Applying Analytical Hierarchy Analysis (AHP) to Select Plastic Capture Devices for Mitigating Marine Plastic Pollution in Indonesian River

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***Abstract*—Marine plastic pollution is mostly caused by the leakage of mismanaged plastic waste that rivers carry from the land. Indonesia was estimated to be the highest land-derrived marine plastic polluter in 2016 worldwide. This study aims to select a plastic capture device design for the specific conditions. We conducted the assessment using Analytic Hierarchy Process (AHP) method to determine the most suitable design based on criteria, such as device effectiveness, durability, ease of operation and maintenance, costs, and river morphology. The TrashBooms emerged as the most preferred design, exhibiting superior performance in multiple criteria, making them the preferred choice for addressing waste leakage in river systems.**

***Keywords*—marine debris, plastic pollution, trash barrier, plastic capture device**

I. Introduction

The issue of plastic pollution has gained significant attention in the environmental community, as evidenced by Indonesia's rise from the second-largest contributor to marine debris in 2010 [1], to the leading polluter globally in 2016 [2] In response to global initiatives aimed at curbing plastic pollution [3], Indonesia has established ambitious targets outlined in Presidential Regulation No. 83 of 2018. The nation aims to reduce oceanic plastic waste leakage by 70% by 2025 and achieve near-zero plastic pollution by 2040, implementing a shift towards a circular economy for plastic products [4]. The circular economy should be implemented in the solid waste management to ensure its sustainability.

Sustainable waste management which is not evenly distributed throughout Indonesia and coastal areas which are prone to “leakages” of plastic waste into the environment are factors that cause plastic to pollute the ocean. However, the majority of plastics found in the environment come from terrestrial sources, and most are transported via river systems and waterways [5, 6]. Recently, increasing research conducted on rivers and waterways has revealed that these are the main sources or pathways of plastic pollution [5].

Plastic waste, predominantly consisting of thick-walled, larger pieces made of low-density polymers, is carried by currents from rivers to the ocean, while the bulk of plastic litter likely remains trapped in sediments or on beaches [7, 8]. For example, plastic waste may be entangled by hyacinth or other vegetation in the river or channel system. Hyacinth patches tend to be associated with larger items, particularly expanded polystyrene, as in the case in a tropical River (Saigon River, Vietnam) [9]. On the other hand, small foils and soft plastics are more commonly detected as free-floating items [9] and can be found on seafloors [10]. Meanwhile, larger plastic debris may be entangled in the river system making them less likely to be carried far from their place of origin [9]. The interaction of size and buoyancy, influenced by volume and average density, determines the duration persistent debris items float, with fouling predominantly occurring on the surface and, thereby impacting their accumulation in mid-ocean gyres [11]. While it is unlikely that riverine plastic waste is 100% transported to oceans [12], it remains imperative to mitigate the influx of plastic pollution from riverine freshwater systems into marine ecosystems [13]. This strategic intervention plays a pivotal role in curtailing the global accumulation of plastic within the environment. Riverine plastic fluxes can be prevented from flowing into the sea by using a capture device.

Riverine plastic cleanup strategies have seen wide implementation across various sites in Indonesia, employing diverse devices such as manual or hand collection, boats, booms, receptacles, and innovative combinations of methods. Helinski *et al.* [13] have categorized these devices into booms, receptacles, watercraft vehicles, or a blend of these fundamental elements. The technology for riverine plastic capture devices remains relatively novel, particularly within Indonesia, underscoring the critical necessity for an effective trash barrier design tailored to accommodate the diverse conditions of the country’s numerous river systems. Indonesia boasts a network of at least 5,590 watersheds [13], yet the adoption of trash barriers has been realized in less than 10% of these watercourses.

Notably, Jakarta Province, situated on Java Island, the most populous island, stands as a pioneering example, having implemented a comprehensive trash collection system across all watercourses and bodies. However, it should be noted that the main goal of this system is to prevent flood in Jakarta. Additionally, several other cities, such as Denpasar (Bali Island), Pontianak (Kalimantan Island), Manado (Sulawesi Island), and Balikpapan (Kalimantan Island), have initiated trash collection programs within their waterways [14]. Moreover, Mataram (West Nusa Tenggara) has recently developed a waterway trash barrier system utilizing repurposed drums.

Crucially, the selection of tools for a specific strategy must carefully consider the social and biophysical dynamics of the river, which significantly impact the effectiveness of plastic capture [15]. The development of an optimal trash barrier stands as a pivotal aspect, aiming to maximize plastic waste capture while mitigating the risk of flooding and curbing marine pollution. Nevertheless, the economic aspects, encompassing both cost, operation, and maintenance, must also factor into these decisions. This research addresses a critical gap in the current waste management landscape. The strategic selection of tools for plastic capture must not only align with local environmental conditions but also consider the broader socio-economic and biophysical dynamics of the rivers.

Therefore, this study selects the most appropriate trash barrier deployed in the river system, particularly in Indonesia. We focus on the worldwide notable plastic capture devices and also trash barriers that have been installed in Indonesia using five criteria. The decision support system employed in this study relied on the Analytical Hierarchy Process (AHP). AHP stands out due to its capacity to directly compare alternatives for each criterion, facilitating a systematic evaluation and selection process. This method is specifically designed to weigh and prioritize various alternatives, enabling the selection of the most suitable options based on rigorous comparisons between them.

II. Methods

A. Analytical Hierarchy Process (AHP)

AHP is a comprehensive theory of measurement that is employed to obtain ratio scales from paired comparisons, regardless of whether they are discrete or continuous [16]. These comparisons can be derived from either actual measurements or a fundamental scale that represents the relative intensity of preferences and feelings [17]. The AHP serves as a robust methodology for establishing the hierarchy and ranking of optimal decision alternatives. When decision makers confront multiple objectives or criteria, AHP facilitates the systematic development of numerical scores that assess the degree to which each alternative aligns with these criteria. This scoring system enables a clear ranking of alternatives based on their alignment with the decision maker's objectives.

AHP was specifically chosen for this study due to its hierarchical structure, which offers enhanced comprehensibility compared to the Analytical Network Process (ANP). ANP utilizes a network structure with interconnected criteria, fostering feedback between elements. However, in this study context, the criteria remain non-reciprocal and devoid of interconnections, making the hierarchical arrangement of AHP more conducive to evaluating and ranking decision alternatives efficiently.

To generate alternative ranks, we conducted the following steps according to Saaty [17].

1) Information gathering

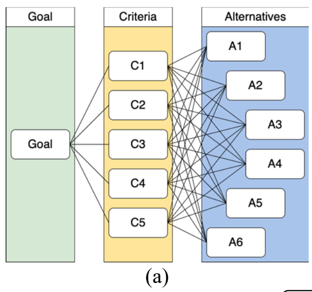
The initial phase involves the information gathering and consolidation of selection criteria. In this particular study focusing on identifying the suitable trash barrier for Indonesia, the criteria were established through comprehensive interviews conducted with two experts. The first expert selected for consultation is an esteemed employee of the local environmental agency in Semarang City, located in Java Island. His inclusion is based on his extensive experience and profound knowledge of the waste management landscape within the city. Additionally, he possesses a comprehensive understanding of the waste management system, further solidifying his suitability for the role.

The second expert enlisted is a distinguished member of the Coastal Environmental and Fisheries Institute. The rationale behind choosing this expert lies in his proven expertise, demonstrated by his involvement in designing and implementing a similar capture device in the rivers located in West Nusa Tenggara Province. This initiative was carried out under the auspices of the Coastal Environmental and Fisheries organization in West Nusa Tenggara, showcasing his practical experience and insights in the field.

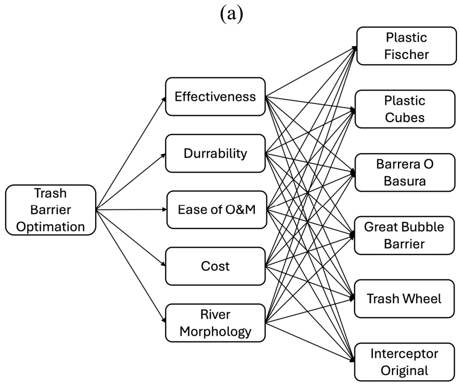
2) Modelling

This phase was conducted by establishing the decision hierarchy commences by outlining the primary objective of the decision-making process, providing a comprehensive perspective. This hierarchical structure progresses through intermediate levels, which encompass the essential criteria on which subsequent elements depend. Ultimately, the hierarchy culminates at the lowest level, comprising a diverse array of alternatives for consideration.

The AHP method organizes predetermined criteria into a hierarchical structure comprising three distinct levels. At Level 1 (top), the goal was established: identifying the most suitable trash barrier design specifically tailored for Indonesian river systems. Moving to Level 2 (intermediate), the criteria for prioritizing plastic capture devices are delineated. Finally, at Level 3 (bottom), the focus shifts to the alternative designs that have been chosen for evaluation. This hierarchical arrangement, illustrating the interrelation between these levels, is visually depicted in Fig. 1.



(a)



(b)

Fig. 1. Hierarchy Arrangement: (a) Hierarchy of goal, criteria, and alternatives, (b) the case study of trash barrier selection.

3) Choice

A series of pairwise comparison matrices was developed, enabling comparisons between elements across hierarchical levels. Within each upper level, elements were systematically compared with those in the immediate lower level, establishing their relative priorities. These priorities derived from comparisons were utilized to assign weights to the priorities within the lower-level elements. By aggregating these weighted values for each individual lower-level element, we derived their overall or global priority. This iterative process of weighting and summation persisted until the final priorities of the alternatives at the lowest level were determined.

For effective comparisons, it is crucial to employ a numerical scale that quantifies the extent of superiority or importance of one element over another concerning the specific criterion or property under consideration. We employed a 9-scale paired wise comparison method, enabling a nuanced evaluation of their relative importance and relevance in the selection process. Moreover, the AHP Super Decision software was used as a tool to employ AHP method in this study.

B. Plastic Capture Device Alternatives

Choosing the optimal trash barrier types demands a methodical approach that resonates effectively with on-site conditions. In this study, we selected three trash barrier types that have been used in Indonesia, namely the TrashBooms, Floating Cubes, and Barrera O Basura, and also three other notable world-wide plastic capture devices, such as the Great Bubble Barrier, Mr. Trash Wheel^{TM}, and the Interceptor^{TM} Original.

1) TrashBoom (A1)

Plastic Fischer developed a trash barrier known as TrashBoom as an open source design [18]. The Trash Barrier specifications, modified with locally available materials, outline dimensions of 1.00 m in length and 0.80 m in width. Each unit has a sturdy load capacity of 100 kg. Crafted predominantly from galvanized materials, these barriers boast an estimated durability of approximately 15 years without necessitating any energy input because the waste collection is manually handled. Their versatile design allows for deployment in diverse river settings, particularly those characterized by smaller dimensions (less than 10 m width and 1.0 m water level).

2) Floating Cube (A2)

The floating cubes represent modular floating docks often employed in establishing compact ports. These specialized structures adhere to specifications featuring dimensions measuring 0.5 m in width, 0.5 m in length, and 0.4 m in height. Weighing around 8 kilograms per unit, these cubes exhibit a commendable load capacity of 90 kilograms, constructed primarily from High-Density Polyethylene (HDPE). With an estimated lifespan ranging between 10 to 15 years, their adaptable nature enables deployment across various river types, serving diverse functions such as floating pontoons or ports.

Notably, the local environmental agency (UPS Badan Air DLH Jakarta) has extensively utilized these floating cubes in numerous waterways within Jakarta Province. Their deployment serves a dual purpose—retaining riverine debris and mitigating flood occurrences.

3) Barrera O Basura (B.O.B.) litter trap (A3)

The B.O.B. Litter Trap, pioneered by Marea Verde in 2018, stands as an innovative solution [19, 20]. Its specifications highlight dimensions measuring 0.4 meters in width and 3.45 meters in length, capable of handling a substantial load capacity of 317 kilograms per unit. Crafted from durable galvanized wire mesh, this trap operates without the need for any external energy sources.

This litter trap was firstly deployed in Río Matías Hernández River, Panama [21]. Over its year-and-a-half operational span, B.O.B has successfully intercepted and retained over 100 tons of waste, preventing its potential discharge into coastal areas and the sea [20]. This B.O.B. Litter Trap has also been deployed in the rivers of West Nusa Tenggara with modifications such as the main material made of repurposed HDPE drums.

4) Great bubble barrier (A4)

A bubble curtain operates by infusing air into a perforated tube situated at the waterway's bottom, creating a rising stream that directs plastic waste toward the water surface [22]. Positioned diagonally across the river, the Bubble Barrier strategically utilizes the water's natural flow, channeling plastic debris towards the perimeter and into the collection system. Moreover, a collection system is purposefully designed to complement and work in tandem with the bubble curtain, effectively capturing and retaining plastic materials. This project is implemented in the Netherlands.

5) Mr. Trash Wheel^{TM} (A5)

Located in Baltimore, U.S.A., Mr. Trash Wheel^{TM} is an autonomous system engineered to capture and eliminate debris accumulated at the river or stream outlets. Positioned at the river's end, Mr. Trash Wheel^{TM} efficiently intercepts waste, eliminating the need for pursuit across the open ocean [23].

Stationary yet highly effective, Mr. Trash Wheel^{TM} harnesses a dual-powered system, leveraging both solar and hydro energy sources. This eco-conscious design ensures operational sustainability and resilience even in adverse weather conditions. Mr. Trash Wheel^{TM} consistently extracts hundreds of tons of garbage from the water each year. Its record for the highest amount of debris collected in a single day is 17.2 tons in Baltimore, US.

6) The interceptor^{TM} original (A6)

The Interceptor^{TM} Original consists of barrier, conveyor belt, shuttle, and storage. The barrier guides riverborne debris towards the entrance of the Interceptor, utilizing its catamaran design to redirect the water flow, ensuring an efficient transfer of plastic waste onto a conveyor belt [24]. This current transports the collected trash along the belt, systematically removing debris from the water and conveying it to the shuttle system.

An automated shuttle efficiently allocates the waste across six containers, distributing it uniformly based on sensor data until each container reaches its maximum capacity. With a storage capacity of 50 m^3, the Interceptor can continuously operate before requiring emptying, showcasing its capability to function effectively in even the most heavily contaminated rivers worldwide [24]. The Interceptor 001 was deployed in Cengkareng Drain, Jakarta, since 2019, which collected approximately 466 kg/day of waterway litter [25].

C. Selection Criteria

In the assessment of an appropriate design of plastic capture devices, various critical criteria were considered, as follows:

1) Effectiveness (C1)

Assessing the performance of capture devices hinges on their efficiency in real-world conditions, particularly in effectively reducing the influx of plastic waste. Given the varied field experiences across Indonesia, evaluating this criterion might require expert judgment due to the diverse and nuanced nature of environmental conditions and operational contexts encountered in different regions.

2) Durability (C2)

The evaluation of equipment resilience involves a thorough examination of its ability to withstand various field conditions, including fluctuations in weather, variations in waste load, and the dynamic nature of the river's current and morphology. The relationship between durability and cost is evident, where higher durability corresponds to lower costs. However, in this specific case, it is noteworthy that the experts assessed these criteria as independent factors, treating durability and cost as separate considerations.

3) Ease of operation and maintenance (O&M) (C3)

Analyzing the operational efficiency of the device, including factors such as ease of waste transport to the collection site, installation and dismantling procedures of the device, and overall maintenance requirements.

4) Cost considerations (C4)

Estimating the capital investment or budgetary needs associated with manufacturing and sustaining the equipment on a per-unit basis.

5) River morphology (C5)

This criterion involves a comprehensive understanding and consideration of the unique characteristics, seasonal variations in water levels, and the overall shape of the river. The design of the barrier should be tailored to align with these specific environmental aspects. In the dry season, water levels of typical Indonesian rivers (particularly in Java Island) tend to be significantly low, often dropping below 1 meter, whereas in the rainy season, they experience a relative increase. Some rivers may even witness a cessation of flow, resulting in the accumulation of riverine debris. Typically, rivers exhibit meandering patterns; however, in urban areas, normalization is implemented to facilitate swift water flow towards the sea. The plastic capture device needs to effectively operate under these varying conditions to ensure optimal performance.

III. Results and Discussion

A. Results of AHP

In Fig. 2, the hierarchy of criteria importance for selecting the trash barrier is depicted, with effectiveness (0.36868) taking precedence as the primary criterion, closely followed by river morphology (0.30369). It is noteworthy that the interdependence of effectiveness and river morphology underscores their mutual significance in the selection process. Following closely is ease of operation and maintenance (O and M) in the third priority slot (0.15343). Meanwhile, the durability and cost criteria share nearly equal importance, namely 0.08658 and 0.08763, respectively. Furthermore, the pairwise comparisons of these criteria reveal low inconsistency value at 0.02949.

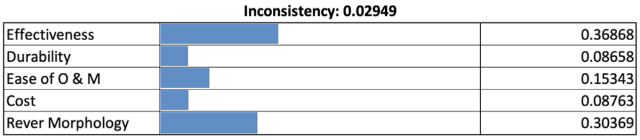


Fig. 2. Cluster of criteria.

Fig. 3 depicts the cluster of alternatives favored by experts in the realm of trash barrier design. Notably, globally recognized capture devices excel in both effectiveness and durability criteria. In contrast, TrashBoom outperforms other alternatives in terms of O and M and cost criteria. Floating cubes and B.O.B Litter Trap exhibit preferences higher than three alternatives (Great Bubble Barrier, Trash Wheels, and Interceptor) yet lower than TrashBoom's in terms of O and M, cost, and river morphology considerations.

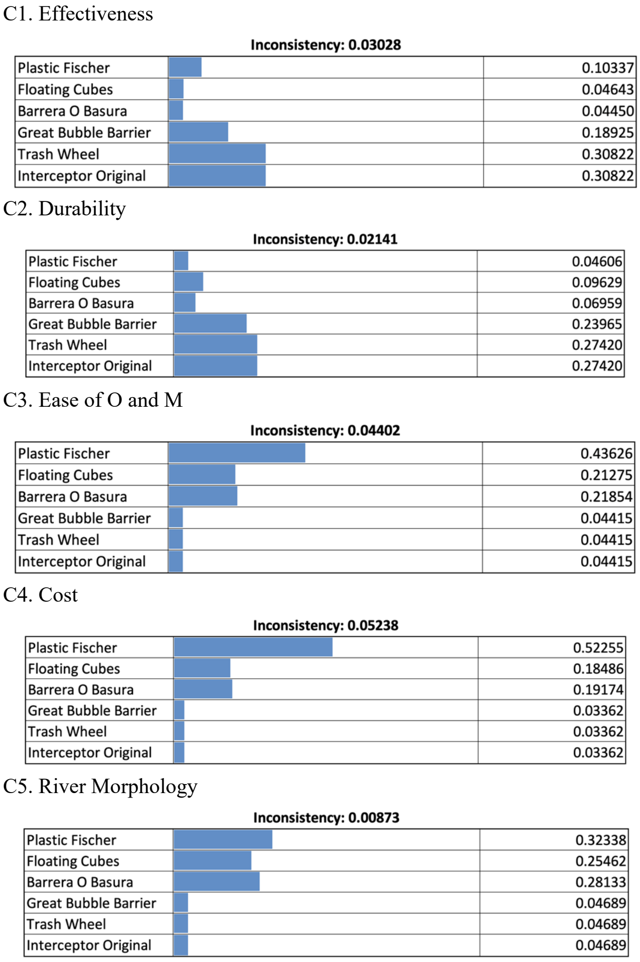


Fig. 3. Cluster of Alternatives. (Plastic Fischer as the founder of TrashBoom).

Upon amalgamating these five criteria, factoring in their respective weights of importance, TrashBoom emerges as the top preference for trash barrier design alternatives in Indonesian watersheds. This is evidenced by its priority weight of 0.253033, as illustrated in Fig. 4.

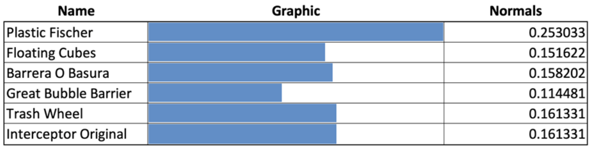


Fig. 4. Conclusion of AHP. (Plastic Fischer as the founder of TrashBoom).

B. Discussion

The rigorous assessment of trash barrier designs against predetermined criteria unveiled distinct performance variations among the alternatives. TrashBooms (A1), Floating Cubes (A2), B.O.B. Litter Trap (A3), the Great Bubble Barrier (A4), Mr.TrashWheels (A5), and the Interceptor Original (A6) were evaluated based on effectiveness (C1), durability (C2), ease of O and M (C3), costs (C4), and river morphology (C5).

TrashBooms emerged as the standout performer across multiple criteria. Its design demonstrated exceptional C3 and C4 preferences. This high effectiveness is pivotal in combatting the pervasive issue of plastic pollution, indicating its potential to significantly mitigate environmental harm.

Furthermore, TrashBooms showcased commendable attributes in terms of ease of O and M. Its design not only addresses waste management effectively but also ensures practicality in handling and upkeep, potentially reducing operational complexities. However, one noteworthy caveat arose in the evaluation: TrashBooms exhibited a comparative drawback in tool durability compared to the Floating Cube design. The floating cubes also may have easier operation because the operator can collect the litters by crossing the cubes. This aspect highlights an area for potential improvement. Enhancing the durability of the TrashBoom design without compromising its effectiveness or other crucial criteria could further elevate its suitability for long-term waste management in river systems.

The three globally recognized plastic capture devices investigated in this study, denoted as A4, A5, and A6, might exhibit higher preferences in river cleanup initiatives with more substantial budgets. Semi-automatic devices, offering a potential reduction in human resource requirements, become more advantageous when labor costs are elevated, although this circumstance does not align with the current conditions in Indonesia. Recognizing the absence of a universal solution, it is imperative to consider the vast variations among rivers, including factors like depth or water level, width, flow dynamics, and seasonality. What works seamlessly for a larger, consistently flowing river might prove ineffective for a smaller, seasonally fluctuating river, particularly during periods of reduced water levels in the dry season.

While the experts in this study possess significant experiences in Java Island (Jakarta) and West Nusa Tenggara (Mataram), their exposure to rivers in other remote areas, such as Kalimantan, Sumatera, Sulawesi, and others, remains limited. Gaining local support and obtaining permissions for new infrastructure can pose challenges, especially in diverse and remote regions. This study also emphasizes the effectiveness of simplicity, particularly in developing countries. Successful solutions often revolve around straightforward technologies—such as booms, barriers, and traps—crafted locally and requiring manual removal of captured waste. Beyond waste management, such approaches have the added benefit of creating additional job opportunities, fostering both environmental stewardship and economic growth, particularly in lower-income countries. Consequently, although the scarcity of resources in lower-income countries may impede the allocation of funds towards the development and implementation of systems aimed at preventing and collecting plastic waste [26], it is still possible to create economic growth by using lower technology.

In Indonesia, several studies revealed that the grey infrastructures might reduce the meso- or macroplastic inputs into the oceans [27–29]. Macro-items positioned in large basins are more likely to be retained by vegetation and other barriers like dams [30]. These items may also become laden with sediments and epiphytes, causing them to sink to deeper river sections and they may fragment into smaller pieces, transitioning into meso- and microplastics, before reaching the ocean [30]. When examining the degradation rates in urban streams, it has been seen that a 6 g-plastic shopping bag can undergo 95% fragmentation within a period of 10 months; hence, there is only a short period of time available for taking meaningful action [31].

However, technical solutions represented by grey infrastructures alone, such as dams and bar screens, are insufficient to achieve the goal of zero plastic emissions into the sea. These structures, incapable of withstanding extreme meteorological events, not only fail to provide a comprehensive solution but also disrupt ecological continuity, hindering the natural feeding of marine ecosystems by organic debris [32]. In this case, A4 (the Great Bubble Barrier) may have higher preference because it does not stop the organic debris from flowing into the sea. The process of transporting and depositing large plastic objects in rivers is intricate and influenced by various parameters, including the polymer's density, the existence of air pockets, the object's shape, and its volume-to-size ratio [33]. The hydrodynamic properties of the river, such as flow velocity and turbulence, impact the movement and settling of large plastic debris [31, 34]. The debris identified in the riverbanks was predominantly composed of single-use plastic and items linked to land-based activities, such as household garbage, agricultural waste, or construction waste [35]. A mesh size of less than 2.5 cm, as employed in TrashBoom's design, proves effective in capturing macroplastics. However, it is important to note that meso- and microplastics might still pass through this barrier. In contrast, the floating cubes, lacking a capturing net below the cubes, may allow submerged plastic in the water to pass through and enter the ocean.

This model's adaptability allows for the incorporation of different experts in various regions or countries. The AHP model's decision relies on expert judgment, introducing a subjective element that may influence both the outcomes and their implications. Consequently, it is essential to approach the AHP results with caution and thoughtful consideration, taking into account the expertise of those involved in the decision-making process. The decision to prioritize TrashBoom design stems from its noteworthy operational ease and cost efficiency, aligning with the overarching goal of significantly reducing plastic waste leakage. However, this selection serves as an initial point, necessitating ongoing monitoring and potential enhancements to optimize its overall efficacy and durability. Given the inevitability of long-term riverine macroplastic monitoring, this is crucial in supporting policy development aimed at pollution reduction [36]. While floating plastic debris remains similar regardless of its origin, the reasons behind this phenomenon differ by location [37]. Despite marine plastic debris being a global issue, its origin traces back to local decisions in countries lacking adequate policies, institutions, law enforcement, and environmental education awareness. Therefore, the AHP stands out as a method that can be easily employed to assist decision-makers in prompt interventions without incurring high investment costs.

IV. Conclusion

In conclusion, the evaluation results strongly advocate for the implementation of the river systems in Indonesia. Its selection signifies a strategic step towards ameliorating the pervasive issue of waste leakage, particularly plastic waste, in Indonesian river waters. In this regard, based on the four criteria (effectiveness, durability, ease of operation and maintenance, cost, and river morphology), a trash barrier with the TrashBoom design was selected as the most appropriate trash barrier in the water body. Nevertheless, continued research and potential refinements in durability can further fortify its effectiveness, contributing to more sustainable waste management strategies in river ecosystems globally.

Conflict of Interest

The authors assert that there are no conflicts of interest.

Author Contributions

The primary authors of this work, W.B. and P.A., were responsible for both the design of the study, funding acquisiton, writing, and reviewing of manuscript draft. W.B., A.M., I.A., and M.I.D. conducted the AHP modeling. Data analysis was conducted by W.B., Y.M.P., and S.S. Data interpretation was performed by all of the authors. The final version had received approval from all authors.

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