International Journal of Environmental Impacts
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Factors That Influence the Management of Household Hazardous Waste in Semarang City, Central Java, Indonesia: A Path Analysis

Glory Nasarani[1*], Hartuti Purnaweni[1,2], Maryono Maryono[1,3], Siti Rachmawati[4], Iwan Suryadi[5], Nofriani Surahman[6], Nurlaila Fitriani[7]

[1] Department of Doctoral Environmental Science, Faculty of Postgraduate, Diponegoro University, 50241 Semarang, Indonesia
[2] Department of Public Administration, Faculty of Social and Political Science, Diponegoro University, 50275 Semarang, Indonesia
[3] Department of Urban and Regional Planning, Faculty of Engineering, Diponegoro University, 50275 Semarang, Indonesia
[4] Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, 57126 Surakarta, Indonesia
[5] Department of Environmental Health, Poltekkes Kemenkes Makassar, 90222 Makassar, Indonesia
[6] Associate Degree of Building Construction Engineering Technology, Public Works Polythechnic, 50166 Semarang, Indonesia
[7] Department of Nursing, Faculty of Nursing, Hasanuddin University, 90245 Makassar, Indonesia

[*] Correspondence: Glory Nasarani (glorynasarani@students.undip.ac.id)

Received: 03-11-2025 **Revised:** 04-14-2025 **Accepted:** 06-11-2025

Citation: G. Nasarani, H. Purnaweni, M. Maryono, S. Rachmawati, I. Suryadi, N. Surahman, and N. Fitriani, "Factors that influence the management of household hazardous waste in Semarang City, Central Java, Indonesia: A path analysis," *Int. J. Environ. Impacts.*, vol. 8, no. 5, pp. 888–898, 2025. https://doi.org/10.56578/ijei080505.

Abstract: This study investigates the factors influencing community willingness to manage household hazardous waste (HHW) in Semarang City, Indonesia, through a path analysis approach grounded in the Theory of Planned Behavior (TPB). A total of 500 respondents were surveyed across 16 sub-districts using stratified random sampling. The analysis explores both direct and indirect effects of demographic (age, education, occupation), socioeconomic (monthly expenses), and cognitive [knowledge] variables on willingness to engage in HHW management. The findings highlight knowledge as the most influential determinant of willingness ($\beta = 0.469, p < 0.001$), emphasizing its mediating role between education and willingness. Education shows no significant direct effect but exerts a strong indirect effect through knowledge ($\beta = 0.282$). Age negatively affects both knowledge ($\beta = -0.176$) and willingness ($\beta = -0.097$), indicating that younger individuals tend to be more knowledgeable and more willing to manage HHW. Monthly expenses also have a positive, though relatively weaker, direct ($\beta = 0.086$) and indirect ($\beta = 0.066$) influence on willingness via knowledge. Employment status was not found to be a significant factor. The model explains 73.6% of the variance in willingness ($R^2 = 0.736$) and 26.4% in knowledge ($R^2 = 0.264$). These results reinforce the relevance of TPB in environmental behavior studies while suggesting the need for context-specific modifications, such as considering digital media exposure and infrastructural access. Policy implications include prioritizing educational interventions, improving access to information and facilities, and targeting youth as key agents in promoting sustainable HHW management.

Keywords: Household hazardous waste; Path analysis; Willingness; Knowledge; Education

1 Introduction

Household hazardous waste (HHW) is waste produced from household activities that is classified as hazardous and has the characteristics of being flammable, corrosive, reactive, caustic, and toxic [1, 2]. There are several types of household wastes based on the Minister of Environment and Forestry Regulation Number 9 of 2024 concerning Management of Waste Containing Hazardous and Toxic Materials and Waste of Hazardous and Toxic Materials, namely household products containing hazardous materials, used packaging for products containing hazardous substances, electronic appliances that are no longer used, and/or products and/or other packaging containing hazardous

materials that are no longer used.

The percentage of household hazardous waste produced is only around 0–4% of the total household waste produced [3, 4]. Even though the amount is not significant compared to other types of household waste, the negative impacts resulting from HHW still exist and are dangerous for the environment and human health [5]. HHW content containing hazardous materials, such as heavy metals, can be dangerous to health if inhaled, touched, or ingested. HHW mixed with rainwater, for example, can result in the formation of leachate, which can contain heavy metals and can pollute groundwater and soil [6]. Of course, the negative impacts it causes warrant concern. Unfortunately, in most developing countries, the majority of the population lacks a comprehensive understanding of household hazardous waste (HHW) and the potential dangers it poses [7]. HHW-generated forms of household waste are generally being mixed and disposed of with other household waste [8]. Therefore, regulations regarding HHW management must be made so that management is right on target and can reduce the negative impacts caused by HHW.

Semarang City is the city that produces the most waste in Central Java Province, with recorded waste generation in 2023 of 431,534.65 tons based on data from the National Waste Management Information System of the Ministry of Environment and Forestry of the Republic of Indonesia. Waste management in Semarang City itself still does not apply the principles of sorting and separating hazardous waste from household waste as a whole [9]. One of the challenges in managing household hazardous waste in Indonesia is the low level of public awareness about the importance of sorting and separating household hazardous waste from other household waste [10]. On the other hand, the success of household hazardous waste management comes from community participation with those who have knowledge and awareness about the dangers of hazardous waste [7, 8]. Good knowledge will have a positive impact on waste management, such as reducing the potential for environmental pollution [11, 12]. Increasing knowledge is one effort to encourage positive behavior toward waste management [13].

The management of HHW in developing countries is significantly shaped by the socio-economic status of communities. In Semarang, for instance, limited access to information and adequate waste management facilities poses a major challenge [9]. A study in Ghana revealed that income and education levels are critical in influencing public awareness and engagement in hazardous waste management [14]. Similarly, Eugenio et al. [15] found that communities in the Philippines with higher economic status were more likely to access proper waste management facilities. In Indonesia, disparities in access to such resources exacerbate existing problems in HHW management.

Although Indonesia has established a legal framework through the Regulation of the Minister of Environment and Forestry Number 9 of 2024 on the Management of Hazardous and Toxic Waste, its implementation at the local level remains problematic. Aprilia, Tezuka, and Spaargaren pointed out that the lack of information dissemination and weak law enforcement hinder the effectiveness of this regulation [10]. Moreover, a study conducted in Thailand found that without adequate infrastructure, hazardous waste management policies are unlikely to be successful [16]. These policy gaps become more pronounced when compounded by limited regional budgets and poor inter-agency coordination.

Previous research in developing countries also underscores similar challenges. For instance, reported that 72% of HHW in Thailand was not properly managed due to low public awareness, mirroring the situation in Semarang [16]. Thakur and Onwubu found that in South Africa, public participation in HHW management was largely driven by access to infrastructure and educational programs two factors that are also limited in many parts of Indonesia [10, 13]. In their study in India, emphasized the importance of applying the Theory of Planned Behavior (TPB) to improve community engagement in waste management, a recommendation that aligns with the initial findings of the current study [17].

This research delves into the factors that impact the management of hazardous waste, particularly household waste, in Semarang City with the aim of enhancing efforts to manage household hazardous waste and preparing government policies for its handling.

2 Method

2.1 Research Design

This research is both qualitative and quantitative. This research was located in Semarang City with 16 sub-districts, including Central Semarang, South Semarang, East Semarang, North Semarang, Gajahmungkur, Candisari, Pedurungan, Gayamsari, Tembalang, Genuk, West Semarang, Ngaliyan, Mijen, Tugu, Banyumanik, and Gunungpati sub-districts, with a total population in 2023 of 1,694.74 thousand people (Semarang City in Figures 2024, BPS Semarang City). The administrative map of Semarang City is presented in Figure 1.

2.2 Sample

The sample used was 500 respondents with a minimum age of 18 years, living in Semarang City, and agreeing to be research respondents. Sample selection was carried out using stratified random sampling. The sample was drawn by stratified random sampling with stratification based on three criteria: region, with 16 sub-district education

level with 4 education strata namely primary school, junior high school, senior high school and university and income group 3 strata. Sample allocation used a proportional approach, with 500 respondents divided based on the percentage of the population of each stratum.

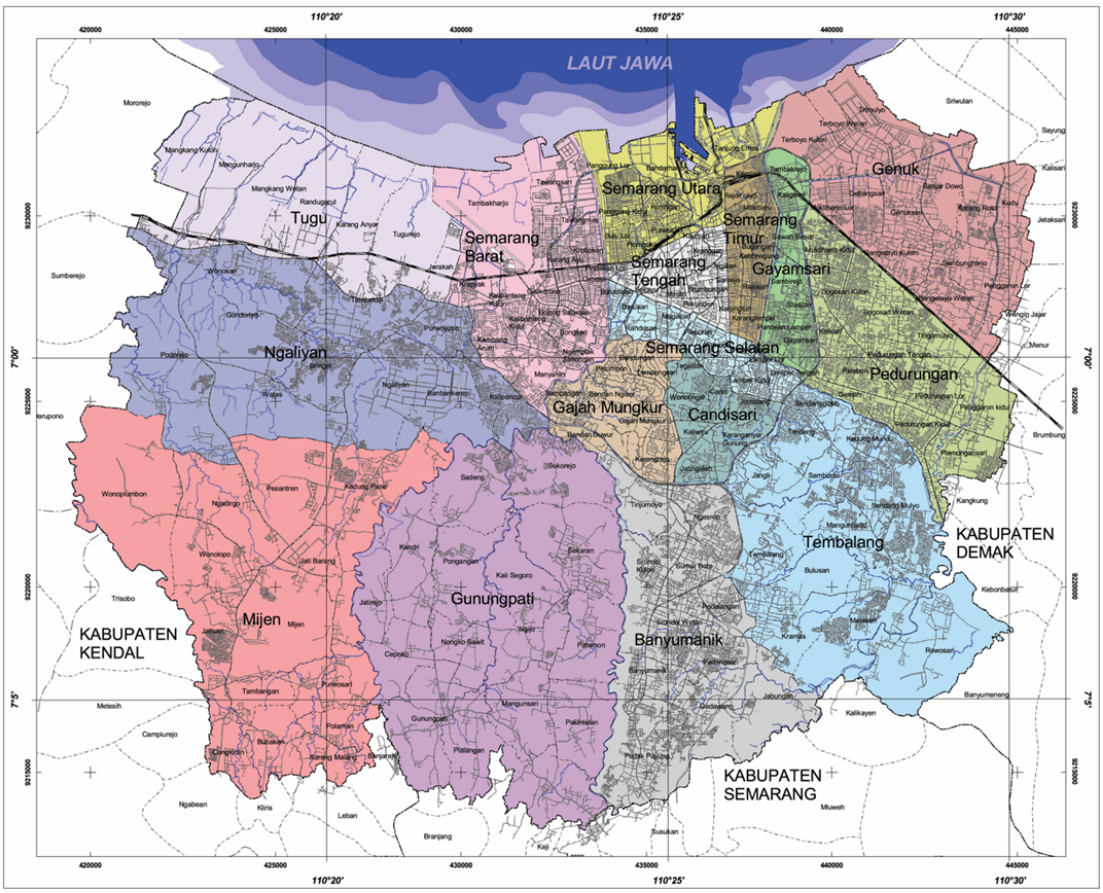

Figure 1. Administrative map of Semarang City

2.3 Data Collection

Data collection was carried out by distributing questionnaires to 500 samples spread across 16 sub-districts in Semarang City. Data collection was carried out from September 2023 to July 2024. Questions were asked of the sample to fill out the questionnaire. The questions in the questionnaire use a 5-point Likert scale where the sample is asked to answer the questionnaire questions on a scale of disagree to strongly agree. The questionnaire was validated through reliability testing with Cronbach's alpha ($\alpha \geq 0.70$) and construct validity testing using CFA. The α value for the knowledge variable was 0.82 and willingness 0.78, indicating good internal consistency.

2.4 Data Analysis

Univariate analysis was carried out to see the frequency distribution and percentage characteristics of research subjects. Bivariate analysis was carried out to see the relationship between the incidence of hypertension and the independent variables using the Pearson correlation test. Multivariate analysis uses path analysis to determine the direct and indirect effects of the relationship between research variables. Path analysis steps include model specification, model identification, model fit, parameter estimation, and model specification.

Path analysis is a statistical technique that provides possible direct or indirect causal relationships between a set of variables. Path analysis begins by developing a diagram with arrows that connect variables and show the causal flow or direction of cause and effect. Each path represents two variables connected by an arrow (a line, usually straight, with an arrow at one end) or a wire (a line, usually curved, without an arrow) or a sling (with two arrows). Variables can be categorized into one of two types: variables that do not have a direct cause (exogenous) and variables that have a direct cause (endogenous). In regression, exogenous variables are sometimes referred to as predictors, independent variables, or explanatory variables. Endogenous variables are called dependent variables or response variables. Figure 2 shows a simple path diagram with two exogenous variables (X1 and X2) and two

endogenous variables (Y1 and Y2). In a path diagram, single-headed arrows indicate direct influence, while cables or slings indicate covariance/correlation.

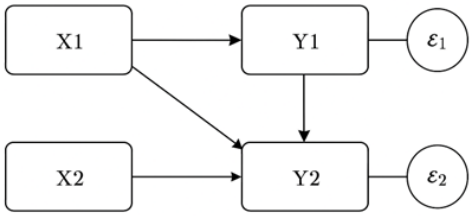

Figure 2. Simple path diagram for two equations causal model

Descriptive statistics and correlations were used to describe sample characteristics and to assess relationships between variables. The form of the path model can be expressed in the following two endogenous variable regression equations:

$$\mathrm{Y} = \beta 1\mathrm{M} + \delta 1\mathrm{X1} + \delta 2\mathrm{X2} + \ldots + \delta \mathrm{nXn} + \epsilon \mathrm{Y}$$

$\beta 1$ is the path coefficient from the mediator variable M to the endogenous variable Y.

$\delta 1$, $\delta 1$, …, δn is the path coefficient of the exogenous variables X1, X2, …, Xn directly to the endogenous variable Y, which represents the direct effect.

ϵY is the error term for the endogenous variable Y.

$$\mathrm{Y} = \beta 1\mathrm{M} + \delta 1\mathrm{X1} + \delta 2\mathrm{X2} + \ldots + \delta \mathrm{nXn} + \epsilon \mathrm{Y}$$

with Y representing willingness, $\beta 1$M representing knowledge, X1 representing age, X2 representing education, X3 representing employment, it is assumed that the covariance between two errors is zero.

3 Result

Table 1. Respondent characteristics

Variable	n	%
Age		
15–24	94	18.8
25–34	99	19.8
35–44	102	20.4
45–54	93	18.6
55–64	67	13.4
$>$ 64	45	9.0
Gender		
Female	265	53.0
Male	235	47.0
Education		
Elementary school	84	16.8
Junior High School	91	18.2
Senior High School	206	41.8
University	116	23.2
Employment Status		
Own account workers	102	20.4
Employer with permanent/paid workers	16	3.2
Laborers/employees	298	59.6
Casual/unpaid workers	31	6.2
Farm laborers/casual workers	28	5.6
Employer with temporary/unpaid workers	25	5.0
Monthly Expenses		
Rp. 0–Rp. 1,218,412	138	27.6
Rp. 1,218,413–Rp. 3,338,247	269	53.8
$\geq$ Rp. 3,338,248	93	18.6

3.1 Statistic Analysis

Table 1 presents the results of the univariate test on the characteristics of 500 respondents, revealing that the largest age group was in the 35–44-year range (20.4%), while the least number was in the age category $>$ 64 years (9%). The majority of respondents were female (53%), and the rest were male. As many as 41.8% of respondents had a high school education level or equivalent, and only 16.8% had reached primary education. The respondents' types of work vary, with laborers making up the largest group at 59.6%, and their average monthly expenditure falls between Rp. 1,218,413 and Rp. 3,338,247.

Table 2 shows the results of the bivariate test of research variables by distinguishing between the direct influence of age, education, employment, monthly expenses, and knowledge and willingness. The test results using the Spearman correlation test showed that age, education, monthly expenditure, and knowledge had a significant influence ($p < 0.05$), and only monthly employment did not have a significant influence. For the indirect influence, where the variables age, education, employment, and monthly expenses are connected to the mediator variable, namely knowledge, it shows that only employment does not have a significant influence; other variables have a significant influence on the respondent's knowledge ($p < 0.05$).

Table 2. Bivariate analysis of independent variables in the form of willingness and mediator variables in the form of knowledge

Independent Variable	Dependent Variable	p-value	R
Age	Willingness (mean + SD = 58.16 + 7.43)	0.002	−0.138
Education		0.000	0.197
Employment status		0.391	0.152
Monthly expenses		0.001	0.038
Knowledge		0.000	0.501
Age	Knowledge (mean + SD = 71.45 + 13.05)	0.000	−0.198
Education		0.000	0.351
Employment status		0.138	0.066
Monthly expenses		0.000	0.501

4 Path Analysis

Figure 3 illustrates a well-identified and complex path analysis model, comprising a total of nine variables—seven exogenous variables and two endogenous variables, namely knowledge as a mediator and willingness as the main dependent variable. The model satisfies the statistical identification criteria with a degree of freedom of 4, indicating that the available data are sufficient to uniquely estimate all parameters within the model.

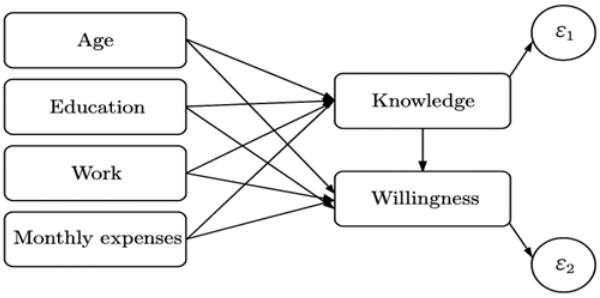

Figure 3. Path model with estimate

In the figure, each of the seven exogenous variables-age, education, occupation, monthly expenditure, and three other background variables (possibly gender, social status, or prior experience with waste management, although not explicitly described in the narrative)-is assumed to have a direct path toward knowledge as the mediating variable. From the estimated path coefficients, age exhibits a significant negative effect on knowledge ($b = -1.461$), suggesting that younger individuals possess greater knowledge regarding household hazardous waste (HHW) management. Conversely, education and monthly expenditure demonstrate significant positive effects on knowledge ($b = 3.675$ and $b = 2.733$, respectively), indicating that higher educational attainment and greater spending capacity are associated with improved understanding of HHW.

Furthermore, knowledge exerts the strongest direct effect on willingness ($b = 0.267$; $\beta = 0.469$; $p < 0.001$), positioning it as a key mediating variable that bridges the influence of background characteristics on individuals'

intention to engage in HHW management. Direct paths from the exogenous variables to willingness are also presented in the model. For instance, age has a significant negative direct effect on willingness ($b = -0.458$; $\beta = -0.097$), while monthly expenditure has a positive and significant influence ($b = 0.967$; $\beta = 0.086$). In contrast, education exhibits a negligible and non-significant direct effect ($b = -0.055$; $\beta = -0.007$); however, its indirect effect through knowledge becomes meaningful and significant (indirect $\beta = 0.132$).

The R^2 value for knowledge is 0.264, indicating that approximately 26.4% of the variance in knowledge is explained by the included exogenous variables. Meanwhile, the R^2 value for willingness is 0.736, suggesting that 73.6% of the variance in willingness is accounted for by knowledge and other factors within the model. This reflects a strong predictive capability of the model. Finally, the model includes error terms ($\varepsilon_1 = 0.836$ for knowledge and $\varepsilon_2 = 0.736$ for willingness), indicating the presence of other unmeasured variables that may influence both endogenous variables. Overall, Figure 4 illustrates a complex yet informative causal structure, with meaningful pathways underscoring knowledge as a strategic mediating factor in enhancing public willingness. This suggests that educational interventions and improved access to information are likely to be more effective than relying solely on demographic or economic factors.

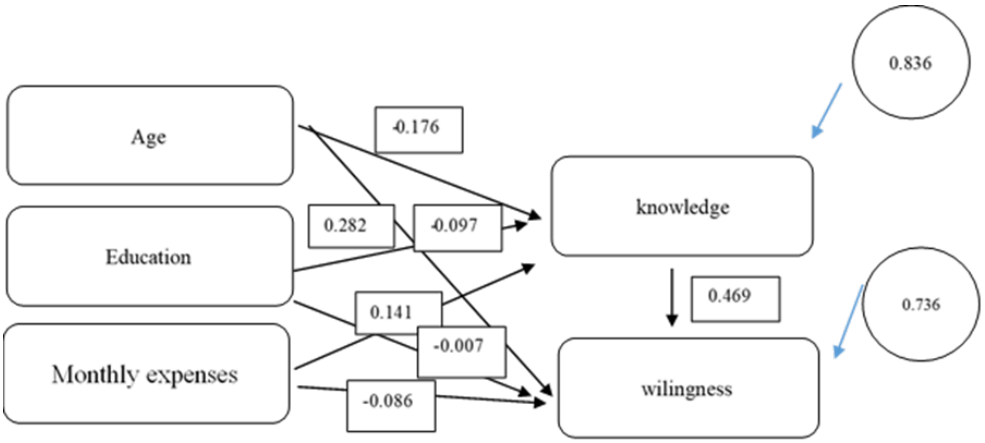

Figure 4. Path model with estimation

Table 3. Results of path analysis in the determinant model that influences willingness in HHW management

Dependent Variable	Independent Variable	$b*$	SE	p	$\beta*$	R Square
	Direct Influence					
Willingness	Age	-0.458	0.200	0.022	-0.097	0.264
Willingness	Education	-0.055	0.324	0.865	-0.007	
Willingness	Monthly expenses	0.967	0.466	0.041	0.086	
Willingness	Knowledge	0.267	0.024	0.000	0.469	
	Indirect Influence					
Knowledge	Age	-1.461	0.367	0.000	-0.176	0.164
Knowledge	Education	3.675	0.582	0.000	0.282	
Knowledge	Monthly expenses	2.733	0.863	0.002	0.141	
N = 500						
$\varepsilon 1$ = 0.836						
$\varepsilon 2$ = 0.736						

Based on the path analysis results presented in Table 3, it was found that knowledge is the most dominant factor influencing the public's willingness to manage household hazardous waste in Semarang City. This is evidenced by the path coefficient β value of 0.469 and a significance level of $p < 0.001$. These findings indicate that a higher level of knowledge is associated with a greater willingness to engage in HHW management practices. Age was also found to have a significant and negative direct effect on willingness ($\beta = 0.097$; $p = 0.022$), suggesting that younger individuals tend to exhibit greater willingness to manage HHW . In contrast, education did not show a significant direct effect on willingness ($\beta = -0.007$; $p = 0.865$), but it demonstrated a strong and significant indirect effect through knowledge, with a coefficient value of $\beta = 0.282$ and $p < 0.001$. This implies that education influences willingness indirectly by enhancing individuals' knowledge.

Furthermore, monthly expenses were found to have a significant direct effect on willingness ($\beta = 0.086$; $p = 0.041$), although the magnitude of this effect is relatively small compared to that of knowledge. Monthly expenses also contributed indirectly to knowledge improvement ($\beta = 0.141$; $p = 0.002$), which in turn positively influenced willingness. However, the magnitude of this indirect effect (0.066) remains smaller than the direct effect. Conversely, age also had a negative indirect effect on willingness through knowledge ($\beta = -0.176$), indicating that younger respondents tend to possess higher levels of knowledge, which subsequently enhances their willingness to manage HHW. Nevertheless, this indirect effect (0.082), calculated as the product of age and knowledge ($-0.176 \times 0.469 = 0.082$), is still smaller than the direct effect of age on willingness.

Overall, the path analysis model demonstrates strong predictive power, as indicated by the R^2 value of 0.736 for the willingness variable. This means that 73.6% of the variance in willingness can be explained by knowledge and other examined factors. For the knowledge variable, the R^2 value of 0.264 suggests that approximately 26.4% of the variance in knowledge can be explained by age, education, and monthly expenses. These findings underscore the importance of enhancing education and public outreach as key strategies to improve the public's willingness to responsibly manage HHW. Based on these calculations, it is known that the direct effect is 0.097 and the indirect effect is 0.082. This shows that the indirect influence is smaller than the direct influence. These results show that there is no significant influence between age and willingness through knowledge.

The education variable has a direct influence of 0.007 and an indirect influence through knowledge, which is achieved by multiplying the education variable with knowledge and knowledge with willingness ($0.282 \times 0.469 = 0.132$). Based on these calculations, it is known that the direct effect is 0.007 and the indirect effect is 0.132. This shows that the indirect effect is greater than the direct effect. These results show that there is a significant influence between education and willingness through knowledge.

The monthly expenditure variable has a direct influence of 0.086 and an indirect influence through knowledge by multiplying the monthly expenditure variable with knowledge and knowledge with willingness ($0.141 \times 0.469 = 0.066$). Based on these calculations, it is known that the direct effect is 0.086 and the indirect effect is 0.066. This shows that the indirect effect is smaller than the direct effect. These results show that there is no significant influence between expenditure and willingness through knowledge.

5 Discussion

Based on the bivariate analysis table, a relationship can be seen between the independent variables (age, education, employment, and monthly expenses) and the dependent variables, namely willingness and knowledge mediators. The correlation r values show the level of relationship between variables, while the p-value is used to determine the statistical significance of the relationship. Overall, knowledge has a significant and strong relationship with willingness ($R = 0.501$, $p < 0.001$) and is significantly influenced by age, education, and monthly expenses, but not significantly by employment ($p = 0.138$). The significant negative relationship between age and willingness ($R = -0.138$, $p = 0.002$) and knowledge ($R = -0.198$, $p < 0.001$) shows that younger individuals tend to have a higher level of willingness and knowledge regarding certain issues, including management of hazardous waste. Previous research conducted by Hajri and Daife supports this finding, where the younger generation is more often exposed to information from the internet and social media, which increases their awareness of environmental issues [18]. Apart from that, education has a significant positive relationship with both willingness ($R = 0.197$, $p < 0.001$) and knowledge ($R = 0.351$, $p < 0.001$). This is in accordance with studies that state that education plays an important role in increasing public awareness and involvement in sustainable environmental practices, including household waste management [19]. This is inconsistent with a study conducted by Thakur and Onwubu, which states that public knowledge and awareness do not have a significant influence on community behaviour in managing waste [13].

Monthly expenditure also has a significant relationship with knowledge ($R = 0.501$, $p < 0.001$), but only has a weak relationship with willingness ($R = 0.038$, $p = 0.001$). This shows that, although financial access can increase public knowledge, this factor may not always be the main determinant of willingness to manage HHW. Previous research shows that apart from monthly expenses, other factors such as access to information and social norms also play a big role in a person's willingness to be involved in waste management [20]. Thus, focusing on education and disseminating relevant information can have a greater impact on increasing people's willingness to HHW than just the economic aspect.

In the context of managing HHW, the community's willingness to participate is very important because HHW has a big impact on health and the environment if it is not managed properly. The results of the analysis in the table show that knowledge is the factor that has the most influence on willingness ($\beta* = 0.469$, $p < 0.001$). This is relevant in HHW management, where previous literature confirms that public understanding of the dangers of HHW and the importance of proper management is often the key to the success of waste management programs [16, 20]. For example, research shows that increasing public knowledge and public awareness about the risks of toxic waste increases public participation in HHW management [7].

Apart from that, monthly expenditure also has a significant direct influence on willingness ($\beta* = 0.086$, $p = 0.041$). In HHW management, this factor can reflect the financial ability to purchase safe waste management equipment or services, such as special waste bags or paying fees for waste collection by a third party. Previous research also supports this, where the availability of economic resources is often linked to the ability of individuals or households to support responsible waste management practices, including HHW [16, 21]. However, although significant, the contribution is smaller compared to knowledge, which highlights that educational interventions can be a more effective approach than simply relying on economic factors.

On the other hand, age shows a negative indirect effect on knowledge ($\beta* = -0.176$, $p < 0.001$), which ultimately affects willingness. This indicates that the younger generation tends to have a better level of knowledge about hazardous waste management, which may be due to exposure to environmental campaigns or formal education related to environmental issues. Education, which has a significant indirect effect on knowledge ($\beta* = 0.282$, $p < 0.001$), is an important aspect in building public awareness of the dangers of hazardous waste. Therefore, increasing environmental education and awareness through socialization programs or integrating hazardous waste management issues into the education curriculum can be an effective strategy to increase the community's willingness to support responsible hazardous waste management.

The path analysis diagram shows the results of the path analysis that describes the direct and indirect relationships between the independent variables age, education, and monthly expenditure, the mediator (knowledge), and the dependent variable willingness. The explanation of this relationship is complemented by the path coefficient values that reflect the strength and direction of the influence of each variable. Age indirectly influences willingness through knowledge, with an influence coefficient of -0.176. This negative relationship indicates that younger individuals tend to have higher levels of knowledge, which then increases willingness ($\beta = 0.469$). Education shows a positive indirect effect on willingness through knowledge ($\beta = 0.282$). This means that individuals with higher levels of education tend to have better knowledge, which ultimately increases willingness. This finding is consistent with the literature that emphasizes the role of education in shaping environmental awareness and community involvement in waste management [22, 23].

Monthly expenditure also has a positive indirect effect through knowledge ($\beta = 0.141$). This relationship indicates that households with better financial capabilities have more access to information and resources that increase the direct effect of knowledge on willingness. Knowledge has the largest direct effect on willingness ($\beta = 0.469$). This finding suggests that knowledge plays a major role in encouraging community willingness to participate in hazardous waste management. Previous studies have also shown that knowledge about the dangers of hazardous waste and how to manage it significantly increases community participation [24, 25].

R-Square and significance of the model: the R^2 value for knowledge is 0.836, which means that 83.6% of the variability in knowledge can be explained by age, education, and monthly expenditure. Meanwhile, the R^2 for willingness is 0.736, indicating that 73.6% of the variability in willingness is explained by knowledge and other independent variables. The high R^2 value indicates that this path analysis model has excellent predictive ability. Knowledge can be explained by age, education, and monthly expenditure. Meanwhile, the R^2 for willingness is 0.736, indicating that 73.6% of the variability in willingness is explained by knowledge and other independent variables. The high R^2 value indicates that this path analysis model has excellent predictive ability.

The results of the path analysis in this study revealed a significant negative relationship between age and knowledge regarding HHW management ($\beta = -0.176$, $p < 0.001$). This finding indicates that younger respondents tend to have higher levels of knowledge compared to older age groups. This pattern is consistent with previous research by Hajri and Daife which found that the younger generation (aged 18–35 years) is more exposed to environmental information through digital platforms such as social media and online courses, resulting in better literacy on issues such as HHW. This mechanism is supported by the theory of the generation gap in technology adoption [18, 26], which posits that younger generations are more adaptive to emerging information sources.

However, the negative association may also reflect an intergenerational educational gap. A study by Almulhim in Saudi Arabia found that individuals over the age of 50 had limited access to HHW education programs, which are often designed with younger audiences in mind. In Indonesia, formal education curricula have only begun to integrate environmental content intensively over the past decade, suggesting that older generations may not have been exposed to this information during their schooling years [7, 21].

This study employed the Theory of Planned Behaviour (TPB) framework to analyse the factors influencing public willingness to manage HHW in Semarang City. The results indicate that knowledge—representing the attitude component of TPB is the most dominant factor shaping willingness ($\beta = 0.469$), aligning with TPB's premise that a positive attitude toward a behaviour increases the intention to perform it. Education functions as a subjective norm that influences knowledge and thereby indirectly increases willingness ($\beta = 0.282$). Meanwhile, monthly expenses—used as a proxy for perceived behavioural control—exert a limited influence ($\beta = 0.086$), suggesting that in developing countries such as Indonesia, infrastructural constraints may present greater barriers to public participation than individual-level factors [22].

Another noteworthy finding is the negative relationship between age and knowledge, highlighting that younger generations are more responsive to environmental issues due to their greater exposure to digital information. However, employment status was not found to significantly influence willingness, contradicting TPB's assumption that occupation may be linked to behavioural control. Overall, this study reinforces the applicability of TPB while underscoring the need to adapt the model by incorporating contextual variables such as infrastructure availability and the role of social media in shaping behaviour in developing countries. The implications suggest that TPB-based interventions in Semarang City should prioritize educational efforts, improve access to infrastructure, and adopt strategies that target younger generations.

One of the key methodological limitations of this study lies in its reliance on self-reported data obtained through structured questionnaires. This approach, while practical for large-scale community-based research, is inherently susceptible to subjectivity bias and social desirability bias, where respondents may overstate their knowledge or willingness to manage household hazardous waste to align with perceived normative expectations. Furthermore, recall bias may affect the accuracy of responses, especially when participants are asked to reflect on past behaviours or decisions related to waste handling.

To mitigate these limitations, several strategies were adopted. First, the questionnaire was anonymously administered, which helped reduce social desirability bias by creating a psychologically safe space for honest responses. Second, items were phrased using neutral and behaviourally specific language to minimize interpretative ambiguity and response distortion. Add itionally, pre-testing of the instrument helped refine the structure and clarity of the questions, thereby improving data reliability.

For future research, it is recommended to incorporate mixed-methods approaches, including direct observations, waste sorting audits, or community-based participatory assessments to triangulate self-reported data with objective indicators of behaviour. Integrating digital tools, such as mobile applications that track waste disposal habits in real-time, may also provide more accurate and granular data. These enhancements will strengthen the internal validity of findings and provide a more comprehensive understanding of the behavioural dynamics related to household hazardous waste management.

6 Conclusions

These findings highlight the importance of knowledge as a key factor in increasing community willingness to participate in household waste management. Education-based interventions and information dissemination can be effective strategies to increase community knowledge, which in turn can strengthen willingness. This shows that implementing policies that focus on environmental education and increasing access to information, especially for older age groups or those with low levels of education, can be a strategic step in supporting sustainable waste management.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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