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CASE STUDY

Consumer awareness, participation, and accessibility in sustainable electronic waste management

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ABSTRACT

BACKGROUND AND OBJECTIVES: The rapid increase in electronic waste has created increasingly complex environmental and health challenges, especially in developing countries like Indonesia. The study objectives were to examine how household awareness and accessibility of electronic-waste management facilities are associated with consumer participation, controlling for socioeconomic factors, demographics, and the region's spatial characteristics.

METHODS: This study uses a quantitative, cross-sectional survey design to examine household consumers living near electronic waste management facilities in Indonesia. To analyze the data, Spearman's rank correlation was employed to evaluate variable relationships, ordinary least squares regression to estimate the associations of awareness and accessibility with participation levels, Kruskal-Wallis test to examine group differences, and Geographic Information System-based spatial analysis to describe the spatial patterns of facility distance, accessibility, and electronic waste management participation.

FINDINGS: Consumer awareness of the consequences of electronic waste showed a significant positive correlation with the intention to manage electronic waste, with a correlation coefficient of 0.340, but showed no significant correlation with actual behavior, with a correlation coefficient of only 0.067. Accessibility showed a significant positive correlation with both intention and actual behavior, with correlation coefficients of 0.197 and 0.416, respectively. Accessibility had the largest reported regression coefficient for actual behavior (β = 0.449), followed by awareness of consequences (β = 0.182). The Kruskal-Wallis test confirmed significant differences in intention and actual behavior across accessibility levels, with chi-square values of 11.67 and 35.91, respectively. Spatial analysis using the nearest neighbor method produced a nearest neighbor ratio of 0.60 with a z score of -10.01. Spatial analysis revealed that highly aware and active residents are significantly clustered rather than randomly dispersed, with the vast majority residing within a functional catchment area defined by 10 to 30 kilometer distances or 10 to 30 minute travel times from e-waste facilities.

CONCLUSION: The findings underscore the need for electronic waste management policies that prioritise facility accessibility and spatially based approaches to strengthen community participation within a circular economy framework.

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NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
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INTRODUCTION

The rapid growth in the consumption of electronic devices has made electronic waste (e-waste) one of the fastest-growing waste streams globally (Baldé *et al.,* 2022, 2024; Arumbinang, 2026). Electronic waste (E-waste) contains various hazardous materials, such as heavy metals and toxic chemical compounds, which have the potential to cause severe impacts on the environment and human health if not managed properly (Ankit *et al.,* 2021; Parvez *et al.,* 2021; Ghulam and Abushammala, 2023; Jain *et al.,* 2023; Bhardwaj *et al.,* 2025). Throughout developing economies such as Indonesia, e-waste management remains heavily constrained by institutional and behavioral barriers, frequently leading to significant volumes of discarded electronics to bypass formal channels and terminate in municipal landfills, informal processing nodes, or indefinite domestic storage devoid of treatment (Islam *et al.,* 2021; Andeobu *et al.*, 2023; Jain *et al.,* 2023; Bhardwaj *et al.,* 2025). From an ecological anthropology perspective, behavioral patterns in e-waste management are inseparable from everyday household practices and the social meanings attached to electronic devices (Ebo, 2026). Unused devices are often stored as spare parts because they are considered to have value still and are therefore not immediately treated as waste. Practices like these demonstrate that e-waste management decisions result from negotiations among individual awareness, household norms, and structural conditions within the human waste management system (Harafah *et al.*, 2026; Heeks *et al.,* 2015; Almulhim, 2022; Arya and Kumar, 2020; Wickramasingha *et al.,* 2025). Achieving long-term circular economy objectives depends fundamentally on active consumer engagement—comprising both behavioral intent and practical execution—in sustainable e-waste practices, such as source separation, authorized facility utilization, and community initiatives, all of which form a critical foundation for overarching system efficiency (Duckworth and Gross, 2020; Alhassan *et al.,* 2020; Koshta *et al.,* 2022). However, several studies have found that the level of public participation often does not align with their level of awareness of the negative impacts of e-waste (Attia *et al.*, 2021; Islam *et al.*, 2021; Garg *et al.,* 2023; Muthukumari *et al.*, 2024; Kosarkar and Barthwal, 2025; Zia and Sukri, 2025). In fact, consumer awareness of the environmental and health risks posed by e-waste is a crucial cognitive factor associated with pro-environmental behavioral tendencies (Wibowo *et al.,* 2022; Liang *et al.*, 2024). Furthermore, awareness alone is insufficient to encourage active participation unless supported by adequate external conditions. One of the most frequently cited external factors is access to e-waste management facilities, including distance, travel time, ease of access, availability of information, and convenience of use (Sari *et al.*, 2021; Michael *et al.*, 2025; Wirtu *et al.*, 2025). Evidence from Frigo *et al*. (2025) indicates that residential waste collection is consistently underreported even by households located within a 100-meter radius, illustrating that operational impediments extend beyond mere spatial proximity to encompass economic travel burdens, transit availability, and logistical convenience. This aligns with previous research by Abha *et al.,* (2025) that found that high travel costs and limited transportation options prevent low-income households from recycling electronic waste (Borthakur and Singh, 2021). In Indonesia, accessibility difficulties in the distribution and management of e-waste are known to remain very high. Consumers living near recycling facilities tend to have greater opportunities to participate than those living in areas with limited access (Sari *et al.*, 2021; Michael *et al.*, 2025; Haq, 2026). Building upon these framework conditions, this investigation evaluates consumer awareness and facility accessibility as factors associated with household behavioral intent and active participation in sustainable e-waste management, while controlling for sociodemographic profiles

(Azkiyah, 2026). Geographic information systems (GIS), as an analytical tool for understanding the dynamics of accessibility in e-waste management and the factors that influence it, is used as one approach in this framework (Nuwematsiko *et al.,* 2021). GIS can serve as a powerful tool when integrated with non-spatial criteria (Cheng *et al.,* 2024; Bante *et al.*, 2025), where specific GIS analyses such as weighted overlay analysis and kernel density estimation have proven effective in resolving and balancing conflicting interests (Bante *et al.*, 2025). GIS serves not only to visualize data but also to bridge the gap between designed policies and actual practices by providing actionable solutions. Ultimately, operationalizing this methodological framework seeks to generate robust empirical backing for inclusive, circular-economy-aligned e-waste policies, while concurrently advancing a deeper analytical understanding of electronic waste management efficacy throughout Indonesia. In the value-belief-norm (VBN) theory, environmental values and beliefs are described as being related to consumers' personal norms and intentions to engage in e-waste management practices (Yeh *et al.,* 2024; Yang *et al.,* 2025). In this study, VBN is used as an interpretive perspective for understanding the potential relevance of environmental awareness to behavioral intention rather than as a framework for empirically testing normative mechanisms. However, this study attempts to integrate it with another approach, namely the environmental behavior approach from ecological anthropology, which views consumer participation (intention and actual behavior) as being related to cognitive, structural, and contextual factors (Vijayan *et al.,* 2023). Consumer awareness of e-waste issues is positioned as an internal factor associated with attitudes and behavioral tendencies, while the accessibility of e-waste management facilities is an external factor associated with opportunities for participation (Linder *et al.*, 2021; Michael *et al.*, 2025; Arain *et al.,* 2025). Rather than functioning as a directly tested empirical mechanism in this study, environmental awareness is conceptualized through this methodological amalgamation as an underlying psychological disposition reflecting individual readiness for electronic waste engagement (Maphosa and Maphosa, 2022). Previous studies have also reported associations between participation and the accessibility of facilities, which may be relevant to opportunities for e-waste management participation (Linder *et al.*, 2021; Asibey *et al.*, 2022; Nawaz *et al.*, 2025; Harnita, 2025). Here, sociodemographic factors can serve as control variables in examining the associations among awareness, accessibility, and participation. Furthermore, spatial dimensions are integrated as core analytical parameters, treating both physical distance and transit duration to e-waste infrastructure as vital factors related to regional disparities in public participation capacity (Rusni, 2025). By integrating GIS-based spatial analysis, this theoretical framework provides a spatial description of geographic patterns in relation to awareness, accessibility, intention, and participation in sustainable e-waste management (Arsanti *et al.,* 2024; Yalcinkaya and Kaleli, 2025). Thus, the theoretical framework of this study positions household consumers' participation in e-waste management as a multidimensional phenomenon associated with individual awareness, perceived accessibility, and spatial conditions. Rather than evaluating mediation, moderation, or direct causal pathways, these theoretical frameworks serve to ground the empirical associations identified herein. Accordingly, this study evaluates household e-waste engagement by integrating risk awareness, perceived infrastructural accessibility, behavioral intent, self-reported actions, core sociodemographic attributes, and spatial dispersion patterns. This study aims to: 1) examine the associations between awareness of e-waste consequences, perceived facility accessibility, behavioral intention, and self-reported actual behavior; 2) estimate the associations of awareness and perceived accessibility with the two behavioral outcomes after adjustment for

selected sociodemographic characteristics; 3) compare behavioral intention and actual behavior across accessibility groups; and (4) describe the spatial pattern of the observations included in the GIS analysis. The study was conducted in Surabaya City, East Java Province, Indonesia, in 2025.

MATERIALS AND METHODS

Research design and location

This study employed a quantitative, cross-sectional survey design to examine associations among awareness of e-waste consequences, perceived accessibility of e-waste management facilities, behavioral intention, and self-reported actual behavior. Owing to the cross-sectional nature of the research design—capturing exposure, perceptions, and outcomes simultaneously—the empirical outcomes are interpreted strictly as associative relationships rather than direct causal effects. Cross-sectional studies are useful for estimating relationships and describing patterns but cannot establish temporal precedence or causal direction (Capili, 2021). Surabaya is located in East Java Province and is one of Indonesia's major metropolitan areas (Fig. 1). According to BPS Statistics Surabaya (2025), the city had a population of approximately 3.02 million in 2024. This municipality was chosen as the empirical setting to investigate urban household e-waste management, focusing on how municipal generation rates, infrastructure proximity, and disposal logistics shape public engagement in formal recycling frameworks**.** The study area was limited to Surabaya City; therefore, the sample should not be interpreted as representative of households in other Indonesian cities or of Indonesia as a whole.

Sampling and participants

The analytical sample comprised 250 respondents selected via purposive sampling from households within the Surabaya study area that satisfied specific eligibility criteria and resided in proximity to designated e-waste collection or recycling infrastructure. The unit of analysis was an individual household member who independently managed household waste and was involved in decisions concerning its storage, disposal, or delivery to e-waste collection facilities.

Data collection

Primary data were collected using a structured questionnaire informed by previous research on environmental behavior and e-waste management (Islam *et al.,* 2021; Sari *et al.,* 2021; Garg *et al.,* 2023). The questionnaire included measures of awareness of consequences, perceived accessibility, behavioral intention, self-reported actual behavior, and sociodemographic characteristics. Awareness of consequences was defined as respondents' perceived knowledge of the environmental and health consequences associated with improper e-waste management (Attia *et al.,* 2021; Almulhim, 2022). Behavioral intention operationalized respondents' self-reported willingness or strategic planning to execute future e-waste management practices (Sari *et al.,* 2021; Islam *et al.,* 2021; Nawaz *et al.,* 2025). Self-reported actual behavior referred to reported past actions. Perceived accessibility referred to respondents' assessment of how readily and conveniently e-waste management facilities could be used (Sari *et al.,* 2021; Kosarkar and Barthwal, 2025; Waheed *et al.,* 2023). The operationalization of the awareness construct incorporated two distinct indicators measuring human health and environmental consequences. Furthermore, behavioral intention was evaluated through three items focusing on recycling, donation, and facility utilization, whereas actual behavior was assessed using three indicators capturing prior drop-offs at official collection or recycling nodes, responsible material storage, and involvement in civic programs. Because these actual-behavior items represent related but not identical actions, the resulting score was treated as a composite index of reported e-waste

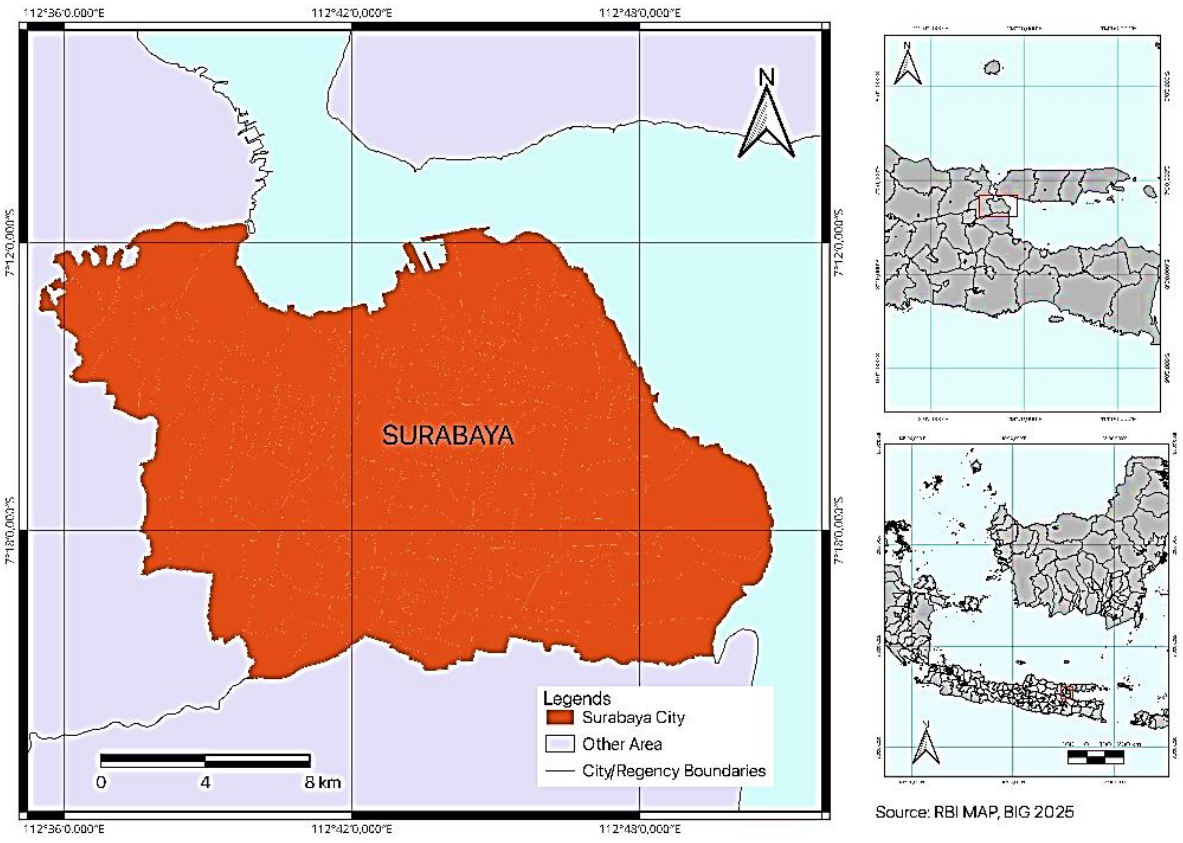

Fig. 1: Geographical location of the study area in Surabaya City, East Java Province, Indonesia

management behavior. The index therefore captures several forms of responsible management rather than formal recycling alone. Perceived accessibility comprised nine items covering facility location, road conditions, directions, number of collection points, operating hours, user-friendliness, perceived distance, willingness to spend time/purchase, and perceived time/energy burden (Alkhazali *et al.,* 2025). Because these indicators capture multiple dimensions of perceived spatial proximity, they were aggregated into a composite index reflecting respondents' overall assessment of facility convenience and operational usability (Sari *et al.,* 2021; Kosarkar and Barthwal, 2025). Perceived accessibility was analyzed separately from objective geographic measures of distance and travel time; the relationship between the two forms of accessibility was not formally tested. All questionnaire items were measured using a five-point Likert response scale from 1 (strongly disagree) to 5 (strongly agree). Composite scores were calculated according to the study's scoring procedure (Huh and Gim, 2025; Koo and Yang, 2025). Spearman correlation was used for bivariate association testing because the item responses were ordinal. Ordinary least squares (OLS) regression was applied to the composite scores as approximately continuous outcomes to estimate adjusted statistical associations. Because the archived manuscript lacks the requisite diagnostic output to explicitly report numerical evaluations for all OLS assumptions, the resulting regression estimates are interpreted with necessary caution and appropriate methodological restraint in this context.

Ethical considerations

Participation was voluntary, respondents were informed about the study before completing the questionnaire, and confidentiality was maintained. No formal institutional ethics approval number or approval date is available for this study; accordingly, the manuscript does not claim that formal institutional ethics approval was obtained.

Data analysis

Data analysis proceeded in four stages. First, descriptive statistics were used to summarise respondent characteristics and the distributions of the study variables. Second, Spearman rank correlation was used to examine bivariate associations among awareness, perceived accessibility, behavioral intention, and actual behavior. Third, OLS regression models estimated the associations of awareness, perceived accessibility, and selected sociodemographic covariates with behavioral intention and actual behavior. The interpretation of OLS coefficients was limited to adjusted statistical associations, not causal effects. The OLS models were used to estimate adjusted associations among the composite study variables and selected covariates. Because the retained manuscript does not include the original diagnostic output, numerical results for residual normality, linearity, homoscedasticity, variance inflation factor (VIF), and influential observations are not reported. Because the archived manuscript lacks the requisite diagnostic output to explicitly report numerical evaluations for all OLS assumptions, the resulting regression estimates are interpreted with necessary caution. Kruskal–Wallis tests were used to compare behavioral intention and actual behavior across the three accessibility groups. Because the available results contain only the omnibus statistics and group mean ranks, pairwise post-hoc comparisons cannot be reconstructed from the retained manuscript data. Effect sizes were estimated from the reported Kruskal–Wallis statistics using epsilon-squared, yielding error $(\varepsilon)^2 = 0.039$ for behavioral intention and $\varepsilon^2 = 0.137$ for actual behavior. Consequently, the statistically significant omnibus findings serve as evidence that at least one accessibility subgroup exhibits a distinct profile, though without identifying the specific pairwise differences. For the spatial analysis, GIS was used to examine the distribution of the observations included in the spatial dataset and their relationship to e-waste facilities. Average nearest neighbor (ANN) analysis was used only to assess whether the analyzed point pattern was more clustered, random, or dispersed than expected under spatial randomness. A nearest-neighbor ratio below 1 indicates clustering, whereas the z-score and associated p-value determine whether the departure from randomness is statistically significant. ANN does not identify the behavioral or social mechanism producing the spatial pattern. The spatial analysis used the household and e-waste facility observations retained in the study's GIS dataset. Although the existing manuscript documents the resulting nearest-neighbor ratio and z-score, it omits critical methodological parameters, including the GIS software and version, geocoding and coordinate source, spatial reference system, facility dataset metadata, and explicit observation-selection criteria used for the spatial analysis and mapping.

Research hypotheses

In light of the theoretical framing, the hypotheses were formulated to examine the associations among awareness, perceived accessibility, behavioral intention, and actual behavior, and to assess differences in behavioral intention and actual behavior across accessibility groups (Fig. 2).

H1: Awareness of the environmental and health consequences of e-waste is positively associated with behavioral intention to manage e-waste.

H2: Awareness of the environmental and health consequences of e-waste is positively associated with self-reported actual e-waste management behavior.

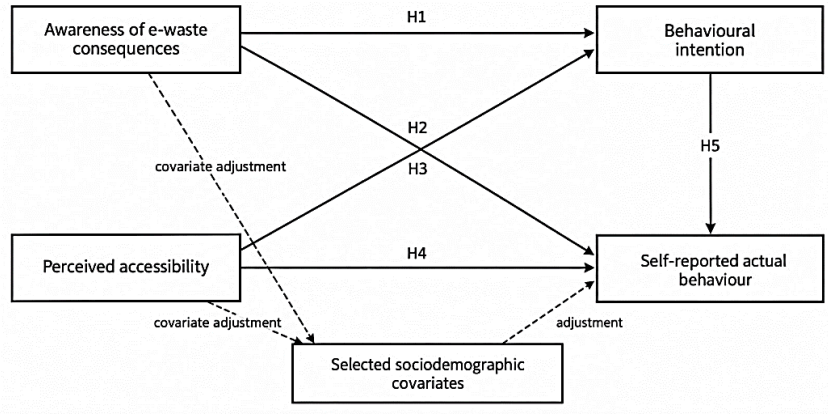

Fig. 2: Research framework showing the tested associations and covariate adjustment

H3: Perceived accessibility of e-waste management facilities is positively associated with behavioral intention to manage e-waste.

H4: Perceived accessibility of e-waste management facilities is positively associated with self-reported actual e-waste management behavior.

H5: Behavioral intention is positively associated with self-reported actual e-waste management behavior.

H6: Behavioral intention differs across levels of perceived facility accessibility.

H7: Self-reported actual e-waste management behavior differs across levels of perceived facility accessibility.

Rather than being evaluated as directional research hypotheses, sociodemographic parameters were treated strictly as analytical covariates, given that the study's primary objective was to control for potential population heterogeneity rather than to establish a priori causal pathways for individual demographic attributes. The framework therefore provides the conceptual basis for the seven hypotheses and for the subsequent correlation, regression, and accessibility-group analyses. Because the study uses a cross-sectional design, these relationships are examined as statistical associations rather than causal effects (Table 1). This approach is known as spatial household behavior analysis using the nearest-neighbor method. Within this spatial analysis framework, the focus of pattern mapping is on households characterised by high awareness, positive behavior, and high participation. The analysis determines the average accessibility to collection facilities for households with positive behavior, allowing the resulting patterns to be categorised as clustered, dispersed, or random (Table 2).

RESULTS AND DISCUSSION

Respondent characteristics

A total of 250 respondents participated in this study, with women comprising 57.6% and men 42.4%. Most respondents were aged 18–35 years (y) (76%), followed by those aged 36–45 y (14.8%). In terms of residential status, 56.8% reported owning a single residence, while the remainder reported other ownership or rental arrangements. The sample's educational attainment leaned heavily toward tertiary or post-secondary credentials. Furthermore, spatial proximity and transit duration relative to e-waste processing facilities were captured across categorical brackets, identifying < 10 kilometers (km) and 10–30 minutes (min.) as the respective modal categories. Beyond the demographic profile, the access-related characteristics presented in Table 3 provide an indication of the physical circumstances surrounding household access to formal e-waste management facilities. Among the

Table 1: Operationalized variables or constructs

Variable	Construct
Awareness of consequences	The accumulation of e-waste will result in long-term negative impacts on human health. E-waste that is not managed properly can lead to environmental pollution.
Behavioral intentions	I intend to recycle my electronic devices in the future. I plan to donate usable electronic devices instead of discarding them. I will actively utilize an e-waste collection facility if one is readily available.
Actual behaviors	I have previously taken my e-waste to an official collection or recycling point. I store my electronic waste so it can be managed responsibly at a later time. I participate in community programs or campaigns focused on e-waste.
Accessibility	The location of the current e-waste drop-off point is easily accessible from where I live/conduct my activities. The road conditions to the e-waste collection location do not pose a problem (example, no traffic jams, good roads). Directions (example, signs or maps) to the e-waste collection location are very clear. The number of e-waste drop-off points available in my area is sufficient. The operating hours of the e-waste collection point are compatible with my free time. The e-waste collection point is user-friendly (example, the drop-off process is quick and uncomplicated). The distance from my house/office to the nearest e-waste collection point is not far. I am willing to take the time to deliver e-waste to the collection point. I feel that the time and energy required to deliver e-waste is not a big burden.

Note: The study applied a 5-point Likert scale to measure all the items in this survey (1 equal to (=) strongly disagree to 5=strongly agree).

Table 2: Pattern categories formed by nearest neighbor analysis

Index	Pattern
Nearest neighbor ratio (T) lower than < 1	Clustered
T= 1	Random
T > 1	Uniform

Table 3: Demographic profile and socioeconomic attributes of household consumers in Surabaya City

Variable/attribute	Component	Frequency	Percentage (%)
Sex	Men	106	42.4
	Women	144	57.6
Age (years)	< 18	11	4.4
	18–35	190	76.0
	36–45	37	14.8
	46–55	12	4.8
Education level	Secondary	7	2.8
	Tertiary	145	58.0
	College	84	33.6
	Master/Doctor	14	5.6
Monthly income	0–2.5 million IDR	157	62.8
	2.5–5 million IDR	49	19.6
	5–7.5 million IDR	36	14.4
	7.5–10 million IDR	8	3.2
Number of household dependents	0	96	38.4
	1–2	88	35.2
	3–4	52	20.8
	5–6	13	5.2
	More than (>) 6	1	0.4
Residential status	Own a single house/residence	142	56.8
	Own more than one house/residence	16	6.4
	Temporary rental/short-term lease	48	19.2
	Long-term rental/lease	44	17.6
Estimated distance from home to electronic waste processing location (km)	< 10	124	49.6
	10–30	84	33.6
	31–50	33	13.2
	51–70	8	3.2
	> 70	1	0.4
Travel time from home to electronic waste processing site (minutes)	< 10	77	30.8
	10–30	116	46.4
	31–45	41	16.4
	46–60	12	4.8
	> 60	4	1.6

250 respondents, 124 (49.6%) reported that the relevant facility was located less than 10 km from their residence, while 84 (33.6%) reported a distance of 10–30 km. The distribution of travel time was somewhat different, with 116 respondents (46.4%) reporting a travel time of 10–30 minutes and 77 (30.8%) reporting less than 10 minutes. This divergence between the two metrics warrants emphasis, given that linear spatial separation fails to capture the true operational burden, encompassing transit time and personal effort, associated with accessing collection facilities. A relatively short distance may still involve longer travel because of road conditions, transport availability, or route characteristics, while a greater distance may be manageable where transport and routes are convenient. When residents must undertake dedicated excursions to discard stored e- waste, cumulative transit duration and logistical demands can severely diminish the perceived utility of formal disposal channels. Conversely, closer facilities may reduce the geographical burden of access, although physical proximity alone does not determine whether households will use them. Previous studies have similarly identified convenience, accessibility, and infrastructure support as important conditions influencing participation in formal e-waste collection and recycling systems (Sari *et al.,* 2021; Nawaz *et al.,* 2025; Kosarkar and Barthwal, 2025). The distance and travel-time distributions in Table 3 therefore provide a useful description of the physical access conditions experienced by the sampled households, while also highlighting why accessibility cannot be represented by distance alone. Accordingly, within this study, these objective parameters were evaluated independently of perceived accessibility, which encapsulates public perceptions regarding the operational convenience, usability, and logistical friction inherent in utilizing e-waste disposal infrastructure (Table 3).

Descriptive statistics and construct reliability

Descriptive statistics show that consequence awareness had the highest mean score (Mean = 4.33; Standard deviation (SD) = 0.706), indicating a relatively high level of respondent awareness of the environmental impacts of e-waste. Behavioral intention also showed a high mean score (Mean = 4.02; SD = 0.682), while accessibility (Mean = 3.55; SD = 0.710) and actual behavior (Mean = 3.66; SD = 0.792) were at a moderate level. Reliability testing showed that the accessibility construct had excellent internal consistency (Cronbach's Alpha = 0.883). The consequence awareness (Cronbach's Alpha = 0.668), behavioral intention (Cronbach's Alpha = 0.647), and actual behavior (Cronbach's Alpha = 0.635) constructs showed more modest internal consistency, but remained within acceptable ranges for exploratory or preliminary confirmatory social research (Table 4). Behavioral intention differed significantly across the low, medium, and high accessibility groups ($\chi^2 = 11.67$, $p = 0.003$), while actual behavior also differed significantly across accessibility groups ($\chi^2 = 35.91$, $p < 0.001$), with the high-accessibility group showing the highest mean ranks for both outcomes.

Spearman correlation analysis

The relationships among the main variables were not uniform across the two behavioral outcomes. Awareness of e-waste consequences had a positive association with behavioral intention ($r = 0.340$, $p < 0.001$), whereas its association with actual behavior was weak and statistically non-significant ($r = 0.067$, $p = 0.293$). Perceived accessibility showed a different pattern, with significant positive associations with both behavioral intention ($r = 0.197$, $p < 0.001$) and

Table 4: Descriptive statistics and reliability test results

Variable/ construct	Mean	SD	Min	Max	Item Total	Cronbach's Alpha
Awareness of consequences	4.33	0.706	1	5	2	0.668
Accessibility	3.55	0.710	1	5	9	0.883
Behavioral intention	4.02	0.682	1	5	3	0.647
Actual behavior	3.66	0.792	1	5	3	0.635

actual behavior ($r = 0.416$, $p < 0.001$). Behavioral intention was also positively associated with actual behavior ($r = 0.407$, $p < 0.001$). The contrast among these coefficients provides an important indication of the relationship between awareness, intention, and reported behavior. While environmental awareness exhibited a stronger correlation with stated behavioral intent than with self-reported past actions, perceived accessibility demonstrated significant associations with both outcomes, displaying a markedly more robust bivariate relationship with actual behavior. This pattern suggests that recognising the health and environmental consequences of e-waste may be relevant to the formation of behavioral intention, but awareness alone does not necessarily correspond to reported engagement in e-waste management practices. Conversely, the pronounced association between perceived accessibility and actual behavior underscores that on-the-ground operational conditions governing facility access exert a profound influence on household participation levels. Previous research has similarly identified gaps between environmental awareness or behavioral intention and actual e-waste participation, particularly where convenience, infrastructure, and other external conditions influence the translation of intention into action (Attia *et al.,* 2021; Kosarkar and Barthwal, 2025; Nawaz *et al.,* 2025). The positive association between behavioral intention and actual behavior ($r = 0.407$, $p < 0.001$) further indicates that intention is related to reported participation, although the relationship does not imply that intention alone is sufficient for behavior to occur. Accordingly, the concurrent correlation of perceived accessibility with both behavioral intent and realized actions highlights how tangible infrastructural access operates as a critical counterpart to individual cognitive awareness and motivation. Awareness and perceived accessibility were themselves weakly and negatively correlated ($r = -0.125$, $p < 0.05$), indicating that these constructs capture relatively distinct dimensions of household e-waste management rather than reflecting the same underlying characteristic (Table 5).

OLS regression analysis

OLS regression results indicate that awareness of consequences (standardized regression coefficient (β) = 0.376; p-value < 0.001) and accessibility (β = 0.253; p-value < 0.001) have a positive and significant association with household intention to manage e-waste. Furthermore, gender was also significantly associated with intention (β = 0.233; p-value = 0.005), indicating differences in intention based on demographic characteristics (Table 6). Regression coefficients are reported as β values as presented in the available manuscript. The original statistical output is not retained, so the coefficients are not further described as standardized or unstandardized beyond this notation. Due to an irreconcilable discrepancy among the coefficient, standard error, and t-statistic reported within the available record for the residential status parameter in Table 6, this specific estimate is excluded from the textual analysis. In the intention model, awareness (β = 0.376, p-value < 0.001), perceived accessibility (β = 0.253, p-value < 0.001), and sex (β = 0.233,

Table 5: Spearman correlation between variables/constructs

Variable/ construct	Awareness of consequences	Accessibility	Behavioral intention	Actual behavior
Awareness of consequences	1.00	-0.125**	0.340***	0.067
Accessibility		1.00	0.197***	0.416***
Behavioral intention			1.00	0.407***
Actual behavior				1.00

Note: *Significant at 10% level; ** Significant at 5% level; ***Significant at 1% level

Table 6: OLS regression results (dependent variable: behavioral intention)

Independent variable	Regression coefficient (β)	Standard error (SE)	t-statistic (t-value)	p-value
Constant	1.293	0.346	3.739	0.000
Awareness of consequences	0.376	0.057	6.574	0.000***
Accessibility	0.253	0.058	4.346	0.000***
Sex	0.233	0.082	2.858	0.005***
Age	-0.104	0.088	-1.188	0.236
Education level	0.091	0.079	1.148	0.252
Monthly income	-0.001	0.067	-0.019	0.985
Number of household	-0.053	0.049	-1.088	0.278
Residential status	-5.09	0.032	-0.002	0.999
Distance to nearest facility (km)	0.019	0.074	0.254	0.800
Travel time to nearest facility (min.)	0.097	0.064	1.511	0.132

Model summary: Coefficient of determination (R^2) = 0.257; Adjusted R^2 = 0.226; F-test statistic (F) = 8.251; p-value < 0.001
Note: *Significant at 10% level; ** Significant at 5% level; ***Significant at 1% level

p-value = 0.005) were statistically associated with behavioral intention after adjustment. Age, education level, monthly income, Number of household dependents, residential status, distance, and travel time were not statistically significant in the reported model. In the actual-behavior model, perceived accessibility (β = 0.449, p-value < 0.001) and awareness (β = 0.182, p-value = 0.008) were statistically associated with the outcome, while sex was not statistically significant at the 5% level (β = 0.177, p-value = 0.068). Within Table 7, the regression coefficients are presented strictly as β values, mirroring the source manuscript. Because the primary statistical output is unavailable, these estimates are deliberately left unclassified as either standardized or unstandardized beyond this specific notation.

Differences in participation (behavioral intention and actual behavior) based on accessibility level

The Kruskal–Wallis test results indicate a significant difference in intention to manage e-waste between the low, medium, and high accessibility groups (Kruskal-Wallis chi-square statistic (χ^2) = 11.67; p-value = 0.003). The high accessibility cohort recorded the highest mean rank, with successively lower values observed across the medium and low accessibility groups. Stronger differences were found in actual behavior/participation. The test results showed a highly significant difference between accessibility groups (χ^2 = 35.91; p-value = 0.000), with a consistent pattern of increasing participation as accessibility levels increased (Table 8). Although the statistically significant omnibus Kruskal–Wallis tests signal overall group-level variations across the accessibility strata, the limitations of the existing manuscript preclude the reconstruction of granular pairwise post-hoc comparisons. Based on the reported H statistics, epsilon-squared was approximately 0.039 for behavioral intention and 0.137 for actual behavior. The findings are therefore reported at the omnibus level only. Effect sizes estimated from the reported Kruskal–

Table 7: OLS regression results (dependent variable: actual behavior)

Independent variable	Regression coefficient (β)	SE	t-value	p-value
Constant	1.153	0.409	2.817	0.005
Awareness of consequences	0.182	0.068	2.686	0.008***
Accessibility	0.449	0.069	6.528	0.000***
Sex	0.177	0.097	1.831	0.068*
Age	-0.165	0.104	-1.589	0.113
Education level	0.025	0.093	0.270	0.787
Monthly income	0.109	0.079	1.379	0.169
Number of household dependents	0.056	0.058	0.962	0.337
Residential status	0.012	0.038	0.311	0.756
Distance to nearest facility (km)	-0.030	0.087	-0.349	0.727
Travel time to nearest facility (minutes)	0.078	0.076	1.029	0.305

Model summary: $R^2 = 0.228$; Adjusted $R^2 = 0.196$; $F = 7.055$; p-value < 0.001
Note: *Significant at 10% level; ** Significant at 5% level; ***Significant at 1% level

Table 8: Kruskal–Wallis test results across accessibility levels

Dependent variable	χ^2	Degrees of freedom (df)	p-value	Mean rank (Low)	Mean rank (Medium)	Mean rank (High)
Behavioral intention	11.67	2	0.003***	112.72	120.28	151.96
Actual behavior	35.91	2	0.000***	95.24	125.07	167.43

Note: *Significant at 10% level; ** Significant at 5% level; ***Significant at 1% level

Wallis statistics were ε^2=0.039 for behavioral intention and ε^2 = 0.137 for actual behavior. While these values quantify the magnitude of overarching group differences; the absence of pairwise post-hoc outputs within the archived manuscript precludes the reporting of specific intergroup contrasts.

Integrated interpretation of the quantitative findings

Collectively, the findings demonstrate that cognitive awareness and perceived accessibility operate as distinct predictors, influencing separate dimensions of household engagement in e-waste management. Awareness was positively associated with behavioral intention but was not significantly associated with self-reported actual behavior in the bivariate analysis. Perceived accessibility was positively associated with both intention and actual behavior, and its adjusted coefficient was larger in the actual-behavior model. These empirical insights align seamlessly with established scholarship, reinforcing the principle that public engagement with e-waste management is fundamentally driven by the interplay between internal psychological motivations and tangible contextual constraints governing disposal (Sari *et al.*, 2021; Mahartin, 2023; Nawaz *et al.*, 2025; Kosarkar and Barthwal, 2025; Haq, 2026). The positive association between awareness and intention is compatible with the Value-Belief-Norm perspective, in which awareness of consequences forms part of the cognitive basis through which environmental concerns can become behaviorally relevant. Prior empirical studies have documented varying associations between environmental awareness and e-waste recycling intention (Elmosaad *et al.*, 2023). However, the effect sizes and underlying mechanisms exhibit considerable heterogeneity across diverse demographic populations and theoretical frameworks (Al Mamun *et al.*, 2022; Duong *et al.*, 2023; Nawaz *et al.*, 2025). The present findings should therefore be interpreted as evidence of an association between consequence awareness and intention rather than

as evidence that awareness causes intention. The absence of a statistically significant bivariate correlation between environmental awareness and actual behavior warrants particular emphasis; rather than representing an analytical contradiction, this finding underscores that cognitive recognition of environmental consequences does not automatically translate into realized action within the specific constraints characterizing this sample. Similar intention–behavior gaps have been documented in pro-environmental behavior research, including e-waste studies, where convenience, perceived control, habits, infrastructure, and institutional arrangements may influence whether an intention is enacted (Trinh and Sakurai, 2025; Nawaz *et al.*, 2025; Kosarkar and Barthwal, 2025). The spatial findings provide a descriptive complement to the survey analysis. They characterize the spatial distribution of the analyzed observations but do not permit these mechanisms to be tested directly. This finding is consistent with Indonesian research indicating that facility accessibility is relevant to e-waste collection intention (Sari *et al.*, 2021) and with recent studies emphasising convenience and formal collection barriers in e-waste management (Alejandro *et al.,* 2025; Nawaz *et al.*, 2025; Kosarkar and Barthwal, 2025). Nevertheless, this outcome must be interpreted strictly as an association with perceived accessibility given that the majority of the accessibility metrics utilized within this study rely on self-reported data. Objective distance and travel time were analyzed separately and should not be treated as interchangeable with perceived accessibility. The regression models further showed that perceived accessibility had the largest reported coefficient in the actual-behavior model (β = 0.449, p-value < 0.001), while awareness was also statistically associated with actual behavior (β = 0.182, p-value = 0.008). Because the retained manuscript lacks the requisite software output to verify whether the estimated coefficients are standardized or unstandardized, their respective magnitudes are intentionally omitted from formal evaluations of predictive strength. The sociodemographic findings were comparatively limited. Gender was statistically associated with behavioral intention in the intention model (β = 0.233, p-value = 0.005), while most other reported covariates were not statistically significant. This observed trend should not be misconstrued as proof that sociodemographic characteristics are universally trivial; rather, within this purposively restricted sample, the majority of evaluated covariates failed to demonstrate statistically significant adjusted associations once all other variables were integrated into the models. The relatively high proportion of respondents with tertiary or college-level education also limits the extent to which these findings can be generalized to more educationally heterogeneous populations.

Spatial analysis

The ANN analysis produced a nearest-neighbor ratio of approximately 0.60 and a z-score of approximately −10.01. Because the ratio is below 1 and the z-score is far from zero, the analyzed point pattern is consistent with statistically significant spatial clustering rather than a random spatial arrangement (p-value < 0.001). However, ANN result outputs do not inherently establish social learning, social contagion, neighborhood effects, collective socialisation, or interpersonal communication. Because none of these underlying mechanisms were directly assessed within the survey framework, ANN serves strictly to characterize the spatial configuration of points rather than elucidate the generative causal processes responsible for that arrangement. Accordingly, statements in the previous version linking the clustering directly to imitation or neighborhood social networks have been

removed. Such mechanisms may be considered as hypotheses for future research rather than conclusions from the present analysis. Table 3 reports distance and travel time as categorical distributions. The modal distance category was < 10 km (49.6%), whereas the modal travel-time category was 10–30 minutes (46.4%). These classifications characterize respondent distributions rather than serving as arithmetic means or definitive accessibility thresholds. Nevertheless, the spatial patterns offer a valuable descriptive complement to the survey evaluation. Specifically, they demonstrate that the analyzed observations exhibit spatial clustering rather than uniform dispersion, highlighting the value of examining the spatial distribution of household participation in relation to collection facility locations. Future studies could extend this approach using network-based travel time, facility capacity, service coverage, population density, and distance-decay models to examine accessibility more directly. Such analyses would be required before proposing a specific facility-planning threshold.

Implications for sustainable e-waste management

The combined findings suggest that awareness-oriented and infrastructure-oriented approaches may address different components of household participation. Awareness campaigns may strengthen recognition of the environmental and health consequences of e-waste, whereas improvements in collection-point availability, operating hours, information, convenience, and service coverage may reduce practical barriers to action. This perspective aligns with contemporary empirical findings indicating that service convenience and structured collection parameters continue to exert a significant influence on e-waste recycling participation (Siringo *et al.,* 2020; Nawaz *et al.*, 2025; Kosarkar and Barthwal, 2025). From a circular-economy perspective, the practical implication is not simply to increase the number of facilities, but to improve the usability and coverage of formal collection pathways and connect them with household routines. Community collection points, retailer take-back schemes, scheduled pick-up services, and clear information on accepted e-waste categories could be considered as complementary measures. Because the current study does not empirically evaluate the efficacy of these interventions, they should be construed strictly as prospective policy options rather than validated causal outcomes. The ecological-anthropological contribution of the study lies in situating household e-waste practices within the material and spatial context in which they occur. Rather than presuming a direct linear trajectory from cognitive awareness to responsible conduct, the findings underscore that contextual disposal conditions play a critical role in turning behavioral intent into actual practice. This contextual interpretation is compatible with research emphasising the role of infrastructure, everyday practices, and institutional arrangements in environmental behavior (Ardoin and Heimlich, 2021; Rippa, 2023; Harafah *et al.*, 2026). H1–H7 correspond to the relationships and group comparisons directly examined in the available analyses. Sociodemographic variables were treated as covariates rather than as separate directional hypotheses. Five hypotheses concerning bivariate associations were supported, whereas H2 was not supported. Awareness of e-waste consequences was positively associated with behavioral intention (H1: $r = 0.340$, $p < 0.001$), but its association with actual behavior was weak and statistically non-significant (H2: $r = 0.067$, $p = 0.293$). This divergence reveals that while individuals possessing a heightened awareness of the ecological and health risks associated with e-waste reported more robust intentions toward proper management, this cognitive recognition failed to manifest correspondingly in their

Table 9: Summary of hypothesis testing

Hypothesis	Testing method	Coefficient/ test statistic	p-value	Decision
H1	Spearman correlation	r = 0.340	< 0.001	Supported
H2	Spearman correlation	r = 0.067	0.293	Not supported
H3	Spearman correlation	r = 0.197	< 0.001	Supported
H4	Spearman correlation	r = 0.416	< 0.001	Supported
H5	Spearman correlation	r = 0.407	< 0.001	Supported
H6	Kruskal–Wallis	χ^2 = 11.67, df = 2	0.003	Supported at omnibus level; post-hoc comparisons required
H7	Kruskal–Wallis	χ^2 = 35.91, df = 2	<0.001	Supported at omnibus level; post-hoc comparisons required

Note: *Significant at 10% level; ** Significant at 5% level; ***Significant at 1% level

self-reported past actions. Comparable disconnects traversing awareness, behavioral intent, and actual disposal practices have been widely documented in previous studies. Attia *et al.* (2021), for example, found that awareness of e-waste issues did not necessarily translate into appropriate disposal practices among households (Table 9).

Spatial analysis results

The Average Nearest Neighbor analysis produced a nearest-neighbor ratio of 0.598616, a z-score of −10.011886, and a p-value of < 0.001 (Fig. 3). The ratio below 1 and the statistically significant z-score indicate that the observed point pattern is significantly clustered rather than consistent with spatial randomness. The ANN result describes the spatial arrangement of the observations included in the analysis and does not demonstrate social learning, social contagion, neighborhood effects, collective socialization, or interpersonal communication. These mechanisms were not directly assessed within the survey framework and therefore cannot be legitimately inferred from ANN spatial metrics alone. The reported distance and travel-time measures are categorical observations. The most frequently reported distance category was < 10 km (49.6%), while the most frequently reported travel-time category was 10–30 minutes (46.4%) (Table 3). These categories describe the observed distribution of respondents and should not be interpreted as arithmetic means or formal accessibility thresholds.

CONCLUSION

This study examined household e-waste participation in Surabaya by considering awareness of e-waste consequences, perceived facility accessibility, behavioral intention, self-reported actual behavior, selected sociodemographic characteristics, and spatial distribution. Awareness was positively associated with behavioral intention (r = 0.340, p-value < 0.001) but not with self-reported actual behavior (r = 0.067, p = 0.293). Perceived accessibility was positively associated with both intention (r = 0.197, p < 0.001) and actual behavior (r = 0.416, p-value < 0.001). In the adjusted OLS models, Perceived accessibility was statistically associated with actual behavior (β = 0.449, p-value < 0.001), while awareness was also statistically associated with actual behavior (β = 0.182, p-value = 0.008). The Kruskal–Wallis tests also indicated differences across accessibility groups for both intention and actual behavior. The ANN evaluation revealed statistically significant spatial clustering across the examined observations, characterized by a nearest-neighbor ratio of approximately 0.60 and a z-score of approximately −10.01. While this outcome delineates an explicit spatial distribution, it must not be construed as indicative of

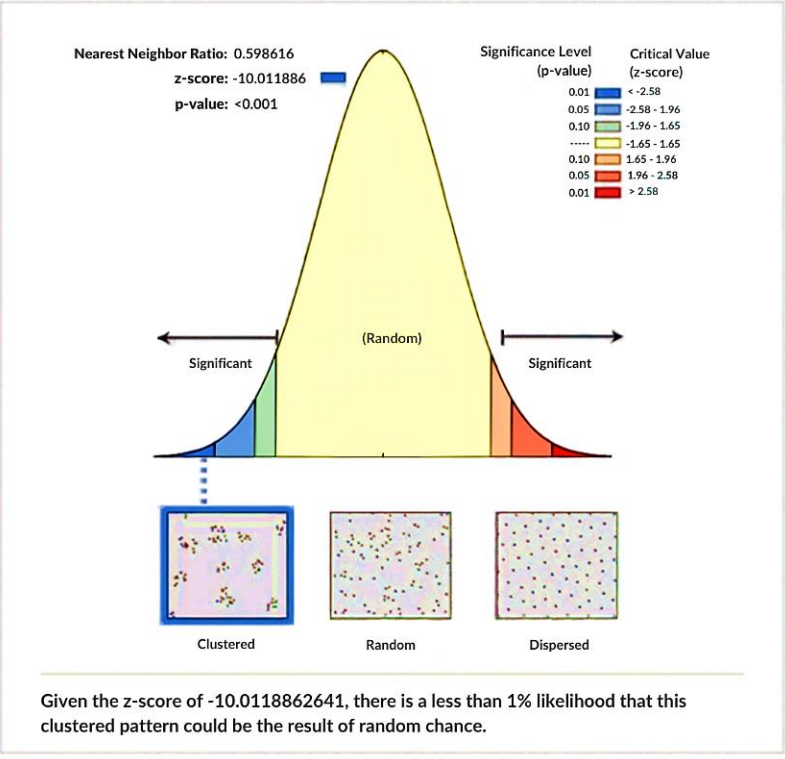

Fig. 3: Spatial distribution of respondents and nearest-neighbor clustering pattern in Surabaya City

neighborhood effects, social learning processes, or alternative underlying causal mechanisms. Similarly, the observed distance and travel-time categories do not establish a specific accessibility threshold. The findings support an integrated interpretation in which household e-waste participation is associated with both cognitive and contextual conditions. Nevertheless, owing to the cross-sectional architecture and purposive sampling strategy employed, these findings preclude definitive causal inferences and broad population-level generalizations. Consequently, the empirical outcomes are most rigorously construed as localized evidence reflecting the sampled households within Surabaya rather than serving as national-level estimates. For practice, the findings suggest that awareness activities can be complemented by improvements in the convenience and usability of formal e-waste collection services. Recommended policy measures encompass expanding geographical service coverage, disseminating transparent information concerning collection points and accepted waste categories, extending operating hours, and integrating e-waste collection mechanisms with existing municipal waste streams or retail take-back programs. These measures should be evaluated through longitudinal, experimental, or quasi-experimental research before their effectiveness is assumed. Several methodological limitations warrant explicit consideration. First, the cross-sectional design inherently precludes the determination of temporal sequencing and directional causality. Second, purposive sampling and the focus on households near e-waste facilities limit generalisability and may introduce facility-proximity selection bias. Third, actual behavior was self-reported and may be affected by recall or social-desirability bias. Fourth, the awareness

construct contained only two items and showed Cronbach's alpha = 0.668, while the actual-behavior construct showed α = 0.635; therefore, the reliability of these measures should be interpreted cautiously. Fifth, perceived accessibility aggregates multiple underlying dimensions that may not constitute a strictly unidimensional construct. Sixth, objective distance and travel time were considered separately from perceived accessibility, but their relationship with perceived accessibility was not formally tested. Finally, the spatial analysis cannot identify behavioral mechanisms underlying clustering. Future research should use probability-based or stratified sampling, stronger multi-item measures, objective behavioral or administrative records, network-based accessibility measures, and longitudinal or quasi-experimental designs. Furthermore, supplementary mediation or moderation modeling could be pursued provided that the underlying constructs of interest have been explicitly and rigorously operationalized. The internal consistency estimates were acceptable for the accessibility construct (Cronbach's alpha = 0.883), whereas the awareness (Cronbach's alpha = 0.668), behavioral intention (Cronbach's alpha = 0.647), and actual-behavior (Cronbach's alpha = 0.635) constructs showed more modest internal consistency. These lower coefficients should be interpreted in light of the limited number of items used to represent these constructs and constitute a measurement limitation of the study.

AUTHOR CONTRIBUTIONS

H. Herdiansyah supervised the study, contributed to the statistical analysis and interpretation, and led manuscript preparation. D. Fitria contributed to interpretation of the statistical findings and manuscript preparation. D.R. Nugraheni prepared the maps and figures and contributed to spatial-data interpretation. M. Qamruzzaman contributed to supervision, data analysis, and interpretation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
=	Equal to
<	Less than
>	More than
–	Through
β	Regression coefficient
ε	Error
χ^2	Kruskal–Wallis chi-square statistic
ANN	Average Nearest Neighbor
df	Degrees of freedom
e-waste	Electronic waste
F	F-test statistic
GIS	Geographic Information Systems
H	Hypotheses
H1–H7	Hypotheses 1–7
km	Kilometer
Max	Maximum
Min	Minimum
Min.	Minutes
OLS	Ordinary least squares
p-value	Probability value
r	Spearman correlation coefficient
R^2	Coefficient of determination
SD	Standard deviation
SE	Standard error
T	Nearest neighbor ratio
VBN	Value-belief-norm
VIF	Variance inflation factor
t-value	t-statistic
y	Year
Z	Standard score (Z-score)

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