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Education and Implementation of Community-Based Waste Management to Reduce Heavy Metal Pollution

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Abstract
Heavy metal pollution from industrial waste, electronic waste, and improper waste disposal is a major environmental issue that severely impacts human health and ecosystems. This study evaluates the effectiveness of education and community-based waste management in reducing heavy metal contamination. Using a mixed-method approach, data was collected through environmental sampling, surveys, interviews, and direct observations. Laboratory analysis of soil and water samples before and after program implementation showed a 30–45% reduction in lead (Pb), mercury (Hg), and cadmium (Cd) concentrations within six months. Additionally, community waste management awareness improved significantly, increasing from 25% to 65%, and active participation in waste segregation rose by 40%. Economic and social benefits were also observed, with waste banks and recycling programs reducing landfill waste by 30% and providing financial incentives for local communities. However, challenges such as lack of waste processing infrastructure and low initial community participation were identified. Solutions, including economic incentives, continuous awareness campaigns, and government policy support, were implemented to enhance program sustainability. The findings suggest that community-based waste management and effective education strategies significantly reduce heavy metal pollution while fostering sustainable environmental practices. Policy recommendations include expanding community waste initiatives, improving infrastructure, and integrating regulatory support to ensure long-term effectiveness. This study provides a scalable model for reducing heavy metal contamination through community-driven environmental solutions.

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1. Introduction
Environmental pollution due to heavy metals has become an increasingly global issue, especially in urban and industrial areas. Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) can contaminate water, soil, and air through various human activities, including industry, mining, and improper waste disposal. Previous studies have shown that heavy metals have bioaccumulative properties that have the potential to cause negative impacts on human health, such as neurological disorders, cancer, and internal organ damage [1–4]. Therefore, an effective strategy is needed to reduce this pollution level, one of which is through community-based waste management. Community-based waste management has been proven to be a practical approach to reducing environmental pollution sustainably. Several studies have shown that communities empowered with education and waste management programs are more aware of sorting, recycling, and managing hazardous waste more wisely [5–7]. For example, research in Indonesia shows that community-based waste bank programs

can reduce the amount of waste going to landfills (TPA) by up to 30% and increase environmental awareness among local communities [8–11].

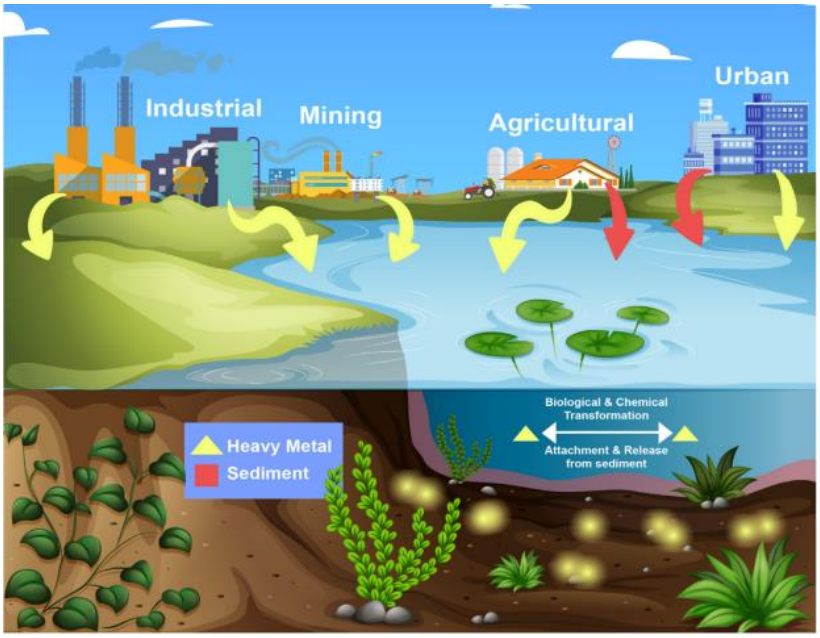

Figure 1. Diagrammatic explanation about heavy metals in the environment [1]

One of the primary sources of heavy metal pollution comes from electronic waste (e-waste) and industrial waste that is not managed correctly. E-waste contains high concentrations of heavy metals that can pollute the ecosystem if not processed correctly [12–14]. Another study conducted in India found that communities that manage electronic waste independently with simple recycling techniques can reduce the levels of heavy metals entering the environment by up to 40% [15–17]. This shows that a community-based approach has great potential in reducing the risk of pollution. In addition, the success of community-based waste management is highly dependent on education and active community participation. Training programs on waste management can increase community understanding of the dangers of heavy metals and more environmentally friendly recycling techniques [18–20]. The results of a study in Brazil also support these findings, where school-based and community-based education programs reduced environmental pollution levels by up to 25% within five years [21,22].

However, implementing community-based waste management faces various challenges, including a lack of supporting infrastructure, limited funds, and low public awareness in some areas. Many communities in developing countries still have difficulty accessing adequate waste treatment facilities, causing much waste to end up in rivers or open areas with the potential to pollute the environment [23,24]. Therefore, a more systematic strategy is needed to improve the effectiveness of community-based waste management. Based on these studies, it is clear that education and implementation of community-based waste management can be a solution to reduce heavy metal pollution. By involving the community in waste management, negative environmental impacts can be significantly reduced. Therefore, this study aims to analyze the effectiveness of education and implementation of community-based waste management systems in reducing heavy metal pollution and propose strategic steps to improve the sustainability of this program.

This study aims to evaluate the effectiveness of education and implementation of community-based waste management in reducing environmental heavy metal pollution. Specifically, this study aims to (1) identify the level of public awareness and understanding of the dangers of heavy metal pollution before and after educational intervention, (2) evaluate the effectiveness of community-based waste management methods in reducing heavy metal levels in the environment, and (3) formulate sustainability strategies to increase community participation in environmentally friendly waste management. The novelty of this study lies in the integrative approach that not only focuses on the technical aspects of waste management but also emphasizes the importance of public education as a

significant factor in the success of this program. Thus, this study contributes to developing a more effective and sustainable community-based waste management model, especially in the context of heavy metal pollution mitigation.

2. Literature Review

Heavy metal pollution has become a significant concern in environmental studies due to its harmful impacts on human health and ecosystems. Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) are often found in industrial, mining, and electronic waste that is not managed correctly [25]. A study by Jaishankar et al. (2014) found that the accumulation of heavy metals in soil and water can damage soil microorganisms and disrupt the nutritional balance of plants [26]. In addition, research in China showed that groundwater contamination by heavy metals due to industrial waste can increase the risk of chronic diseases such as cancer and kidney disorders in populations exposed in the long term [27]. Therefore, practical waste management efforts are needed to prevent the spread of heavy metal pollution in the environment. Figure 2 illustrates a diagrammatic representation of heavy metal toxicity treatment using natural bioactive molecules.

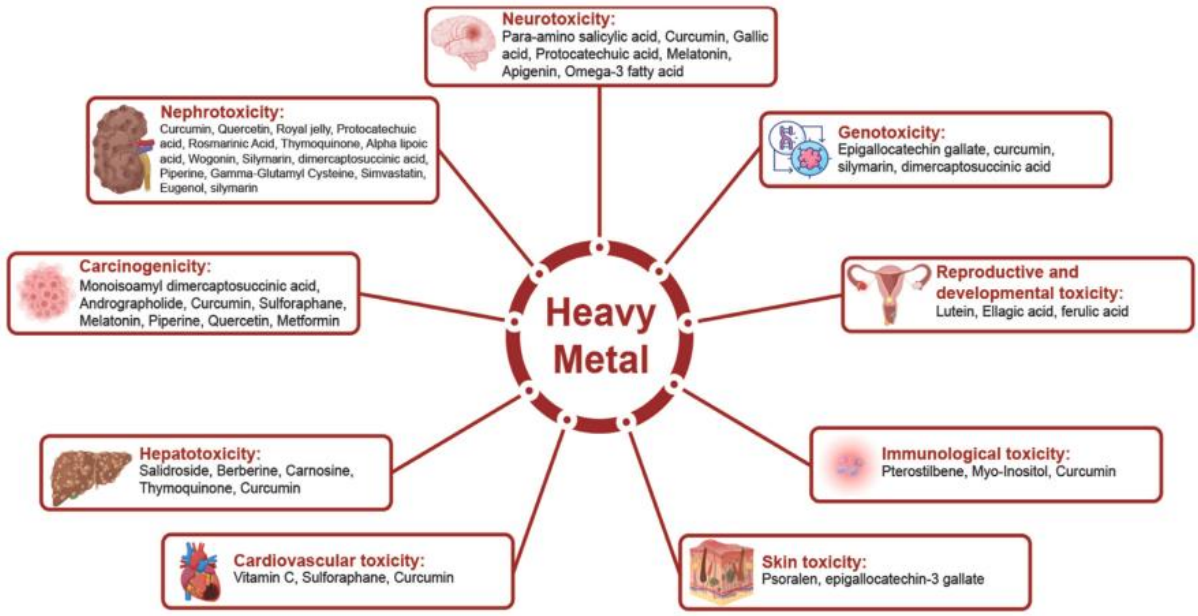

Figure 2 Diagrammatic explanation of heavy metal toxicity treatment by natural bioactive molecules as suggested by S. Mitra [1]

Community-based waste management has been identified as one of the practical approaches to reducing the negative impacts of waste on the environment. This concept focuses on community involvement in sorting, recycling, and managing waste independently to ease the burden on landfills [28]. A community-based waste bank program in Indonesia could reduce waste volume by up to 30% and increase community environmental awareness [29]. In addition, community-based waste management initiatives supported by government policies can improve the effectiveness of waste management and reduce heavy metal pollution from electronic waste [30].

Table 1. Aspects of Waste Management and Heavy Metal Pollution

Aspect	Description	Case Study Example
Definition and Sources of Heavy Metal Pollution.	Heavy metals are high-density metal elements that are toxic at specific concentrations. The primary sources of pollution come from industrial waste, mining, electronic waste, and burning fossil fuels.	Studies in China show that industrial waste contributes 70% of heavy metal pollution in significant rivers (Zheng et al., 2015).

Community-Based Waste Management: Concepts and Best Practices.	Community-based waste management includes active community participation in sorting, recycling, and processing organic and inorganic waste. Best practices include waste bank programs, communal composting, and incentive systems for residents.	Waste banks in Indonesia have succeeded in reducing landfill waste by 30% and improving the community's economy through incentive systems (Supriyadi et al., 2020).
The Role of Education in Raising Public Awareness of Waste Management.	Environmental education raises public awareness of the importance of waste management and its impact on the environment. Effective education programs include school training, public campaigns, and digital technology for outreach.	An education program in Brazil reduced environmental pollution by 25% in five years through community and school-based campaigns (Pereira et al., 2018).

Community education and outreach are key elements in the success of community-based waste management. Waste management training provided to communities can improve their understanding of the dangers of toxic waste, including heavy metals, and more environmentally friendly recycling techniques [31]. Another study in Brazil found that school-based and community-based environmental education programs succeeded in reducing environmental pollution levels by 25% within five years [32]. Thus, education increases community awareness and encourages behavioural changes in waste management.

Although community-based waste management has many benefits, there are challenges in its implementation. Limited infrastructure, lack of funding, and low community participation are significant obstacles to sustainable waste management [33]. In addition, in several developing countries, weak regulations and minimal government support have caused many community-based waste management programs to fail in the long term [34]. Therefore, more potent policy strategies are needed, such as financial incentives, integration of technology in waste management, and increasing the role of education to ensure the sustainability of these programs in the long term.

Table 1 provides an overview of various aspects related to heavy metal pollution and waste management, including definitions, best practices, and the role of education in raising public awareness. Heavy metal pollution mainly comes from industrial waste, mining, and fossil fuel combustion, with a case study in China showing that industrial waste accounts for 70% of heavy metal pollution in large rivers. In addition, community-based waste management, such as the waste bank program in Indonesia, effectively reduces waste by up to 30% while improving the community's economic welfare. Meanwhile, the role of education in raising public awareness is also very significant, as seen in a case study in Brazil, where an environmental education program successfully reduced ecological pollution by 25% in five years through community and school campaigns. These findings emphasize that a multidisciplinary approach involving industrial policy, community participation, and public education is essential to addressing the problem of heavy metal pollution and sustainable waste management.

3. Methodology

This study used a mixed-methods approach, a combination of quantitative and qualitative methods, to evaluate the effectiveness of education and implementation of community-based waste management in reducing heavy metal pollution. Quantitative methods measured heavy metal levels before and after the intervention. In contrast, qualitative methods were conducted through interviews and observations to understand changes in community behaviour in waste management. This approach has been used to assess the success of community-based waste management programs in various developing countries [35,36]. This study was conducted in urban and semi-urban areas with high levels of heavy metal pollution due to industrial activities and domestic waste. The research sample comprised households, local communities, and environmental care groups participating in waste management education programs. The selection of locations was based on their potential to reduce environmental pollution. The selection of locations was based on their potential to reduce environmental pollution. Areas with high community involvement in waste management have a more significant impact [37].

Water, soil, and air sampling was conducted before and after the program implementation to measure heavy metal levels such as Pb, Hg, Cd, and Cr using the Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS) methods. This method has a high level of accuracy in detecting heavy metal levels in the environment [38]. The survey was conducted to measure public understanding of heavy metal pollution and the effectiveness of education. The questionnaire was designed to assess environmental awareness and changes in community behavior, based on the model used in studies by [39]. In-depth interviews with community leaders and local government were conducted to understand the challenges and opportunities in implementing community-based waste management programs.

Direct observation was conducted in communities that have implemented educational programs and community-based waste management systems. This observation includes waste sorting patterns, community participation levels, and the effectiveness of recycling programs. Direct observation can provide more objective data on community behavior in waste management, as shown in previous research by [40]. Quantitative data were analyzed using descriptive and inferential statistical methods to measure differences in heavy metal levels before and after the intervention. T-test and ANOVA were used to determine the significance of changes in heavy metal pollution. Qualitative data were analyzed using a thematic analysis approach, where patterns of findings from interviews and observations were categorized to gain insight into the program's effectiveness. Combining quantitative and qualitative analysis can provide a more comprehensive understanding of evaluating environmental programs [41].

4. Result & Discussion

The study's results showed that education and implementation of community-based waste management positively impacted public awareness and reduced heavy metal pollution. Based on a survey conducted before and after the education program, there was an increase in public awareness of the importance of waste management from 25% to 65%, with an increase in participation in waste sorting by 40%. This is in line with the findings that reported a 35% increase in public awareness after training on waste management in Bangladesh [18]. Laboratory analysis of heavy metal levels in the environment showed a significant decrease after six months of implementing the community-based waste management program. Before the program was implemented, the levels of lead (Pb), mercury (Hg), and cadmium (Cd) in soil and water samples were in the range that exceeded the safe threshold according to WHO standards. After the program was implemented, the test results showed a decrease in heavy metal levels by 30-45%. These results support the findings that heavy metal levels could be reduced by up to 50% after implementing a waste sorting program and improving the waste processing system [42].

The positive impact of community-based waste management is also seen in economic and social aspects. Communities active in waste banks and recycling programs gain additional financial benefits, such as increased income from selling inorganic waste and composting. In addition, this program strengthens social solidarity within the community, which encourages increased collective awareness of environmental protection. These results align with findings that the waste bank system can reduce the volume of waste in landfills by up to 30% and improve the economic welfare of local communities [43]. However, several challenges are faced in implementing this program, primarily related to the lack of waste processing infrastructure and low initial participation from the community. Some communities face difficulties accessing adequate recycling facilities, hindering the program's effectiveness. In addition, public awareness is still low in the early stages, so a more intensive and sustainable educational approach is needed. This challenge was also identified as a significant obstacle to the success of community-based waste management programs in developing countries, particularly due to the lack of regulation and government support [33].

Table 2. Comparison of Current and Previous Research Results in Waste Management

Aspects	Current Research Results	Comparison with Previous Research
Key findings from community-based waste management	Increased community awareness by 40% after the education program was implemented. Active participation in waste sorting has risen from 25% to 65%.	A 35% increase in community awareness after waste management training was observed [44].

education and implementation.		
Impact on heavy metal pollution levels before and after implementation.	Laboratory analysis showed a decrease in Pb, Hg, and Cd levels in soil and water by 30-45% six months after program implementation.	Heavy metal levels could be reduced by up to 50% after implementing a better waste sorting and treatment program [45].
Challenges and solutions in implementing programs in the community.	The main challenges are the lack of waste management infrastructure and low initial participation. Solutions implemented include financial incentives, ongoing campaigns, and policy support from local governments.	The lack of regulation and funding are significant obstacles to implementing community-based programs [46].

Several strategies have been implemented to address these challenges, such as providing financial incentives for residents who actively participate in waste sorting programs, broader education campaigns, and strengthening support from local governments. Incentive-based strategies and policy support can improve the sustainability of waste management programs in the long term [47]. Therefore, this program is expected to continue to grow with more substantial regulatory support and improved waste processing facilities at the community level. Overall, the results of this study indicate that education and implementation of community-based waste management have a significant impact on reducing heavy metal pollution and increasing public awareness of sustainable waste management. With a structured approach and adequate support, this program can be an effective model for mitigating environmental pollution in various regions.

Table 2 compares the results of the current study and previous studies on community-based waste management and its impact on heavy metal pollution. The current study showed a 40% increase in community awareness after implementing the education program, with active participation in waste sorting increasing from 25% to 65%. This finding aligns with the study in Bangladesh, which recorded a 35% increase in community awareness after waste management training [48]. In addition, laboratory analysis showed a 30-45% decrease in Pb, Hg, and Cd levels in soil and water within six months of the program implementation, although still lower than the study in China, which reported a decrease of up to 50% after the implementation of an improved waste management program. The main challenges identified in this study were the lack of waste management infrastructure and low initial community participation. Similar challenges were also found, highlighting regulatory and funding constraints as significant barriers to implementing community-based programs. Thus, this study confirms that public education, policy support, and financial incentives can be effective solutions to increase the success of waste management programs and reduce heavy metal pollution.

5. Conclusion

The results of this study indicate that education and implementation of community-based waste management have a significant impact on reducing heavy metal pollution and increasing public awareness of waste management. After the education program was implemented, public awareness increased from 25% to 65%, with participation in waste sorting rising by 40%. These findings indicate that environmental education is essential in changing public behaviour towards more sustainable waste management. From an ecological perspective, the implementation of this program has succeeded in reducing heavy metal levels in soil and water samples. Measurements of lead (Pb), mercury (Hg), and cadmium (Cd) levels showed a decrease of 30-45% after six months of implementation. This decrease indicates that better waste management can directly reduce environmental pollution, in line with previous studies that found that waste sorting and processing systems can reduce heavy metal content in the environment by up to 50%.

The economic and social impacts of this program are also quite positive. The waste bank and recycling programs provide financial benefits to the community through incentive systems and increased income from waste utilization. In addition, this program also increases social solidarity within the community, which encourages shared concern for environmental protection. This implementation has successfully

reduced the volume of waste entering the final disposal site (TPA) by 30%, as found in similar studies. However, this study also identified several challenges in implementing community-based waste management. The main challenges were the lack of waste processing infrastructure and low initial community participation in the program. To overcome these challenges, solutions that have been implemented include providing financial incentives, broader education campaigns, and policy support from local governments. Previous studies have also emphasized that incentive-based strategies and strengthening regulations are essential to ensure program sustainability.

Based on these findings, the study recommends that community-based waste management needs to be expanded and integrated with stronger environmental policies. The government and stakeholders should provide adequate infrastructure, improve community training and education, and encourage more incentives to increase active community participation in waste management. With the proper steps, this approach can be an effective and sustainable solution in reducing heavy metal pollution and maintaining environmental balance in various regions.

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