Journal of Geosciences and Environmental Studies: Vol. 2, No. 3, 2025, Page: 1-20

# Analysis of Potential Areas of Plastic Waste Pollution Sources into the Ciliwung River Based on GIS and Multi-Criteria Decision Analysis (MCDA)

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DOI: https://doi.org/10.53697/ijgaes.v2i3.4975

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Received: 29-09-2025
Accepted: 28-11-2025
Published: 30-11-2025

**Abstract:** Plastic waste pollution increasingly threatens the ecological and hydrological functions of the Ciliwung River Basin, yet identifying its sources remains difficult due to interacting physical and socio-economic factors. This study aims to map potential plastic waste source areas to support upstream waste management interventions. A Geographic Information System (GIS) combined with Multi-Criteria Decision Analysis (MCDA) using a Weighted Linear Combination (WLC) approach was applied to integrate six variables: settlement typology, population density, market distribution, presence of waste facilities, distance to the river, and riverbank condition. Results show that 16.37% of the basin is classified as high-potential, 35.24% as medium, and 48.40% as low-potential. Scenario 1—emphasizing settlement typology and population density—most closely matched field observations, identifying densely populated informal settlements on disturbed riverbanks as the primary contributors to plastic waste leakage. These findings underscore the role of demographic pressure and riverbank settlement characteristics in shaping pollution risks and provide a basis for targeted interventions in high-risk areas.

**Keywords:** Ciliwung River Basin, Plastic Pollution Source, GIS, MCDA

## Introduction

The Ciliwung River Basin (DAS Ciliwung), covering approximately 44,007 hectares, extends across West Java Province and DKI Jakarta. The Ciliwung River itself stretches for about 117 kilometers, with a main river channel length of 12 kilometers, originating in Bogor Regency and passing through Bogor City, Depok City, and DKI Jakarta. The river plays a vital role in shaping the West Flood Canal system, which encompasses more than one-quarter of the total Ciliwung Basin area (Farid et al., 2022). Its presence is crucial for water resource management and environmental sustainability across the regions it traverses, given its considerable potential as a freshwater source. However, the river's condition is increasingly threatened by land-use change and solid waste issues. Rapid population growth and urban expansion have driven significant conversion of land surrounding the river into settlements and cultivated areas, which, in turn, threaten riverbank conservation, reduce infiltration zones, and diminish green open spaces (Setiowati et al., 2018). Urbanization has also contributed to rising levels of plastic and microplastic pollution (Harahap, 2013; Farid et al., 2022) and exacerbated flood risks by reducing infiltration capacity (Hartono et al., 2010; Ogden et al., 2011; Emam et al., 2016; Tellman et al., 2016).

In the context of contemporary climate change, which is increasingly altering weather and rainfall patterns across Indonesia, safeguarding the Ciliwung River Basin is critical. Flooding and pollution are recurring hazards in the basin, and their intensity is expected to increase as climate conditions worsen. These challenges are complex, shaped not only by physical and environmental factors but also by social, economic, and governance dimensions (Rahayu et al., 2024). Among these issues, plastic waste pollution stands out as a persistent problem. The Ciliwung River has long suffered from waste dumping driven by community behavior, with much of the response historically focused on downstream cleanup rather than prevention at the source (Zaikatussoleha, 2022). This indicates the need for approaches that can identify and map potential sources of plastic waste pollution upstream, thereby providing a stronger basis for preventive and policy interventions (Farid et al., 2022).

The application of Geographic Information Systems (GIS) has recently expanded significantly in addressing urban waste management challenges. Spatial analysis and remote sensing have been employed in diverse applications, such as identifying suitable sites for waste management facilities (Lesmana, 2017), estimating domestic waste volumes (Manullang & Hadibasyir, 2023), and assessing potential plastic pollution risks (Chukwuma et al., 2021). However, studies that specifically analyze behavioral patterns of waste disposal remain limited. Karimi et al. (2023) highlighted the growing use of remote sensing data to identify waste-dumping sites, noting that advances in high-resolution imagery and temporal coverage, coupled with deep learning and image-processing techniques, have enriched this field. Meanwhile, Fraternali et al. (2024) emphasized that GIS and remote sensing methodologies have primarily focused on physical land attributes in waste monitoring and mapping, while more holistic approaches that account for socio-economic and demographic drivers of illegal dumping are still underexplored.

Against this backdrop, this study seeks to develop a spatial analysis model to identify areas within the Ciliwung Basin with high potential to become sources of plastic pollution feeding into the river system. Given the complexity of waste disposal behavior, an integrative approach is required. GIS offers a multidimensional analytical framework that allows these complex problems to be abstracted into useful cartographic outputs. Accordingly, this research employs a Multi-Criteria Decision Analysis (MCDA) framework using a Weighted Linear Combination (WLC) approach, integrating both physical land indicators and socio-economic variables.

# Methods

## A. Location

The study was conducted within the Ciliwung River Basin, which spans seven cities—North Jakarta, West Jakarta, Central Jakarta, East Jakarta, South Jakarta, Depok, and Bogor City—and one regency, Bogor Regency, within the Greater Jakarta metropolitan area. The headwaters of the Ciliwung River are located in the highlands of the Puncak region (Bogor Regency), originating from Mount Pangrango. The basin exhibits an elongated form, with its upstream area shaped like a fan, characterized by dendritic tributary networks that converge into a single main river channel flowing from Bogor City through South Jakarta and eventually discharging into three outlets in North Jakarta.

Field surveys were conducted to collect primary data through direct observation and interviews, which informed the selection of sampling points. The distribution of sampling locations was determined using a purposive sampling technique, based on pre-field mapping of selected variables. Instead of proportional weighting, sample points were selected from areas classified into low, medium, and high categories to capture variation in waste management practices across municipalities within the Ciliwung Basin. The study area and spatial distribution of sampling points are shown in **Figure 1**.

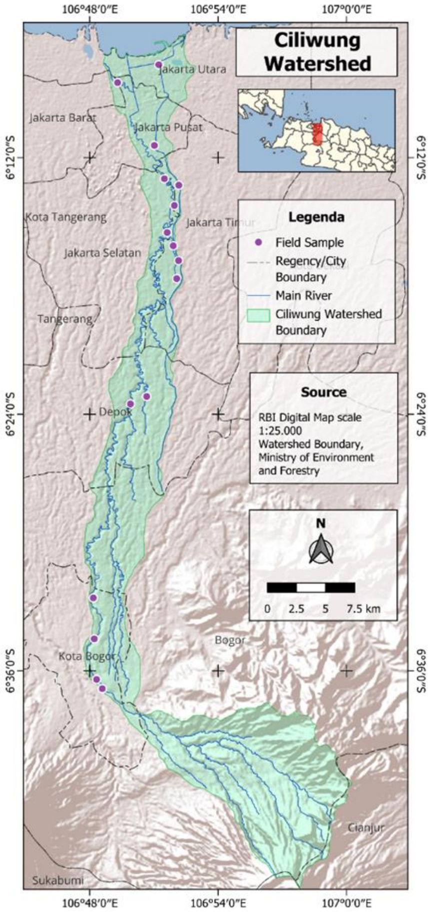


**Figure 1.** Profile of the Ciliwung River Basin and Spatial Distribution of Sampling Points

## B. Research Methods

In general, this research was carried out in three main stages: (1) the pre-field stage, which involved data acquisition, pre-processing, and the preparation of field maps; (2) the field stage, encompassing observations and interviews to validate research variables as well as waste disposal behaviors within the study area; and (3) the post-field stage, which focused on developing multi-scenario maps and selecting the most appropriate scenario based on the field data collected.

Data pre-processing centered on digitizing spatial data into vector format and assigning scores to the classification of each research variable. Field observations and interviews were conducted using structured questionnaires, supported by documentation of field conditions, to identify potential sources of plastic waste pollution. The collected field data were then used to determine multi-scenario weights, generate multi-scenario maps, and identify the optimal scenario map. The detailed framework is shown in **Figure 2**.

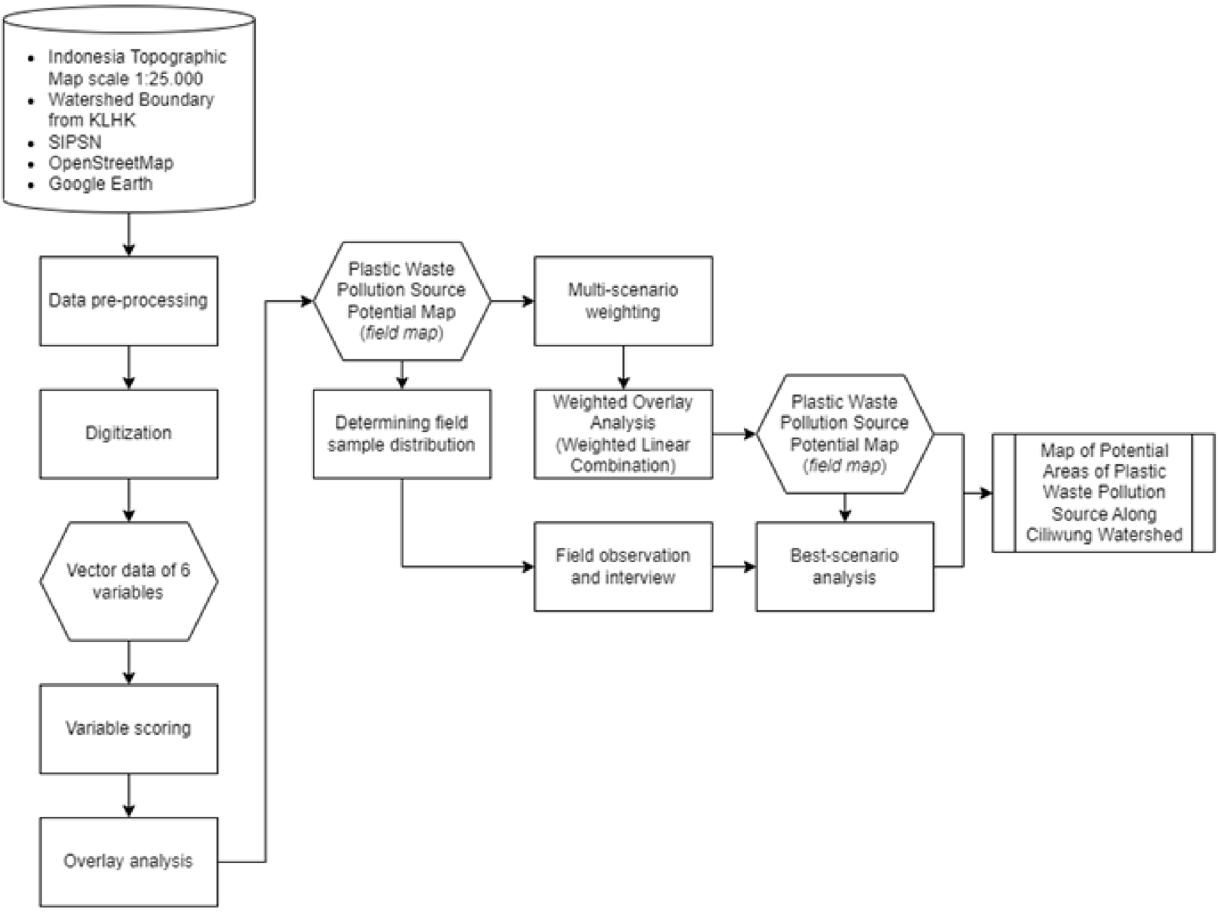


**Figure 2.** Research Workflow

This study employs a quantitative approach using a weighted multi-scenario framework, incorporating six variables and six scenarios, which are presented in the following table.

**Table 1.** Research Indicators and Variables

| No | Indicator | Variable | Classification | Score | Description | Source |
|---|---|---|---|---|---|---|
| 1 | Economy (Income Level) | Settlement Typology | Elite Cluster, Apartment Complex, Housing Estate | 1 | Residents' income level influences their environmental sensitivity. Those with lower incomes tend to be less responsive to environmental concerns. Economic level can be identified through settlement typologies. High-end settlements generally produce less domestic waste that pollutes rivers. | Google Earth, 2022 |
| | | | Public Housing, Residential Complex | 2 | The presence of public housing or residential complexes increases the potential for domestic waste to contribute to river pollution. | |
| | | | Traditional Settlements (Villages) | 3 | Traditional settlements generally generate more domestic waste. Poorer sanitation infrastructure increases the likelihood that waste will be disposed of in rivers (Darwaman & Fatchiya, 2018; Thoyibah & Warmadewanthi, 2023). | |
| 2 | Population | Population Density | Low Density | 1 | Population density in an area serves as an indicator of the amount of plastic waste generated daily (Chukwuma et al., 2021). | BPS, 2022 |
| | | | Medium Density | 2 | | |
| | | | High Density | 3 | | |

| No | Indicator | Variable | Classification | Score | Description | Source |
|---|---|---|---|---|---|---|
| 3 | Presence of Commercial Areas | Buffer around Traditional Market locations | Distance 0–250 m | 3 | Commercial and human activities generate plastic waste that can pollute rivers (Chukwuma et al., 2021). | OpenStreet-Map |
| | | | Distance 250–500 m | 2 | | |
| | | | Distance > 500 m | 1 | | |
| 4 | Presence of Waste Banks/Temporary Waste Disposal Sites (TPS/TPST) | Buffer around Waste Bank/TPS/ TPST locations | Distance 0–250 m | 1 | 3R TPS facilities serve households at the neighborhood (RW) scale, with a service area of 200–500 m² (Regulation of the Minister of Public Works No. 3/PRT/M/2013 on the Provision of Infrastructure and Facilities for Handling Household Waste and Similar Household Waste). | OpenStreet-Map, SIPSN |
| | | | Distance 250–500 m | 2 | | |
| | | | Distance > 500 m | 3 | | |
| 5 | Proximity to River Body | Buffer of River Proximity | Distance 0–250 m | 3 | Human activities located closer to the river body are more likely to become sources of plastic waste pollution to the river (Indrawati & Purwaningrum, 2018). | Google Earth, 2022 |
| | | | Distance 250–500 m | 2 | | |
| | | | Distance > 500 m | 1 | | |
| 6 | Condition of River Buffer Zone | Buffer of Riverbank | Naturalized, natural | 1 | River buffer zones are ideally designated as green areas and conservation zones free from destructive disturbances (Government Regulation No. 38/2011 on Rivers). | Google Earth and field validation, 2022 |
| | | | Normalized, concrete barrier | 2 | | |
| | | | Disturbed | 3 | Disturbed riverbanks (e.g., converted into housing areas) can pollute river flows. | |

The data used in this study consisted of both primary and secondary sources. Primary data were collected through field observations and in-depth interviews with residents at the selected sample locations, as well as settlement-type information derived from the interpretation of Google Earth imagery from 2022. Secondary data were obtained from the Ministry of Environment and Forestry, government sources such as population density and income level statistics from the Central Bureau of Statistics (BPS), waste management facility distribution data from SIPSN, and open-source mapping services such as OpenStreetMap, which provided information on waste collection sites, settlements, rivers, and commercial areas.

The development of scenarios was guided by potential sources of riverine waste identified from field observations. Scenario 1 emphasized settlement types as a proxy for residents' socio-economic conditions, population distribution, and infrastructure. Scenario 2 focused on riverbank conditions and settlement distribution. Scenario 3 incorporated the influence of commercial areas. Scenario 4 was based on the assumption of waste spillover from temporary disposal sites (TPS) and waste banks. Scenario 5 expanded upon Scenario 4 by adding the aspect of proximity to the river body. Finally, Scenario 6 emphasized population density combined with river proximity. The detailed weighting of each indicator is presented in **Table 2**.

**Table 2.** Details of Scenarios and Indicators' Weight

| No. | Indicator | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|---|---|---|---|---|---|---|---|
| 1 | Population (Population Density) | 17.50% | 15.00% | 10.00% | 7.50% | 2.50% | 25.00% |
| 2 | Settlement Typology | 22.50% | 20.00% | 15.00% | 12.50% | 12.50% | 10.00% |
| 3 | Presence of Commercial Areas | 10.00% | 2.50% | 22.50% | 17.50% | 17.50% | 15.00% |
| 4 | Presence of Waste Banks/TPS/TPST | 12.50% | 10.00% | 2.50% | 20.00% | 22.50% | 17.50% |
| 5 | Proximity to River Body | 15.00% | 12.50% | 10.00% | 12.50% | 25.00% | 20.00% |
| 6 | Condition of River Buffer Zone | 2.50% | 20.00% | 20.00% | 15.00% | 10.00% | 12.50% |
| **Total** | | **100%** | **100%** | **100%** | **100%** | **100%** | **100%** |

**Greyed cells represent significant weights

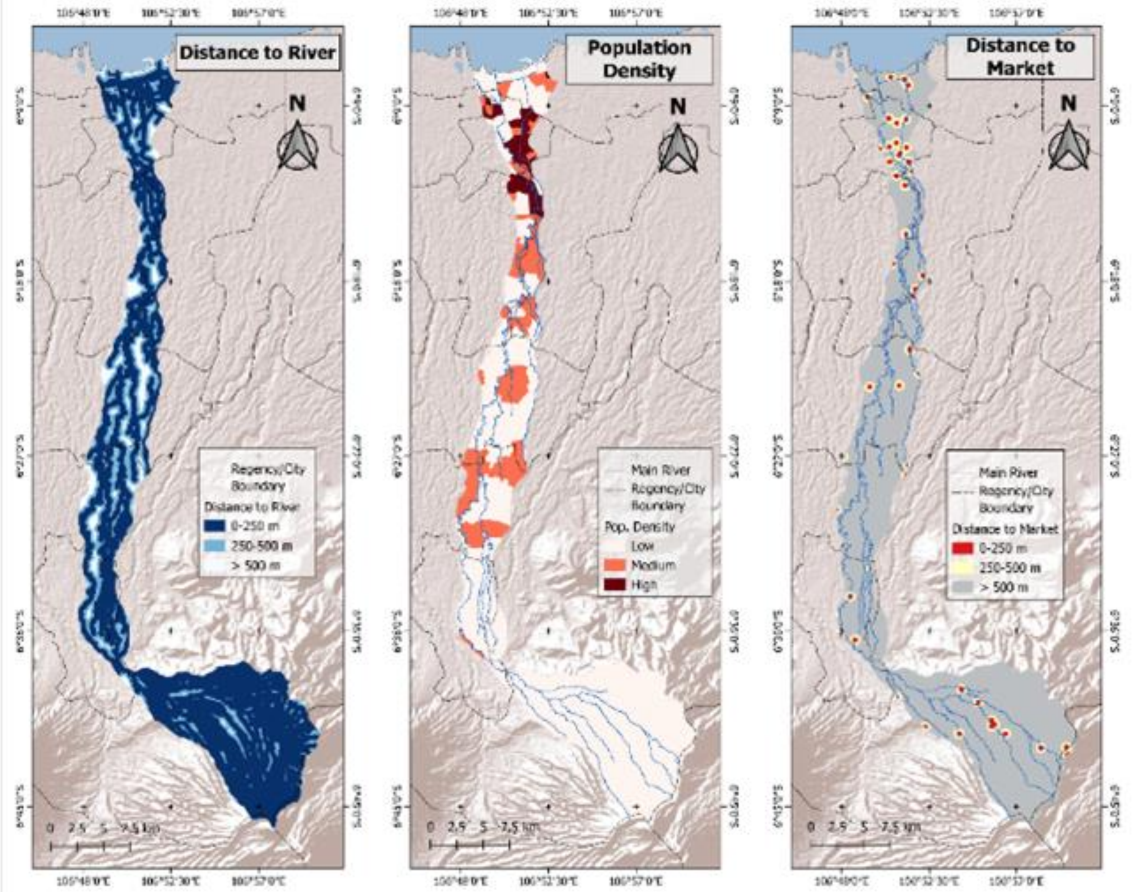
All collected data sources were first preprocessed and digitized, then scored and overlaid. These steps were then complemented with field observations and a Multi-Criteria Decision Analysis (MCDA). Given the multifaceted nature of plastic waste pollution, an analytical approach capable of integrating numerous interacting factors within one coherent framework is required (Rahayu et al., 2014). For this reason, MCDA was employed, as it integrates both physical and socioeconomic dimensions within a single evaluation process, thereby enabling the production of a comprehensive map identifying potential sources of plastic-waste pollution along the Ciliwung River. The Weighted Linear Combination (WLC) method was applied, combining the scores of each variable class with their assigned weights from the defined scenarios, based on a simple ranking principle (Dereli & Tercan, 2020). The calculation of the final value for each scenario followed the principle outlined below:

$$PSP_i = \sum_{j=1}^{n} W_j x_{ij}$$

Where $PSP_i$ Represents the potential value of plastic waste sources in each scenario. $W_j$ represents the weight of each variable in the scenario, and $x_{ij}$ Represents the score of each class of variables (Malczewski, 2000). The WLC results indicate the range of potential plastic waste source values for each scenario, which are then classified into high-, medium-, and low-potential areas using the equal-interval method. These classifications were also used to analyze the selection of the optimal scenario by matching the data with field observation and interview results.

## Results and Discussion

The research incorporated six variables for the Weighted Linear Overlay analysis. The variables are visualized in maps, as shown in **Figure 3**.



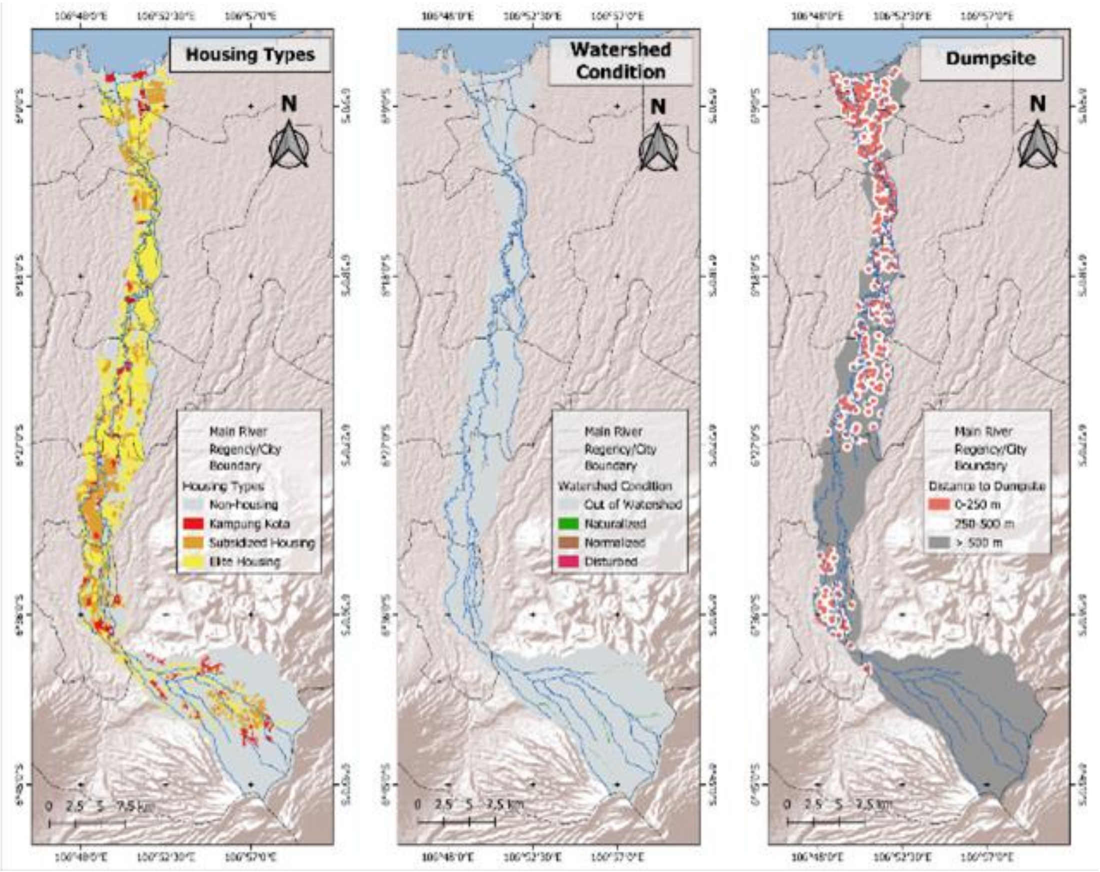


**Figure 3.** Research Variables

The six variables are scored accordingly to their feature classification. Each variable is assigned a score of 1 to 3 based on its contribution to the potential for plastic waste pollution. Population density within the Ciliwung watershed varies significantly and is closely shaped by settlement morphology. Village-level PODES data show that the southern downstream areas are dominated by industrial land uses with relatively low density. At the same time, Central Jakarta records the highest density due to the prevalence of compact kampung kota settlements. Transitional zones along the South–East Jakarta boundary generally exhibit medium to low density, reflecting a mix of kampung kota and subsidized housing. Moving upstream into Depok and Bogor, density decreases further as the built environment shifts toward subsidized and elite housing interspersed with agricultural and open spaces. This spatial gradient is further reflected in market accessibility: traditional markets are clustered in downstream and central areas, supporting densely populated communities, whereas in upstream regions such as Depok and Bogor, markets are more dispersed and often located beyond 500 meters from settlements. The combination of lower density, more spacious housing forms, and greater non-residential land use upstream explains the reduced immediacy of market access compared to the compact and highly populated urban core.

The distance to the river is generated using multiple buffer rings with distance intervals of 250 meters, 500 meters, and more than 500 meters. The farther from the river, the less likely it is for plastic pollution to occur. Proximity to solid waste collection facilities was also measured using multiple buffer rings of 250 meters, 500 meters, and more than 500 meters. The distances were determined by the facility's service radius, which is generally effective to 250 meters. Lastly, the condition of the riverbanks is considered by the treatment applied along the Ciliwung Riverbanks. Natural riverbank segments with natural vegetation are less likely to be sources of plastic waste pollution, while disturbed riverbanks with housing units are far more likely to generate it. The riverbank condition is generated using a 30-meter buffer, in accordance with Government Regulation No. 38/2011 on Rivers regarding the utilization of riverbank buffer zones.

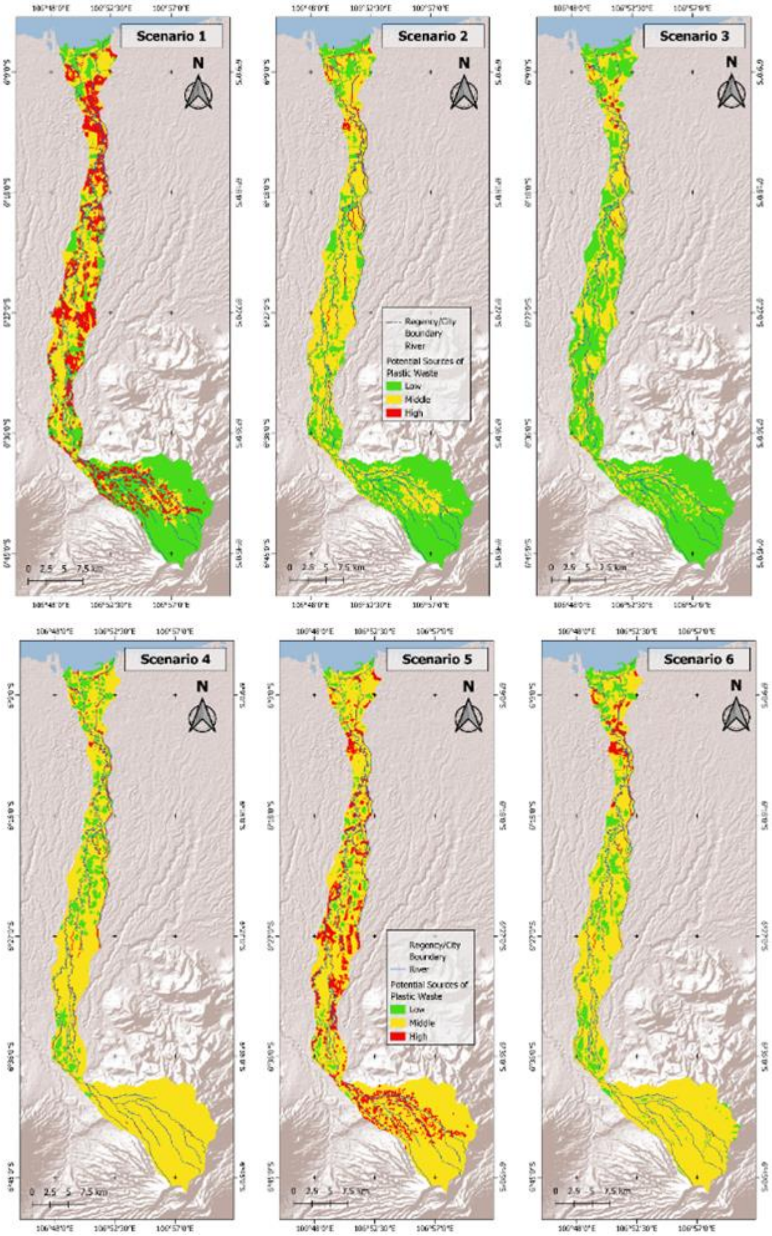


**Figure 4.** Multi-Scenario Mapping of Potential Plastic Waste Sources to the Ciliwung River

The weighted overlay of the six mapping scenarios produced maps as shown in **Figure 4**. Based on the variable weights presented in **Table 2**, Scenario 1 emphasizes settlement typology and population density as the most dominant variables, resulting in high-risk zones of plastic waste pollution concentrated in densely populated residential areas. Scenario 2 highlights settlement typology and riverbank conditions, with high-risk zones concentrated in disturbed riverbank areas located near dense informal settlements; however, the influence is limited to areas immediately adjacent to the riverbanks. Scenario 3 emphasizes the presence of commercial areas and riverbank conditions, leading to high-risk zones along riverbanks disrupted by commercial centers, particularly traditional markets. Scenario 4 focuses on the presence of waste banks or waste management facilities alongside commercial areas, where waste banks exert an effect opposite to that of commercial zones: areas within their service coverage tend to exhibit lower risk levels. Consequently, high-risk zones in Scenario 4 are generally located near commercial areas but outside waste bank service areas. Scenario 5 highlights proximity to the river body and the presence of waste banks. High-risk zones tend to be concentrated in areas within 250 meters of the river body, regardless of land use type, but outside waste bank service coverage. Finally, Scenario 6 emphasizes population density and river proximity, producing high-risk zones in densely populated residential areas within 250 meters of the river.

A comparative examination of the six scenarios highlights how different weighting schemes influence the spatial distribution of high-risk zones. Scenarios 1 and 6 emphasize demographic pressure, showing that population density and proximity to rivers are strong drivers of potential plastic pollution. In contrast, Scenarios 2 and 3 reveal the critical role of environmental conditions—particularly disturbed riverbanks—and commercial activity in shaping localized pollution risks. Meanwhile, Scenarios 4 and 5 demonstrate the counterbalancing effect of waste management infrastructure, where the presence of waste banks reduces potential risks even in otherwise vulnerable locations. Taken together, these findings suggest that no single factor determines the Ciliwung Basin's vulnerability to plastic waste pollution; rather, it is the interaction among socio-economic drivers, land-use practices, and infrastructure availability that creates varying patterns of risk. Such insights are valuable for guiding targeted interventions that account for both physical and social dimensions of waste management.

Based on interviews and direct field observations conducted at 16 sample points, Scenario 1 was identified as the most suitable for mapping the vulnerability to plastic waste pollution in the Ciliwung River Basin. This was based on the alignment between the vulnerability characteristics indicated in the model and the actual conditions observed in the field, further corroborated by testimonies from residents living along the riverbanks. Scenario 1 proved to be the most representative, as extensive evidence of plastic pollution was found predominantly in informal settlements along the riverbanks. This result aligned with the Chukwuma et al. (2021) study, which found that high-density areas with considerably low socioeconomic conditions tend to have a higher risk of solid waste pollution. In these areas, daily practices of indiscriminate waste disposal persist, waste collection services are absent, and community awareness of the importance of not dumping waste into the river remains low. The dense settlement patterns also make it difficult to establish effective waste transport systems, often leading residents to dispose of waste directly into the river or burn it in vacant lots near the riverbanks. In other words, community behavior plays a decisive role in shaping the level of plastic waste pollution entering the Ciliwung River.

The most representative scenario was Scenario 5, in which high-potential plastic waste sources were concentrated in residential areas. However, this scenario was considered less suitable because it failed to adequately represent upstream regions, which are primarily non-residential and contribute less to plastic waste pollution. Its strong emphasis on proximity to the river led it to overlook land-use factors, thereby classifying low-activity areas as medium-vulnerability zones. The subsequent ranking of scenarios, from most to least representative, was Scenario 4, Scenario 6, Scenario 2, and Scenario 3. These findings were further validated by similarities observed across several sample points.

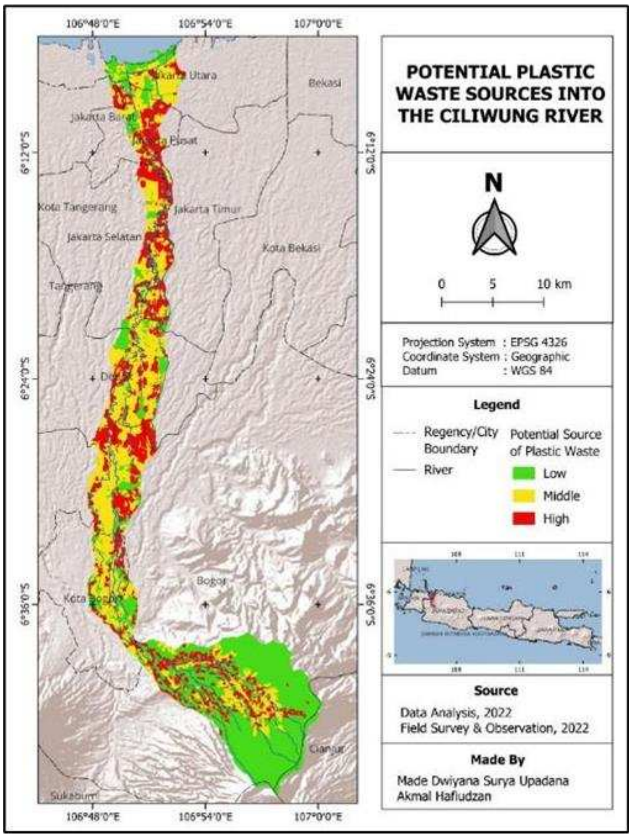


**Figure 5.** Best Scenario Map of Potential Plastic Waste Pollution Sources into the Ciliwung River

The multi-scenario mapping results identified Scenario 1 as the most suitable, with 14 of 16 field observation points showing consistency between the modeled potential sources of plastic waste pollution and the actual field conditions. This finding was further reinforced by community interviews, which validated behavioral patterns of waste disposal in the areas surrounding the sample sites. As illustrated in **Figure 5**, areas classified as high potential frequently exhibited significant waste accumulation along riverbanks. This was exacerbated by the direct use of riverbank zones as residential or commercial areas, such as in Sunter Agung and Pasar Induk Kramat Jati. Settlements constructed immediately on riverbanks were typically high-density informal housing (slum areas), where waste collection and disposal systems were either absent or ineffective. Consequently, residents tended to dispose of their waste directly into the river or burn it in vacant lots near the riverbanks.

**Figure 6.** Plastic Waste Pollution in Sunter Agung (left) and Kampung Pulo (right)

An interesting finding was observed in North Jakarta, where most areas were classified as low potential. However, some areas, such as Sunter Agung, fell into the high-potential category due to poor coverage by waste banks or TPS facilities, combined with the presence of "*kampung kota*" (urban village) settlements categorized as slums. These neighborhoods were characterized by very high population density, predominantly low-income residents, poor sanitation, and inadequate waste processing infrastructure. A similar pattern was found in Kampung Melayu and Pasar Induk Kramat Jati, where waste dumping along the riverbanks was common due to low environmental awareness (Zaikatussoleha, 2022). Low levels of education further exacerbated this situation, as many residents worked as plastic waste collectors for recycling plants. The river channel's boxed morphology in these areas, combined with rapid urbanization and demographic imbalances, has worsened riverbank conditions by encouraging the development of settlements directly adjacent to the river.

**Figure 7.** Plastic Waste Pollution in Central Depok (left) and Pancoran Mas (right)

Moving southward, informal landfilling practices were frequently observed along the river in non-residential areas, though with lower intensity. These findings align with Scenario 1 results, which showed extensive areas of medium potential. This was attributed to the widespread practice of burning domestic waste at the neighborhood (RT) or block level in vacant lots near riverbanks. Waste typically accumulates for less than a week before being burned, contributing to both air pollution and the release of microplastics from incomplete combustion. This problem was compounded by residents dumping waste into large drainage channels (width > 1 m) with fast-flowing water, which ultimately carried the waste into the Ciliwung River. Such conditions were observed in Mekar Jaya and Pancoran Mas, Depok. Waste accumulation was also facilitated by the U-shaped morphology of the midstream river channel and by deposited river materials, which trapped debris during floods along with sand, mud, and gravel.

**Figure 8.** Riverbank Characteristic in Baranangsiang (left) and Northern Bogor City (right)

In Bogor City and the upstream Puncak region, the river morphology transitions into a V-shaped form, characterized by narrower channels, riffle flows, and large boulders in the riverbed. Settlements in this region were more sporadically distributed, typically located along riverbanks and accessible roads, unlike the denser patterns found in midstream and downstream areas. Field observations revealed that settlement distribution was linked to river sections connected to major roads, due to gentler slopes that facilitated garbage truck collection in both Bogor City and Puncak.

In the upstream Puncak area, the proportion of high- and medium-potential zones decreased significantly. Here, plastic waste sources originated from households and tourism activities along the national highway. This explains the medium-potential classification of certain high-elevation upstream areas, where numerous tourist attractions and villas are scattered. Waste collection services in these areas were limited due to steep terrain, with facilities concentrated mainly in large housing clusters. As a result, most residents burned their waste, contributing to microplastic spillover from incomplete combustion.

Another notable finding was the practice of disposing of waste near bridge infrastructure, observed from upstream to downstream areas. According to residents, this practice emerged because bridge edges were considered convenient disposal points accessible to many people and easily reached by sanitation workers. Over time, however, this behavior worsened, with residents increasingly throwing household waste directly into the river from bridges rather than depositing it at existing TPST facilities. These field findings further support Scenario 1, which emphasizes settlement typology, population density, and proximity to rivers as key indicators of plastic pollution risk in the Ciliwung Basin.

**Table 3.** Extent of Potential Plastic Waste Source Areas in the Ciliwung Basin

| No. | Plastic Waste Pollution Source Categories | Area (km²) | Percentage |
|---|---|---|---|
| 1 | High | 63,20457 | 16,36% |
| 2 | Medium | 136,0757 | 35,24% |
| 3 | Low | 186,9122 | 48,40% |
| | Total | 386,1925 | 100% |

The classification of potential plastic waste sources under Scenario 1 revealed that low-potential areas dominate the Ciliwung Basin, covering 186.912 km² (48.4%) and mainly comprising upstream forested regions and the coastal zones of North Jakarta, with elite housing clusters, recreational parks, and port facilities. Medium-potential areas accounted for 136.076 km² (35.24%). They were distributed relatively evenly along the river corridor, where risk is moderated by factors such as distance from the river, natural or normalized riverbanks, and the availability of waste collection services. High-potential areas, though the smallest in extent at 63.204 km² (16.36%), are dominated by slum settlements built directly on the riverbanks, where poor waste disposal practices remain prevalent. Despite their limited coverage, these areas contribute disproportionately to plastic waste entering the Ciliwung River, underscoring the urgent need for targeted interventions in high-risk zones while sustaining broader preventive measures in medium- and low-potential areas.

## Discussion

Overall, the mapping result successfully identified areas with potential to become sources of plastic waste entering the Ciliwung River, particularly those with high potential. Both modeling results and field observations indicate that community waste-disposal behavior is the primary driver of plastic pollution, with domestic waste accounting for the majority of riverine debris. This finding aligns with the research of Indrawati and Purwaningrum (2018) and Zakiatussoleha (2022), which identifies domestic waste as the primary source of plastic pollution. Moreover, the presence of households along riverbanks increases the likelihood that these areas will become informal dumping sites. High-density settlements lacking adequate waste collection and management systems further exacerbate the accumulation of unmanaged plastic waste, which ultimately contaminates the river. Spatial modeling provided valuable insights into priority areas for intervention. However, classifying areas into high, medium, and low potential remains somewhat reductionist. While the maps offer an abstraction of potential source areas, the classification does not yet rely on standardized or discrete indices. Moreover, the categorization is still based solely on land characteristics and demographic factors, without clear differentiation in terms of actual waste volumes. Since this study focused primarily on spatial modeling, measuring the volume and composition of plastic waste would be necessary to validate and refine the characteristics of areas identified as potential pollution sources. The identification of high-risk areas for plastic pollution, combined with reliable data on waste volumes, provides an essential foundation for formulating a practical framework for waste management interventions (Chukwuma et al., 2021).

Field findings further highlight that the sources of plastic waste pollution are difficult to pinpoint with certainty, as community dumping behavior is sporadic, random, and not easily monitored in real time. The presence of bridges was also found to encourage direct waste disposal into the river. This is supported by the findings of Pinto et al. (2025), who state that dumping unmanaged plastic waste into riverine environments is sporadic, difficult to detect, and highly dependent on human activities. Therefore, a more comprehensive approach is required to more accurately pinpoint the entry points of plastic waste into river systems. A customized network analysis could be integrated into the research framework, as dumping behavior is also shaped by accessibility to the river channel. Furthermore, minor river tributaries and gutters were found to be far more likely to be polluted by solid waste due to a lack of monitoring and provision (Indrawati & Purwaningrum, 2018). Nonetheless, this spatial model demonstrates strong locality-specific characteristics, meaning that each area is influenced by different supporting factors, particularly demographic and socio-economic indicators.

Future research could address several limitations of this study. First, the absence of temporal analysis restricts understanding of seasonal variation in waste accumulation, particularly during flood events when river flow and waste transport dynamics change significantly. Second, the lack of integration with hydrological modeling limits the ability to trace downstream movement and identify hotspots of plastic debris accumulation. Third, the reliance on remote sensing and socio-demographic proxies means that behavioral and cultural drivers of waste disposal were only partially captured. Incorporating participatory mapping, citizen science, or crowdsourced data could provide richer insights into localized dumping practices. Finally, expanding the framework to include analysis of plastic waste composition would help establish clearer links between land-based sources, waste management infrastructure, and in-river pollution levels. Such improvements would not only refine the model but also enhance its utility for policymakers in designing targeted interventions along the Ciliwung River Basin.

## Conclusion

Geographic Information Systems (GIS) using the MCDA approach effectively mapped areas with potential to become sources of plastic waste pollution in the Ciliwung River. The issue of plastic waste contamination sources is highly complex, as it involves multiple factors ranging from physical land conditions and community socio-economic characteristics to regional policy frameworks. The spatial analysis conducted in this study demonstrated that community behavior plays a decisive role in influencing the risk of plastic waste pollution in the Ciliwung River. High-potential areas were generally found along disturbed riverbanks, where informal, densely populated settlements (slums) were located. Such areas were predominantly identified in DKI Jakarta, particularly in South Jakarta, southern Depok, and parts of the Puncak Bogor region. Inappropriate land use, poor waste-disposal practices by riverbank communities, and local policies that are insufficiently focused on watershed conservation were all reflected in the mapping results, even if not explicitly shown. Nonetheless, each of the mapped variables has the potential to be further developed into extended analyses with broader research foci, particularly regarding watershed land-use patterns and strategies for addressing environmental challenges within watershed areas.

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