided a convenient and quick option for participants, potentially increasing the willingness to participate.

Throughout the data collection process, ethical considerations were strictly adhered to. Participants were informed about the purpose of the study and their rights regarding data privacy and voluntary participation. Informed consent was obtained from all participants, and assurances were given that all responses would be anonymized and used solely for research purposes. These ethical practices not only complied with academic and professional standards but also built trust with participants, which is crucial for collecting honest and thorough responses. By employing these rigorous data collection methods, the study aimed to gather high-quality data that could be robustly analyzed to provide insights into the community's perceptions and behaviors towards microplastic management in Jakarta, guiding future interventions and policies.

The survey utilized in the Jakarta microplastic management study was carefully constructed to explore a broad range of factors affecting individual and community attitudes towards microplastic pollution. Table 1 details the specific items included in the questionnaire, each crafted to gauge the perceptions and proactive stances of residents regarding various aspects of microplastic management. These items encompass a variety of themes from adaptive sampling methods, which are crucial for monitoring pollution levels, to the importance of community education and corporate involvement in microplastic reduction efforts. Each question in the survey begins with a personal affirmation ("I believe," "I find," "I consider," etc.), inviting respondents to express their level of agreement on a five-point Likert scale. This approach ensures that the data collected reflects personal conviction and the perceived efficacy of different microplastic management strategies. The questions were designed to cover both technical aspects, such as the identification of microplastic sources and real-time data analysis, and community-oriented responses like public health initiatives and educational outreach. The questionnaire's structure aims to capture a holistic view of the community's engagement with and attitudes towards microplastics, addressing both direct management strategies and broader educational and policy-related aspects. By doing so, the study seeks to identify key factors that drive effective microplastic management and highlight areas where public knowledge and engagement can be enhanced. This comprehensive approach ensures that the findings will provide actionable insights for policymakers, environmental organizations, and community leaders to develop targeted interventions for reducing microplastic pollution in Jakarta.

3.4. Data analysis

In the study focused on microplastic management in Jakarta, a comprehensive data analysis was structured to unravel the intricacies of public perceptions and behaviors towards microplastic pollution. This involved a series of statistical techniques tailored to extract, analyze, and interpret the underlying data collected from 445 residents of Jakarta. The initial step in the data analysis was an Exploratory Factor Analysis (EFA) using the principal component analysis (PCA) method with Varimax rotation. This approach helped identify latent constructs by reducing the dataset to a few interpretable factors. The Varimax rotation, a method that simplifies the factor structure by maximizing the variance of squared loadings, was particularly beneficial. It clarified which variables grouped together under the same factors, thus aiding in the interpretation of data by producing factors that are mutually orthogonal.

To verify the appropriateness of EFA, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was calculated, ensuring that the data was suitable for the analysis. The KMO measure was complemented by Bartlett's Test of Sphericity to confirm that the correlation matrix of the items was not an identity matrix, thus justifying the factor analysis. Following the factor identification, the study applied cluster analysis to segment the surveyed population into meaningful groups. K-means clustering was chosen for this task due to its efficiency in handling large

Table 1
Survey statement for assessing community attitudes towards microplastic management.

Items	5-Likert Statement	Public involvement in microplastic management
Adaptive sampling techniques for microplastics	I believe adaptive sampling techniques are crucial for the effective monitoring of microplastics.	Implementing versatile sampling methods that adapt to various environmental conditions to monitor microplastic pollution accurately.
Dynamic analytical techniques	I find dynamic analytical techniques essential for the accurate analysis of microplastic pollution.	Employing advanced analytical methods to identify and quantify microplastic particles, providing essential data for tracking pollution and assessing mitigation strategies.
Community response to microplastics	I consider community response critical in addressing the challenges posed by microplastics.	Engaging local communities in microplastic cleanup efforts and prevention activities to reduce environmental impact and promote sustainable practices.
Wildlife adaptability studies	I think studies on wildlife adaptability to microplastics are important for understanding ecological impacts.	Investigating how wildlife adapts to or is affected by microplastics, providing insights into ecological impacts and informing biodiversity conservation strategies.
Source identification of microplastics	I feel that identifying the sources of microplastics helps significantly in mitigating pollution.	Determining the primary sources of microplastic pollution to target reduction efforts effectively and prevent further environmental contamination.
Public health response to microplastics	I agree that public health responses to microplastics are adequate in addressing associated risks.	Evaluating the health risks associated with microplastic exposure and implementing public health measures to protect communities.
Biodegradable alternatives research	I support research into biodegradable alternatives as vital for reducing microplastic pollution.	Promoting the development and use of biodegradable materials to replace conventional plastics, thereby reducing future microplastic pollution.
Microplastic education and adaptation	I advocate for education on microplastics to be adapted to increase community awareness and action.	Enhancing public awareness through education on the sources, impacts, and ways to mitigate microplastics, adapting content as new research emerges.
Corporate adaptation to microplastic reduction	I perceive corporate adaptation to reduce microplastic pollution as necessary.	Encouraging industries to adopt production processes that minimize microplastic waste, as well as promoting corporate responsibility in environmental stewardship.
Ecosystem resilience studies	I see studying ecosystem resilience as helpful in formulating effective microplastic management strategies.	Studying ecosystems' ability to recover from microplastic pollution and identifying key resilience factors that can help in restoration and management.
Techniques for microplastic quantification	I recognize advanced techniques for quantifying microplastics as necessary for environmental monitoring.	Developing precise methods for measuring microplastic levels in various environments to monitor trends and evaluate the effectiveness of control measures.
Modular research approaches	I view modular research approaches as effective in addressing various aspects of microplastic pollution.	Utilizing flexible research frameworks that can be tailored to address different aspects of microplastic pollution and dynamically adapt to new findings.
Quick response monitoring systems	I value quick response monitoring systems as essential for real-time tracking of microplastic levels.	Setting up real-time monitoring systems that can provide immediate data on microplastic pollution levels, enabling swift responses and adjustments in management strategies.
Adaptive experimental designs	I appreciate adaptive experimental designs as crucial for the evolving nature of microplastic research.	Designing experiments that can be adjusted based on initial findings to better understand microplastic dynamics and control methods.
Flexible data collection models	I endorse flexible data collection models as necessary to manage the diverse sources of microplastics.	Creating data collection frameworks that can integrate diverse environmental data sources, enhancing the comprehensiveness and depth of microplastic research.
Real-time data analysis techniques	I find real-time data analysis techniques crucial for immediate insights into microplastic pollution.	Applying real-time analytics to process large volumes of environmental data, offering timely insights that can inform microplastic control efforts.
Responsive stakeholder engagement	I trust that responsive stakeholder engagement enhances the effectiveness of microplastic management policies.	Fostering active collaboration among stakeholders, including governments, businesses, NGOs, and the public, to ensure a unified approach to microplastic management.
Scalable pollution tracking systems	I affirm that scalable pollution tracking systems are important for national and global microplastic management.	Developing scalable systems capable of expanding in response to increased data needs or broader geographic coverage for comprehensive microplastic tracking.
Dynamic resource allocation strategies	I uphold dynamic resource allocation strategies as improving the efficiency of microplastic research and cleanup.	Dynamically allocating resources based on the most pressing needs and opportunities in microplastic control, ensuring optimal use of available funds and efforts.
Agile policy implementation frameworks	I support agile policy implementation frameworks as necessary to respond quickly to new research on microplastics.	Crafting flexible policy frameworks that can quickly incorporate scientific advancements and community feedback into microplastic legislation and regulation.
Adaptive cleanup technologies	I believe adaptive cleanup technologies are essential for effectively reducing microplastic pollution.	Investing in technologies designed to efficiently remove microplastics from various environments, adapting to different types and scales of pollution.
Integrated microplastic monitoring networks	I acknowledge integrated microplastic monitoring networks facilitate better management and control of microplastic pollution.	Building networks that combine data from multiple monitoring efforts to provide a holistic view of microplastic pollution and its control across regions.
Standardized sampling protocols	I maintain that standardized sampling protocols are crucial for consistent and reliable	Establishing consistent protocols for sampling microplastics to ensure

(*continued on next page*)

Table 1 (*continued*)

Items	5-Likert Statement	Public involvement in microplastic management
	microplastic data collection.	reliable data collection across studies and locations.
Centralized data repositories	I argue for centralized data repositories to enhance the sharing and analysis of microplastic research data.	Creating central databases to store and share microplastic research data, facilitating access for researchers and policymakers globally.
Coordinated clean-up initiatives	I advocate for coordinated clean-up initiatives as effective in reducing microplastic pollution.	Organizing widespread cleanup events that mobilize communities to physically remove microplastics from local environments.
Systematic public awareness programs	I insist that systematic public awareness programs are essential for educating the public about the dangers of microplastics.	Conducting regular educational campaigns to increase public knowledge of microplastics and encourage preventative actions.
Unified microplastic research agendas	I propose a unified research agenda on microplastics to facilitate focused and comprehensive studies.	Aligning research priorities across institutions and countries to tackle the most critical issues in microplastic control effectively.
Organized stakeholder forums	I confirm organized stakeholder forums are important for collaborative decision-making in microplastic management.	Hosting forums that bring together key stakeholders to discuss and coordinate microplastic control strategies effectively.
Regulatory compliance systems	I agree that regulatory compliance systems are necessary to ensure adherence to microplastic pollution standards.	Implementing systems to ensure that microplastic regulations are followed, supporting enforcement with technology and policy.
Strategic resource allocation	I champion strategic resource allocation as crucial for supporting long-term microplastic management initiatives.	Carefully directing resources to areas that maximize impact on microplastic reduction and control, including research, public education, and infrastructure.
Community outreach programs	I believe community outreach programs effectively engage the public in microplastic reduction efforts.	Extending outreach efforts to engage communities directly in learning about and participating in microplastic control activities.
Academic studies on microplastics	I think academic studies on microplastics are essential for deepening our understanding of their impacts.	Supporting academic research that deepens understanding of microplastic pollution's sources, impacts, and management.
Microplastics curriculum development	I consider developing a microplastics curriculum crucial for educating future generations on environmental conservation.	Developing educational curricula that incorporate lessons on microplastics, their impacts, and how to combat them.
Public seminars on microplastic pollution	I find public seminars on microplastic pollution effective in spreading knowledge and fostering community action.	Offering seminars to educate the public on microplastic issues and gather community feedback on proposed solutions.
Research publications on microplastics	I hold that publishing research on microplastics is important for informing the public and policymakers.	Publishing detailed research findings to broaden the knowledge base and inform public and policy discussions on microplastics.
Educational workshops for policymakers	I recognize educational workshops for policymakers as necessary to guide informed microplastic legislation.	Providing workshops for policymakers to ensure they are informed about the latest research and effective strategies for microplastic control.
Online courses on microplastic management	I support online courses on microplastic management for reaching a broader audience.	Offering comprehensive online courses to educate a broader audience about microplastics and how to mitigate their presence.
School programs on environmental conservation	I see school programs on environmental conservation as crucial for early education on microplastics.	Implementing educational programs in schools to teach young students about environmental conservation and the specific challenges posed by microplastics.
Community-led microplastic initiatives	I value community-led microplastic initiatives as effectively addressing local pollution issues.	Supporting grassroots initiatives that empower local communities to take action against microplastic pollution.
Policy advocacy for microplastic reduction	I advocate for policy advocacy for microplastic reduction as essential for influencing governmental action.	Engaging in advocacy to promote policies that reduce microplastic production and increase recycling and proper waste management.
Stakeholder collaboration in microplastic studies	I support stakeholder collaboration in microplastic studies as enhancing the scope and impact of research.	Enhancing collaboration among all parties involved in microplastic research to increase the scope and impact of studies.
Public engagement in microplastic cleanups	I participate in public engagement in microplastic cleanups to foster a hands-on approach to pollution reduction.	Encouraging the public to participate in cleanups, fostering a hands-on approach to reducing microplastic pollution.
Grassroots movements against microplastics	I encourage grassroots movements against microplastics as crucial for community-driven environmental advocacy.	Supporting movements that push for greater awareness and action on microplastics at the community level.

datasets. This method partitioned the respondents into clusters based on their responses (Sianipar et al., 2024; Suryawan et al., 2024; Suryawan and Lee, 2024), reflecting distinct attitudes and perceptions towards microplastic management. The next analytical step was to employ binary logistic regression to understand how the factors derived from the EFA influenced the willingness of respondents to engage in microplastic management practices. This regression analysis was crucial for testing the hypotheses:

- H1 (Asset integration): The integration of environmental assets influences public willingness to engage in microplastic management.
- H2 (Responsive flexibility): The ability of systems to adapt responsively enhances engagement in microplastic management.
- H3 (Coordinated systems): Well-coordinated environmental management systems increase public participation in microplastic management.
- H4 (Empowerment through knowledge): Educational outreach about microplastics significantly impacts public willingness to participate.
- H5 (Stakeholder activation): Active involvement of stakeholders is crucial for effective microplastic management.
- H6 (Age group): Different age groups perceive the need for microplastic management differently, influencing their anxiety and willingness to engage.

In the study examining community socio-demographic factors and attitudes toward microplastic management in Jakarta, the Chi-Square test of independence was used to analyze the effects of demographics on engagement. This test is particularly effective for determining significant associations between categorical variables, such as age, gender, income level, and educational background, and levels of engagement

with microplastic management. The data for this analysis was cross-tabulated to align demographic categories with engagement levels. A traditional significance level of 0.05 was adjusted to recognize more nuanced associations within the data. The thresholds for significance were set at less than 1 % ($p < 0.01$), less than 5 % ($p < 0.05$), and less than 10 % ($p < 0.10$). A result with $p < 0.01$ indicated a very strong likelihood that the observed association was statistically significant, suggesting substantial demographic effects on engagement levels. A p-value less than 0.05 confirmed reliable associations, while a p-value less than 0.10 indicated potential trends that, although not as strong, were still worthy of consideration. The report also included Asymptotic Significance (2-sided) values to provide a more accurate p-value, particularly useful for large sample sizes typical in community surveys. This adjustment helps verify whether the observed patterns are generalizable to the wider population and does not assume a specific direction of influence by demographic factors. This statistical approach allowed the study to deliver a detailed analysis of how various demographic groups in Jakarta interact with microplastic management initiatives, facilitating the development of more targeted and effective strategies for community engagement.

Each hypothesis was tested by examining the coefficients in the logistic regression model, which provided insights into the predictors of willingness to participate in microplastic management. The analysis included checks for model adequacy, ensuring that the logistic regression model fit the data well. This involved evaluating the model's classification accuracy, the pseudo-R-squared values, and conducting a Hosmer-Lemeshow goodness-of-fit test. Ultimately, this layered analytical approach provided a robust framework for understanding the dynamics influencing public attitudes towards microplastic management in Jakarta. By systematically assessing how different demographic and psychographic factors affect these attitudes, the study offered concrete insights into the development of targeted interventions aimed at enhancing microplastic pollution control measures in urban settings. This methodical examination not only validated the initial hypotheses but also highlighted areas where policy and practice need to converge to mitigate the impacts of microplastics effectively.

4. Results

The Exploratory Factor Analysis (EFA) conducted on responses from 445 residents of Jakarta, regarding their perceptions and behaviors towards microplastic management, elucidated several key factors that underpin public attitudes and initiatives towards addressing microplastic pollution (Table 2). This statistical procedure was pivotal in revealing the structured relationships among various survey items, thereby identifying distinct themes that residents associate with effective microplastic management strategies. To ensure the reliability and appropriateness of the factor analysis, the Kaiser-Meyer-Olkin Measure of Sampling Adequacy was employed, yielding a value of 0.5139. This measure indicates a moderate level of adequacy for conducting an EFA, suggesting that the sample size and the interrelationships among the items were sufficient but highlight the room for improvement in future surveys for more robust factor structures. Additionally, Bartlett's Test of Sphericity was performed, resulting in a statistic of 521.399 with > 0.001, confirming that the variables are sufficiently correlated and thus suitable for the factor analysis. These statistical tests validate the factor structure extracted from the data and reinforce the interpretability and significance of the identified factors in understanding public sentiments and actions towards microplastic management in Jakarta.

The EFA revealed five primary factors which included "Asset Integration," "Responsive Flexibility," "Coordinated Systems," "Empowerment through Knowledge," and "Stakeholder Activation." Each factor is comprised of several items that collectively represent a specific dimension of microplastic management. "Asset Integration" involves the availability and utilization of physical and logistical assets to manage pollution, whereas "Responsive Flexibility" refers to the adaptive

Table 2
Results of exploratory factor analysis on community responses.

Factors and items	Factor loadings	Eigenvalues	% of Variance	Cronbach alpha
Asset integration		11.613	16.401	0.941
Adaptive sampling techniques for microplastics	0.830			
Dynamic analytical techniques	0.815			
Community response to microplastics	0.797			
Wildlife adaptability studies	0.794			
Source identification of microplastics	0.789			
Public health response to microplastics	0.785			
Biodegradable alternatives research	0.783			
Microplastic education and adaptation	0.772			
Corporate adaptation to microplastic reduction	0.770			
Ecosystem resilience studies	0.765			
Techniques for microplastic quantification	0.686			
Responsive flexibility		5.445	11.475	0.879
Modular research approaches	0.698			
Quick response monitoring systems	0.688			
Adaptive experimental designs	0.679			
Flexible data collection models	0.672			
Real-time data analysis techniques	0.649			
Responsive stakeholder engagement	0.649			
Scalable pollution tracking systems	0.626			
Dynamic resource allocation strategies	0.608			
Agile policy implementation frameworks	0.606			
Adaptive cleanup technologies	0.524			
Coordinated systems		3.218	10.875	0.87
Integrated microplastic monitoring networks	0.684			
Standardized sampling protocols	0.675			
Centralized data repositories	0.669			
Coordinated clean-up initiatives	0.666			
Systematic public awareness programs	0.647			
Unified microplastic research agendas	0.625			
Organized stakeholder forums	0.601			
Regulatory compliance systems	0.595			
Strategic resource allocation	0.523			
Empowerment through knowledge		1.896	9.331	0.852
Community outreach programs	0.718			
Academic Studies on Microplastics	0.673			

(*continued on next page*)

Table 2 (*continued*)

Factors and items	Factor loadings	Eigenvalues	% of Variance	Cronbach alpha
Microplastics curriculum development	0.654			
Public seminars on microplastic pollution	0.634			
Research publications on microplastics	0.630			
Educational workshops for policymakers	0.609			
Online courses on microplastic management	0.587			
School programs on environmental conservation	0.563			
Stakeholder activation		1.199	6.271	0.766
Community-led microplastic initiatives	0.670			
Policy advocacy for microplastic reduction	0.659			
Stakeholder collaboration in microplastic studies	0.591			
Public Engagement in microplastic cleanups	0.546			
Grassroots movements against microplastics	0.518			

*Kaiser-Meyer-Olkin Measure of Sampling Adequacy= 0.5139; Bartlett's Test of Sphericity= 521.399 ($p > 0.001$)

measures and systems in place to respond to environmental challenges dynamically. "Coordinated Systems" highlights the structured and systematic approach taken towards environmental management, "Empowerment through Knowledge" underscores the importance of educational endeavors in empowering the public, and "Stakeholder Activation" focuses on the engagement and collaboration of community members in microplastic initiatives.

Table 3 details the results of a cluster analysis that effectively categorized respondents into two distinct groups based on their perceptions and attitudes towards microplastic management in Jakarta. The two identified groups, termed **proactive participants** and **skeptical observers**, exhibit markedly different responses to the various dimensions of microplastic management that were previously delineated through exploratory factor analysis. **Proactive participants** (Cluster 1), encompassing a larger subset of the sample with 328 individuals, display generally positive scores across the factors, particularly emphasizing strong engagement in coordinated systems and active stakeholder participation. This cluster represents a segment of the population that is more positively inclined towards current microplastic management efforts, showing a readiness to support and engage in initiatives that aim to address the microplastic issue. On the other hand, **skeptical observers** (Cluster 2), which includes 117 respondents, demonstrate negative scores across all identified factors, especially showing significant skepticism in the areas of coordinated systems and stakeholder activation. This group's critical perspective highlights concerns or dissatisfaction with the existing approaches to microplastic management, possibly perceiving them as ineffective or misaligned with their expectations. The statistical measures accompanying the cluster profiles, including mean squares and F-values, underscore significant differences between the two groups' perceptions. Notably, the factors of responsive flexibility, coordinated systems, and stakeholder activation showed highly significant differences ($p < 0.001$), indicating strong variance in how these elements are valued by the two clusters.

Table 3
Results from cluster analysis identifying community segments.

Factors	Cluster 1 (n = 328) Proactive Participants	Cluster 2 (n = 117) Sceptical Observers	Mean Square	F	p-value
Asset integration	0.036	−0.100	1.576	1.578	0.210
Responsive flexibility	0.107	−0.301	14.376	14.823	< 0.001
Coordinated systems	0.317	−0.889	125.399	174.361	< 0.001
Empowerment through knowledge	0.088	−0.248	9.760	9.957	0.002
Stakeholder activation	0.360	−1.008	161.403	253.015	< 0.001

Table 4 presents the demographic segmentation of the two clusters identified in the study on perceptions towards microplastic management. This segmentation illustrates how demographic factors such as gender, age, education, and income vary across the clusters, potentially influencing their attitudes towards microplastic issues. The analysis reveals significant differences in the demographic composition between the clusters. For gender, there is a notable distribution difference ($p = 0.007$), with a higher percentage of males in the Proactive Participants compared to the sceptical observers. The age group analysis highlights a profound variance ($p < 0.001$) across clusters, indicating different levels of concern and engagement in microplastic management that may correlate with age. Younger participants, particularly those between 20 and 29 years, are more prominent in the sceptical observers, suggesting that younger residents might be more critical of current management efforts or feel less engaged by existing measures. Education and income levels, while showing variation, do not exhibit statistically significant differences between the clusters in terms of educational attainment, indicating that educational background may not be a primary driver of differences in perceptions regarding microplastic management. However, income levels do show significant disparity ($p < 0.001$), with the Proactive Participants generally encompassing a broader income range, suggesting that economic factors might influence perceptions and potential engagement in microplastic management strategies.

Table 5 delineates the outcomes of a logistic regression analysis that quantifies the influence of various factors on the willingness of Jakarta residents to participate in microplastic management programs. Asset integration (H1) significantly increases the likelihood of participation is statistically significant ($p = 0.004$). This result implies that well-integrated management strategies, which encapsulate both advanced technologies and active community involvement, are essential in motivating residents to engage in microplastic management activities. Responsive flexibility (H2) emerges as another significant predictor ($p = 0.010$), indicating that the ability of management practices to adapt swiftly to environmental changes plays a critical role in fostering community involvement. Coordinated systems (H3), shows a profound effect ($p < 0.001$), suggesting that synchronized efforts across various management domains greatly enhance participation. This underscores the necessity for a seamless operation among different stakeholders and systems to effectively address microplastic pollution. Contrastingly, empowerment through knowledge (H4), while positive, does not reach statistical significance ($p = 0.422$), indicating that educational efforts alone may not be sufficient to significantly drive participation without the support of other systemic and practical interventions. Stakeholder Activation (H5) demonstrates a very strong influence ($p < 0.001$), highlighting the critical role of active community involvement and stakeholder engagement in promoting significant participation in microplastic management. The analysis of demographic influences such as the age group (H6) reveals nuanced insights. Particularly, the age group of 20–29 shows a markedly lower propensity to participate ($p = 0.002$), suggesting potential disengagement or differing priorities among younger residents, which may require targeted communication strategies to enhance their involvement. Other age groups did not show significant effects, indicating a more uniform willingness to participate

Table 4
Segmentation of community attitudes towards microplastic management.

Cluster Segmentation				
Variables	**Cluster 1 (n = 328) Proactive Participants**	**Cluster 2 (n = 117) Sceptical Observers**	**Chi-Square**	**Asymptotic Significance (2-sided)**
Gender			7.401	0.007
Male	177 (38.90 %)	46 (10.11 %)		
Female	151 (33.19 %)	71 (15.60 %)		
Age			88.792	< 0.001
20–29 years	95 (20.88 %)	92 (20.22 %)		
30–40 years	86 (18.90 %)	13 (2.86 %)		
41–50 years	88 (19.34 %)	7 (1.54 %)		
51–60 years	48 (10.55 %)	3 (0.66 %)		
Over 60 years	11 (2.42 %)	2 (0.44 %)		
Higher Education			5.927	0.313
Elementary	5 (1.10 %)	2 (0.44 %)		
Middle School	19 (4.18 %)	3 (0.66 %)		
High School	133 (29.23 %)	57 (12.53 %)		
Diploma	43 (9.45 %)	15 (3.30 %)		
Bachelor's	125 (27.47 %)	37 (8.13 %)		
Bachelor's above	3 (0.66 %)	3 (0.66 %)		
Income			38.734	< 0.001
< Rp. 4901,798	87 (19.12 %)	65 (14.29 %)		
IDR 4901,799 - IDR 5751,800	82 (18.02 %)	28 (6.15 %)		
IDR 5751,801 - IDR 6601,800	72 (15.82 %)	11 (2.42 %)		
IDR 6601,801 - IDR 7451,800	40 (8.79 %)	6 (1.32 %)		
IDR 7451,801- IDR 8301,802	26 (5.71 %)	2 (0.44 %)		
> IDR 8301,802	21 (4.62 %)	5 (1.10 %)		
Willingness to Participate Segmentation				
	Yes (n = 325)	**(No=120)**		
Gender			7.401	0.007
Male	174 (53.7 %)	46 (14.2 %)		
Female	151 (46.5 %)	74 (22.8 %)		
Age			88.792	< 0.001
20–29 years	95 (29.2 %)	92 (28.3 %)		
30–40 years	86 (26.5 %)	13 (4.0 %)		
41–50 years	85 (26.2 %)	10 (3.1 %)		
51–60 years	48 (14.8 %)	3 (0.9 %)		
Over 60 years	11 (3.4 %)	2 (0.6 %)		
Higher Education			5.927	0.313
Elementary	5 (1.5 %)	2 (0.6 %)		
Middle School	133 (41.0 %)	57 (17.5 %)		
High School	19 (5.9 %)	3 (0.9 %)		
Diploma	43 (13.2 %)	15 (4.6 %)		
Bachelor's	122 (37.5 %)	40 (12.3 %)		
Bachelor's above	3 (0.9 %)	3 (0.9 %)		
Income			38.734	< 0.001
< Rp. 4901,798	87 (26.8 %)	65 (20.0 %)		
IDR 4901,799 - IDR 5751,800	82 (25.2 %)	28 (8.6 %)		
IDR 5751,801 - IDR 6601,800	72 (22.2 %)	11 (3.4 %)		
IDR 6601,801 - IDR 7451,800	37 (11.4 %)	9 (2.8 %)		
IDR 7451,801- IDR 8301,802	26 (8.0 %)	2 (0.6 %)		
> IDR 8301,802	21 (6.5 %)	5 (1.5 %)		

Table 5
Binary model of community willingness to participate in microplastic management initiatives.

Variables	B	S.E.	Wald	df	Sig.	Exp (B)
H1. Asset integration	1.009	0.348	8.401	1	0.004	2.742
H2. Responsive flexibility	0.932	0.360	6.689	1	0.010	2.539
H3. Coordinated systems	3.252	0.436	55.745	1	< 0.001	25.831
H4. Empowerment through knowledge	0.279	0.348	0.645	1	0.422	1.322
H5. Stakeholder activation	3.653	0.462	62.637	1	< 0.001	38.588
H6. Age group			23.764	4	< 0.001	
> 60	−0.431	1.243	0.120	1	0.729	0.650
20–29	−2.107	0.693	9.259	1	0.002	0.122
30–40	−0.545	0.768	0.504	1	0.478	0.580
41–50	−0.452	0.809	0.311	1	0.577	0.637
Constant	−2.028	0.827	6.010	1	0.014	0.132

Note: Cox & Snell R Square= 0.684; Nagelkerke R Square= 0.999; Percentage Correct= 73.70 %

across older demographics.

5. Discussion

The intersection of marine conservation and public participation in microplastic management is critically important given the complexity and urgency of the pollution issue plaguing global waterways. This analysis delves into the various factors influencing public willingness to engage in microplastic management initiatives, with an emphasis on how integrated strategies and systemic coordination can enhance participation rates and lead to more effective outcomes. Asset integration in microplastic management (H1), which combines various tools, technologies, and frameworks, has shown to significantly increase community involvement. By leveraging comprehensive asset integration (Chen et al. 2021a; Wang et al. 2024b), stakeholders can ensure that resources are not only pooled effectively but also utilized in a manner that maximizes the impact of environmental protection efforts. This holistic approach enables the development of robust systems capable of addressing the multifaceted nature of microplastic pollution from monitoring and collection to analysis and disposal (Sunil et al. 2024). The strong influence of this factor highlights the critical need for well-coordinated strategies that integrate across different sectors and disciplines to tackle the pervasive issue of microplastics.

Responsive flexibility (H2), another critical factor identified, refers to the ability of management systems to adapt and respond to new challenges and information regarding microplastic pollution. The dynamic nature of marine environments and the ongoing changes in regulatory landscapes demand flexible management strategies that can pivot and evolve as circumstances change (Tian and Wang 2024b; Wang et al. 2024a). This adaptability is crucial for maintaining the effectiveness of environmental strategies over time (Foster, 2020; Settembre-Blundo et al. 2021), particularly as new sources of pollution are identified and as our understanding of the impacts of microplastics

continues to grow. Coordinated systems (H3) play an indispensable role in enhancing participation in microplastic management. The effectiveness of any environmental strategy is often dependent on the level of coordination among various stakeholders (Ahmed et al. 2020; Sheng et al. 2020; Journeault et al. 2021), including government agencies, non-profits, community groups, and researchers. Effective coordination ensures that efforts are streamlined (Chen et al. 2021b; Busert and Fay, 2021), that resources are used efficiently, and that all stakeholders are working toward common goals. This synergy is essential for scaling up efforts and for implementing comprehensive strategies that address microplastic pollution at various levels from local communities to global initiatives.

Empowerment through knowledge (H4), while not showing a strong statistical significance in this analysis, remains a foundational element of effective environmental management. Education and awareness campaigns that inform the public about the dangers of microplastic pollution and the ways in which individuals can contribute to mitigation efforts are vital (Garcia-Vazquez and Garcia-Ael, 2021; Onyena et al. 2022; Sandu et al. 2022). These programs not only raise awareness but also empower individuals with the knowledge needed to make informed decisions and to take actionable steps in their daily lives. Continuous investment in public education can transform public perception and behavior concerning plastics and recycling, ultimately fostering a more environmentally conscious society. Stakeholder activation (H5), significantly influencing participation, underscores the importance of engaging community members not just as beneficiaries of clean water initiatives but as active participants in the fight against microplastics. Community-led initiatives can be particularly effective as they often employ localized knowledge and strategies that are more tailored to specific environmental and cultural contexts (Simon et al. 2020; Marín-González et al. 2022; Morris et al. 2024). Moreover, when stakeholders see direct benefits to their communities, their engagement can lead to sustained environmental efforts and can encourage broader community support for regulatory and cleanup initiatives.

Demographic factors such as age have also revealed interesting patterns in participation (H6). The findings indicate that younger individuals are less likely to engage in microplastic management activities, suggesting a potential disconnect between the messaging or strategies currently employed and the preferences or motivations of younger demographics. Tailoring environmental messages and engagement strategies to align with the values and communication styles of younger people could increase their involvement. Strategies might include the use of digital platforms, social media, and interactive educational tools that resonate more effectively with younger audiences (Qian et al. 2024). Furthermore, the analysis has on the differences in participation rates among different age groups and income levels, suggesting that while microplastic pollution is a universal concern, the drivers of participation can vary significantly across demographic segments. Understanding these nuances is crucial for designing targeted interventions that can engage diverse groups effectively.

The insights gleaned from the study on microplastic management underscore the pressing need for comprehensive policies that address the multifaceted challenges posed by marine microplastics. These findings are particularly relevant for informing policy frameworks and strategies aimed at controlling and mitigating the impact of microplastics in marine environments. The significance of asset integration in enhancing public participation points towards the necessity for policy frameworks that encourage and facilitate the pooling and efficient use of resources across various sectors. Policymakers could develop incentives for industries to adopt best practices in waste management (Ardiansyah et al. 2022; Budihardjo et al. 2022), including funding for innovative microplastic collection and recycling technologies. Policies should support the integration of resources among government bodies (Budiman and Smits, 2020; Galdino de Magalhães Santos, 2024; Zarghami, 2025), private entities, and research institutions to foster collaborative approaches to microplastic pollution. Responsive flexibility in policy design is crucial due to the dynamic nature of microplastic pollution and our evolving understanding of its impacts. Policies must be adaptable (Benmenzer and Beghdad, 2022; Hanan et al. 2024), allowing for quick updates and adjustments in response to new scientific findings or technological advancements. This could involve setting legislative frameworks that mandate regular review and revision of microplastic management strategies, ensuring they remain effective and relevant.

Coordinated systems are essential for the effective implementation of microplastic policies (Yang et al. 2021; Amesho et al. 2023). This requires clear communication channels and collaborative networks between policymakers, enforcement agencies, environmental organizations, and the public. Establishing task forces or committees dedicated to microplastic management can help synchronize efforts and ensure that policies are implemented efficiently and cohesively across different levels of government and sectors. Stakeholder activation is another critical area where policy can make a significant impact. Policies that encourage public participation in microplastic reduction efforts, such as community clean-up programs and citizen science projects, can enhance engagement. Financial and logistical support for grassroots movements and local NGOs working on microplastic issues can help mobilize broader community action. Furthermore, policies that facilitate stakeholder involvement in the decision-making process, ensuring that community voices are heard in the planning and implementation of strategies (Suryawan et al., 2025b), are vital for the success and sustainability of these initiatives.

Regarding demographic influences, policies must recognize and address the varied drivers of participation across different age groups and income levels. Targeted interventions that cater to the specific needs and preferences of these groups can improve engagement rates. For younger demographics, integrating technology and social media into outreach programs can be particularly effective. For lower-income groups, providing subsidies or financial incentives to participate in microplastic management activities could alleviate potential financial barriers to involvement. The development of comprehensive and adaptive policies that not only aim to control but also prevent the future accumulation of microplastics in marine environments is imperative. These policies should be grounded in robust scientific research and risk assessments and should strive to involve a broad range of stakeholders in a coordinated effort to tackle one of the most pressing environmental issues of our time. The path forward will require a commitment to innovation, education, and collaboration, guided by the policy implications derived from rigorous empirical research on microplastic management.

6. Conclusion

The investigation into microplastic management in Jakarta has highlighted several crucial factors that influence public willingness to participate in mitigation strategies, drawing attention to the broader implications for environmental policy and sustainability. This study successfully applied various statistical analyses to dissect the attitudes and behaviors surrounding microplastic management among residents of Jakarta, providing a nuanced understanding that can inform targeted intervention strategies. Key findings from this research underscore the importance of integrating assets across various sectors to enhance public engagement in microplastic management efforts. The analysis revealed that well-coordinated systems, responsive policy frameworks, and community empowerment through knowledge significantly influence the public's willingness to engage in these environmental initiatives. These elements are essential for developing effective and sustainable microplastic management strategies that not only address current pollution levels but also aim to mitigate future impacts. Moreover, the research highlights the need for policies that are flexible and adaptable to the rapidly evolving scientific understanding of microplastics and their impacts. This adaptability is crucial for maintaining the relevance

and effectiveness of policies over time, especially in a dynamic urban environment like Jakarta.

6.1. Future study

Findings from the study indicate significant variation in community willingness to participate in microplastic management based on demographic factors and socioeconomic status. Further exploration of behavioral patterns across different seasons could reveal variations in participation in microplastic management. Such seasonal analysis is crucial, as environmental behavior might be influenced by weather conditions, local cultural events, or tourism seasons, all of which can affect both waste generation and community engagement in management activities. Considering the dynamic nature of environmental challenges, particularly those related to microplastics, the development of adaptive management programs is recommended. These programs would allow for real-time adjustments of policies and strategies based on continuous environmental monitoring and feedback loops. Adaptability ensures that microplastic management strategies remain effective under changing environmental conditions and socioeconomic contexts. To support the sustainability of these policies, conducting an economic valuation of the benefits derived from effective microplastic management is suggested. This valuation would help in understanding the economic incentives that can motivate different stakeholders, including the public, to actively participate in these initiatives. It would also provide policymakers with concrete data to justify the allocation of resources toward microplastic management, ensuring long-term commitment and sustainability for these efforts.

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Author contributions

N. U. contributed to the conceptualization, writing, and project leadership of the study. M. M. S. and A. S. assisted in conceptualization and writing. K. J. was involved in conceptualization, writing, and also served as a project leader. S. Suhardono added expertise in conceptualization, writing, visualization, and methodology. D. V. S. and N. N. were responsible for data collection and analysis. C.-H. L. contributed to conceptualization, writing, methodology, project leadership, and supervision. I. W. K. S. was instrumental in conceptualization, writing, methodology, project leadership, and supervision, ensuring the study adhered to high academic standards.

Consent to participate

Not applicable.

Consent to publish

All authors have thoroughly reviewed the final manuscript and have approved it for submission and publication.

Compliance with Ethical Standards

This study was conducted in strict accordance with the ethical standards of the Taiwan Academic Research Ethics Education (AREE). Full informed consent was obtained from all participants, who were comprehensively briefed about the research objectives, data management procedures, and their rights. Confidentiality was assured, and participants were explicitly informed that they could withdraw from the study at any time without repercussions.

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CRediT authorship contribution statement

Khairiraihanna Johari: Funding acquisition, Formal analysis, Conceptualization. **Ditha Verenia Sanda:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **Sapta Suhardono:** Visualization, Validation, Supervision, Methodology, Investigation. **I Wayan Koko Suryawan:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Chun-Hung Lee:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Netriyunita Netriyunita:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **Ariyanti Sarwono:** Writing – review & editing, Supervision, Data curation, Conceptualization. **Mega Mutiara Sari:** Writing – review & editing, Writing – original draft, Supervision, Data curation, Conceptualization. **Nova Ulhasanah:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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