Analysis of Illegal Waste Disposal Site Situation through Community Engagement to Enhance Sustainable Solid Waste Management in Indonesia

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Chapter 1 Introduction

1.1. Background

The rapid economic development observed worldwide has brought about a concomitant increase in waste generation and resource depletion, posing substantial challenges. Among these challenges, proper municipal solid waste (MSW) management emerges as a critical issue, particularly in numerous developing countries across the globe. The quantity of MSW is also expected to increase substantially due to an increasing population and rapid urbanization. Coupled with the still limited supporting facilities and infrastructure, especially waste transportation, which causes the waste problem in cities to become more complex. Globally, approximately two billion individuals lack access to proper waste management services. In developing countries, the challenge is evident, with urban areas only managing to collect 48% of waste, while rural areas fare even worse, with a mere 26% of waste being collected. In waste management systems, an integrated approach encompassing community awareness, individual habits, efficient household collection services, and various associated factors has emerged as indispensable. In regions lacking adequate waste management services, illegal waste dumping, open waste burning, waste dumping on waterways, and other uncontrolled waste management practices persist as significant challenges.

Over the past decades, illegal waste disposal sites (IWDS) have become a chronic and severe environmental concern worldwide (Niyobuhungiro and Schenck, 2022). IWDS is an ongoing, costly waste management problem to control and solve. Illegal dumping, also known as fly-tipping, fly-dumping, or indiscriminate waste disposal, refers to the unauthorized and unlawful act of discarding waste. This activity involves disposing of waste materials in locations not designated or approved for waste disposal, such as public areas, open spaces, or natural environments. IWDS usually

manifests inadequate waste management systems, suggesting inefficiency, but it is not excluded within well-managed waste management systems. Research on IWDS has been conducted extensively in both developing (Khumalo et al., 2021; Nagpure, 2019; Niyobuhungiro and Schenck, 2021) and developed countries (Du et al., 2023; Hidalgo et al., 2019; Karimi and Ng, 2022; Kubasek and Hrebicek, 2013; Quesada-Ruiz et al., 2019; Tasaki et al., 2007).

1.2. Introduction of waste management in Indonesia

Indonesia is one of the countries with the fastest-growing economies in Asia and one of the most biologically diverse countries in the world, with ecosystems ranging from terrestrial to marine and teemed with unique life forms, Indonesia is rich in natural resources. Indonesia is one of Southeast Asia's largest economies, an archipelagic country consisting of more than 17,500 islands, 6,000 of which are inhabited. The additional surrounding sea areas bring Indonesia's recognized territory (land and sea) to about 5 million sq.m, extending 5.120 kilometers from east to west and 1,760 kilometers from north to south. The country is comprised of 34 provinces, 502 cities and regencies, 6,543 districts, 8,506 wards and 74,961villages.

According to the latest Census of Indonesia in 2020, the population of Indonesia in 2020 was 270 million, which makes Indonesia the fourth most populated nation in the world. Meanwhile, according to published statistics, Indonesia's population increased by 3.26 million people, or 1.25% each year, from 2010 to 2020 (Hadiwinata T, 2020). Since the country's average output of municipal solid waste has grown from 0.8 kg per capita to 2.1 kg per capita over the last decade, the country has become exposed to environmental effects. With an increasing population, Indonesia is also a growing economy with an average annual economic growth rate of 5.3 percent from 2000 until 2019 Figure 1.1 Despite the fact that the COVID-19 epidemic reduced Indonesia's real GDP growth from 5% in Q4 2019 to 0% in 2020, it is expected to rise to 4.8% in 2021 and 6% in 2022 (World Bank, 2020).

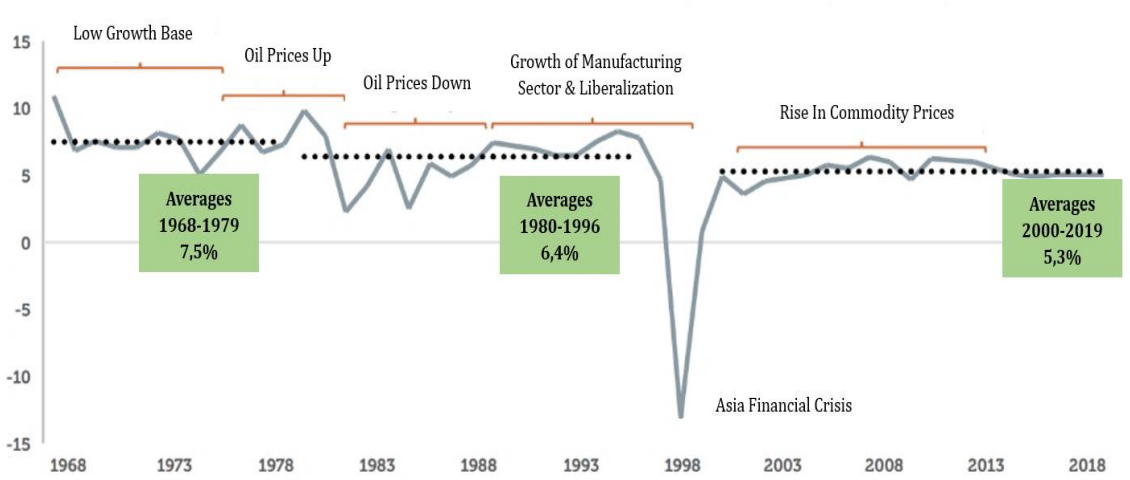

Figure 1. Indonesia's economic growth 1968-2019

The large population and the diversity of city activities in Indonesia have resulted in problems in urban infrastructure services (Munawar et al., 2018). One of the negative impacts of urban development is the increasing complexity of solid waste management problems (Pasang et al., 2007). In line with increasing urban complexity, waste emerges as a problem that requires special attention and handling (Muis et al., 2023). As a result, one of Indonesia's most pressing concerns today is managing the exponentially expanding volumes of municipal solid waste (MSW) generated. Currently, waste management in Indonesia still needs to be improved, in part due to policies or management programs that are less integrated and a lack of support and community participation (Fariz et al., 2023). Coupled with the still limited supporting facilities and infrastructure, especially waste transportation, which causes the waste problem in cities to become more complex.

With a total population of 270,200,000 people (BPS, 2020), Indonesia generates 194,002 tons/day of MSW in a total area of 1,910,931 km2. This amount of waste generation is dominated by urban centers. Currently, more than 55% of Indonesians

live in cities. With the current rate of urbanization, more than 73% of Indonesians will live in cities by 2030.

In Indonesia, solid waste is classified as domestic or non-domestic, the latter being further divided into non-hazardous and hazardous waste. Based on data from the National Waste Management Information System (SIPSN) of the Ministry of Environment and Forestry (MoEF), Indonesia produced 35.93 million tons of waste throughout 2022. This number increased by 22.04% annually (year-on-year/yoy) from 2021, and only 62.49% of the total waste generated was effectively managed, amounting to 22.45 million tons. Alarmingly, the remaining 37.51% of waste, equivalent to 13.47 million tons, remained unmanaged (illegal waste disposal sites, open waste burning, buried).

According to data on total waste generation in 2022, 38.49% comes from households, while commercial sectors account for 25.16% and traditional markets for 13.16%, as shown in Figure 2. (a) Meanwhile, based on its composition, food waste dominates the waste generated in Indonesia, accounting for 41.83% of the total waste generation in 2022. Plastic waste is the second-largest contributor, with 18.07%, as shown in Figure 2. (b)

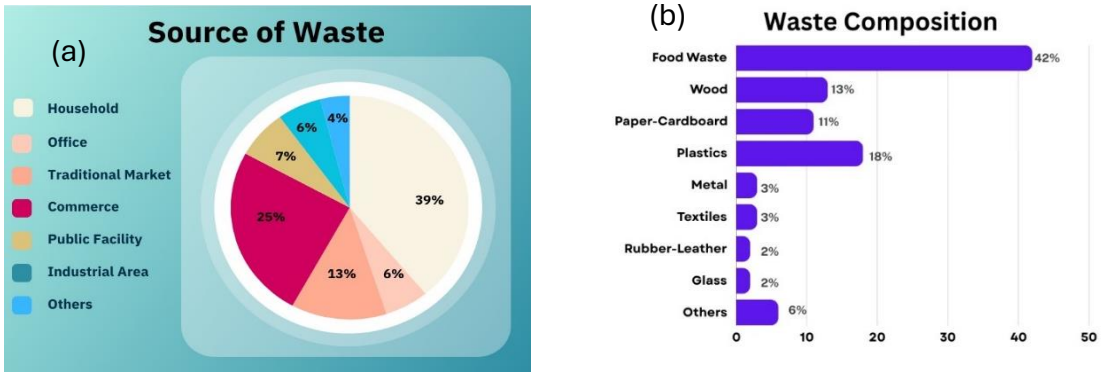

Figure 2. (a) Source of Waste (b) Waste Composition

The waste in the big cities of Indonesia is estimated that only about 60% can be transported to landfills. However, the amount of uncollected waste is most likely not recorded properly and systematically. That happens because it is usually calculated based on the trip of the waste truck to the landfill.

Waste management presents a multifaceted challenge that demands a comprehensive and sustained effort, particularly in countries like Indonesia. The complexity of the issue is underscored by various interconnected aspects, including technical, institutional, financial, environmental, and social dimensions. From a technical standpoint, effective waste management involves the development and implementation of suitable infrastructure and technologies for collection, sorting, recycling, and disposal. Ensuring the proper functioning of these technical systems requires expertise and investment. On an institutional level, clear governance structures, policies, and regulations are essential to oversee and enforce waste management practices. Coordination among governmental agencies, local authorities, and other stakeholders is crucial for effective implementation and enforcement of waste management policies. Financial considerations play a significant role as well. Adequate funding is necessary to support the development, maintenance, and operation of waste management infrastructure and services. Sustainable financing mechanisms must be established to ensure long-term viability and resilience of waste management systems. Moreover, the environmental dimension of waste management encompasses concerns such as pollution prevention, resource conservation, and ecosystem protection. Sustainable waste management practices aim to minimize environmental impacts, promote recycling and reuse, and mitigate pollution. Social aspects also play a pivotal role in waste management. Community engagement, education, and awareness-raising initiatives are essential for fostering behavior change and promoting responsible waste disposal practices. Social equity considerations must also be addressed to ensure that waste management solutions benefit all segments of society.

Previously, all planning, design, and construction of landfills, temporary waste storage areas, and other solid waste facilities, as well as waste management throughout Indonesia, were handled centrally by the Ministry of Public Works which is currently known as the Ministry of Public Works and Housing (MPWH). However, after decentralization in 1999, waste management responsibility was transferred to provinces and regencies/cities. With the issuance of Law 32/2004 about regional autonomy and Government Regulation (GR) 38/2007 about the division of governmental affairs between the central government, provincial governments, and regency/city governments, the responsibility for municipal waste management was transferred from the central government to local governments with the hope that municipal waste management could be improved more efficiently and effectively. This change resulted in a transitional phase for provincial and regency/city governments to develop knowledge and capacity in managing municipal solid waste in their regions.

Nowadays, in Indonesia, municipal solid waste management falls under the jurisdiction of local government, which are responsible for ensuring the cleanliness and sanitation of their respective areas. Typically, local governments have dedicated offices or agencies tasked with managing solid waste. While some larger cities may outsource certain waste management services to third-party contractors, many local governments still prioritize waste management services relatively low.

The old paradigm of 'collect-transport-disposal' waste management still occurs frequently in cities in Indonesia. Crude open dumping is the mainstay of a city's solution to its waste problem, leading to dire conditions at landfill sites. The acute waste problem has resulted in several disasters in Indonesia. Examples are the Bantar Gebang, Bekasi landfill fire in 2015, and the waste landslide at Leuwigajah landfill in Bandung in 2005. The latter tragedy was one of the deadliest in Indonesia, causing 71 houses to be buried and 143 people to be killed. (Ferdinan et al., 2022). Local

governments tend to pay little attention to the landfill, so cases of landfill failure arise (Munawar et al., 2018). Local governments think that landfills can solve all waste problems without having to pay proportional attention to these facilities. The quality of the landfills and waste collection and transportation system is highly dependent on the quality of its management, maintenance, and development.

Solid waste generation cannot be stopped but must be managed, reduced, or appropriately minimized. Funding for waste management must be managed effectively by the local government (Hertomo et al., 2018). Because in general, waste management requires a large budget or cost, especially for technical operational costs from collection, transportation, and processing to the landfills.

In recent years, in several developing countries, efforts have been made to reduce the amount of waste disposed of in landfills by means of stricter solid waste regulations, promoting the reduction of waste at its source, reuse and recycling, and converting waste to energy (SAMBO et al., 2020). Only now, the problems that often arise in solid waste management include the increasingly expensive operational costs and the low availability of land for waste disposal facilities (Arni Sarah et al., 2018). Many of the existing landfills in urban areas were constructed years ago when land was still plentiful, and currently, many of the landfills have exceeded their capacity (Abubakar et al., 2022). Table 1. shown the landfill distribution in Indonesia. Mountains of waste are gradually forming in many landfills in Indonesia, not to mention illegal waste disposal sites that should not be used to dispose of solid waste, such as rivers and open spaces (Munawar et al., 2018). Such conditions lead to the emergence of various environmental problems.

Table 1. Landfill Distribution in Indonesia

Province	Landfill Amount	Total Landfill Area (Ha)	Landfill Services Coverage (Households)	Landfill Capacity (m^3/Volume)
Aceh	15	85,8	286,076	1,766,394
Bali	3	38,19	449,291	2,116,088
Banten	6	93,4	454,949	1,062,908
Bengkulu	9	12,05	1,311,571	630,923.20
DI Yogyakarta	3	18	598,208	1,124,350
Gorontalo	4	19,28	38,763	223,518.60
Jambi	9	35,91	327,004	697,881.55
Jawa Barat	11	203,14	1,058,883	2,750,025.85
Jawa Tengah	15	31,32	641,013	740,535.60
Jawa Timur	21	133,75	1,295,570	1,873,841.90
Kalimantan Barat	6	8,11	160,614	141,400
Kalimantan Selatan	13	139,5	301,073	951,285
Kalimantan Tengah	12	132,99	310,446.80	763,281.80
Kalimantan Timur	4	75	323,166	1,252,156
Kalimantan Utara	4	33,89	141,200	2,661,740
Kep. Bangka Belitung	7	50,16	112,995	205,151.95
Kepulauan Riau	3	11,4	33,520	130,000
Lampung	6	21,57	25,500	1,784,850
Maluku	12	15,21	330,290	2,066,581
Maluku Utara	11	47,9	76,075.59	398,201
Nusa Tenggara Barat	5	22,5	45,200	343,431
Nusa Tenggara Timur	8	16,18	364,600	603,694.69
Papua	7	67	127,600	127,282
Papua Barat	5	45	29,779	107,198.20
Riau	1	4,6	26,000	677,440
Sulawesi Barat	5	19,55	129,031	35,076.48
Sulawesi Selatan	15	42,3	197,590	1,128,329.45
Sulawesi Tengah	6	65,96	173,157	604,042
Sulawesi Tenggara	14	83,7	577,066	750,076.52
Sulawesi Utara	13	79,26	341,883	1,588,271
Sumatera Barat	7	62,9	139,040	177,970.40
Sumatera Selatan	6	32,01	76,625	91,961.64
Sumatera Utara	5	25,17	340,479.60	1,108,894.80
Indonesia	**271**	**1,772.69**	**10,835,258.99**	**30,684,758.78**

Source: Ministry of Public Works and Housing, 2023

Indonesia has drafted various municipal solid waste management (MSWM) policies since the 1970s when the government incorporated MSWM in the third National Medium-Term Development Plan 1979-1984. Following this, 1990 the Indonesian Environmental Impact Management Agency was founded, and in 1989, the government launched an award program for the city with the cleanest environment, named *Adipura*. In its development of conducting waste management in Indonesia, the Indonesian government has made various policies regarding waste management, such as Law 18/2008 about waste management, Law 32/2009 about environmental protection and management, Government Regulation 81/2012 about domestic waste and domestic waste equivalent management, Presidential Regulation 97/2017 about national policy and strategy for domestic waste and domestic waste equivalent management, known as *JAKSTRANAS*, as well as various regulations issued by each region in Indonesia for waste management.

In Indonesia, two laws regulate waste management: Law 18/2008 about Waste Management, which focuses on municipal solid waste management, and Law 32/2009 about Environment Protection and Management. Indonesia introduced the Law of Solid Waste Management (Law 18/2008) on May 7, 2008, initially drafted in 2003. Table 2. shown core provisions of Indonesia's national legal instruments concerning waste management. Indonesia's Law 18/2008 on Waste Management stated the need for a fundamental paradigm change in waste management. Changes in the paradigm of collect-transport-dispose to processing that relies on reducing waste and handling the waste. All levels of society, both government, business and the wider community, carry out activities to reduce waste generation, recycle and reuse the waste or known as Reduce, Reuse and Recycle (3R) (KLH, 2013). The government has set a target in the form of a National Strategy Policy on Waste Management, which sets 30% through reduction and 70% handling activities in 2025 (KLHK, 2018).

Table 2. Core Provisions of Indonesia's National Legal Instruments Concerning Waste Management

National Laws and Regulations	Core Provisions
Law 18/2008 about Waste Management	There are two mechanisms involved in solid waste management: reduction and handling. The reduction mechanism involves limiting solid waste generation and recycling and reusing waste. On the other hand, the handling mechanism involves sorting, collecting, transporting, processing, and final waste process.
GR 81/2012 about Domestic Waste and Domestic Waste Equivalent	
GR 27/2020 about Specific Waste Management	
PR 97/2017 about National Policy and Strategy for Domestic Waste and Domestic Waste Equivalent Management (JAKSTRANAS)	In 2025, the goal is to reduce waste by 30%, equivalent to about 20.9 million tons, and handle 70% or 49.9 million tons of waste.

1.3. Current Status of IWDS research

Due to rapid global economic growth, significant challenges have arisen in the form of increased waste generation and resource depletion (Sharholy et al., 2008). The volume of waste produced is growing, accompanied by a rise in illegal dumping cases aimed at avoiding the costs of proper waste disposal. Recent research underscores that illegal dumping has emerged as a critical environmental and social issue worldwide in recent decades (Seror and Portnov, 2020; Yang et al., 2019). The extent of illegal dumping varies across regions and fields of study. Generally, waste refers to solid materials like construction debris, household refuse, and decorative items, though some studies also consider electronic waste due to its toxicological implications. These wastes pose significant environmental risks, potentially containing hazardous substances such as heavy metals that can harm human health. Consequently, urgent action is required to address illegal dumping and its associated impacts.

In response to this challenge, extensive efforts have been made to explore various facets of illegal dumping, investigating the legal frameworks governing this issue across several countries, such as the United States (EPA, 1998), Israel (Jakiel et al., 2019), the United Kingdom (Liu et al., 2017), and China (Lu, 2019). Studies have also delved into the decision-making processes among stakeholders involved in illegal dumping (Sahramaki and Kankaanranta, 2017; Santos et al., 2019). Additionally, research has explored the factors influencing illegal dumping, including personal motivations (Comerford et al., 2018), environmental conditions (Wright et al., 2018), social factors (Seror and Portnov, 2020), and external factors like weather (Mihai, 2019). Given the toxic nature of illegally dumped materials (Sharma et al., 2018), studies have assessed the physical and ecological impacts of illegal dumping by examining the presence of heavy metals and organic substances in the vicinity of these sites (Benedetti et al., 2015; Ferrante et al., 2017).

In order to achieve the aims of research, articles related to IWDS are searched through Scopus databases. This study comprises of three parts, as shown in (Figure 3). Part of the synthesis theory uses the Preferred Reporting Items for Systematic Literature Reviews and Meta-Analyses (PRISMA) methodology. PRISMA is a set of guidelines and a checklist to improve systematic reviews' transparency, completeness, and quality There were 1,893 documents from Scopus with illegal dumping as the first keyword. After applying essential limits such as years (publication age: 10 years from 2012 to 2022), document types (articles, conference papers, and reviews), source papers (journal and conference proceedings), language (English), and publication stage (final and in press), 875 documents were registered. Duplicate documents with the same title and digital object identifiers (DOI) were excluded. The second phase was screening. In this phase, the title and abstract of each record were read and rechecked to determine whether the article contained material relevant to the illegal waste disposal sites, illegal dumping condition, illegal dumping monitoring.

Consequently, 185 articles were included in this analysis. The next step was the eligibility assessment. Documents must meet these criteria, such as documents must discuss environmental issues, municipal solid waste, illegal dumping process, illegal dumping condition and illegal dumping monitoring and detection. Only 81 documents met the inclusion criteria. The third phase was the inclusion phase. The full texts of the articles were read to ensure that all the papers were related and answered the purpose or research questions. Finally, 81 articles were eligible for qualitative content analysis.

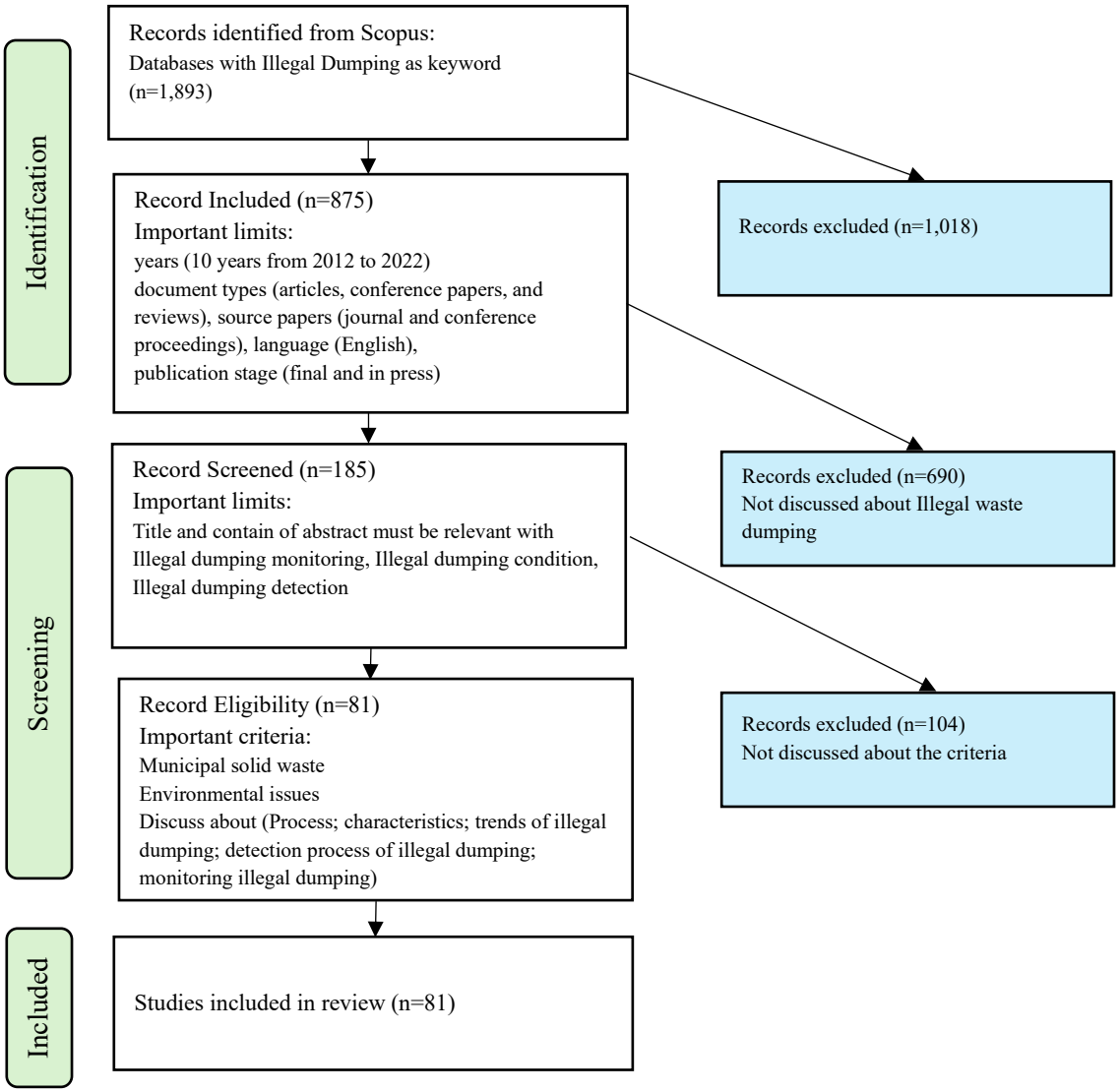

Figure 3. Result of PRISMA methodologies

The VOSviewer tool was used to understand the relationship between the literature (81 documents) and research trends in the IWDS. In VOSviewer, scientific concepts in a document are examined by using words (co-words). Co-word analysis is based on the co-occurrence of words or keywords from two or more documents that are used to index documents. The higher the co-occurrence, the more frequently the term was used and the greater its influence on a study or article. Furthermore, VOSviewer applies a similarity visualization technique (VOS), that displays keywords based on their strength at a distance (a distance-based map). The closer the two keywords are, the stronger the relationship. VOSviewer also uses a unique algorithm to determine which terms can and cannot be displayed without overlapping terms. Consequently, the terms in the VOS cluster do not overlap.

The two maps show the research overlay for publication using terms (Figure 4) and years (Figure 5). The map provided information on the research topic, which was divided into four clusters based on the highest occurrence and total strength of the terms listed in Table 3. The classification of terms within each cluster is based on term density. The number of neighboring terms and term weights influence the term density. The higher the term density, the more neighboring terms there are and the shorter the distance between them. Furthermore, the greater the weight of the nearby terms, the greater the term density will be. The term densities are described in a color scheme.

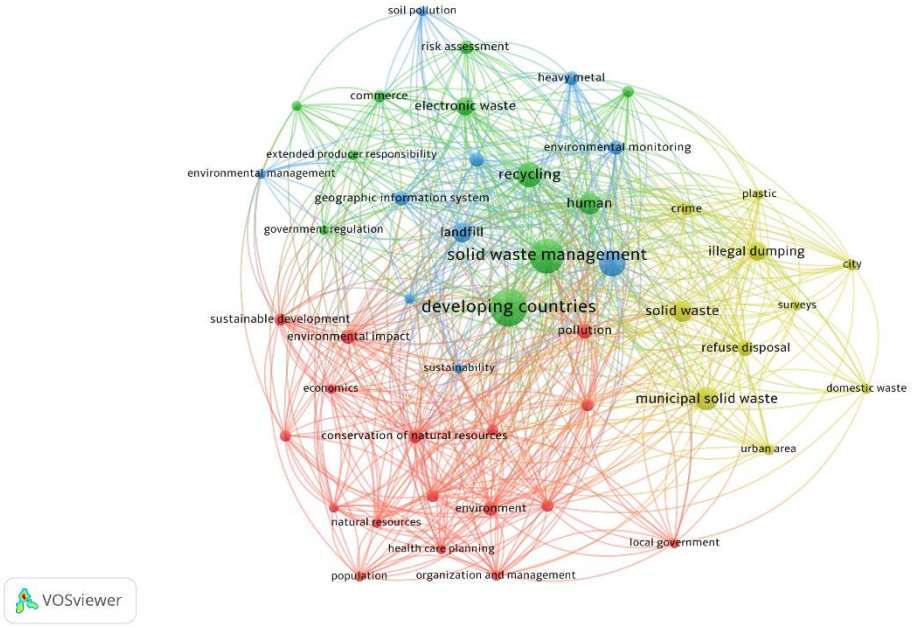

Figure 4. The Map of Research Cluster

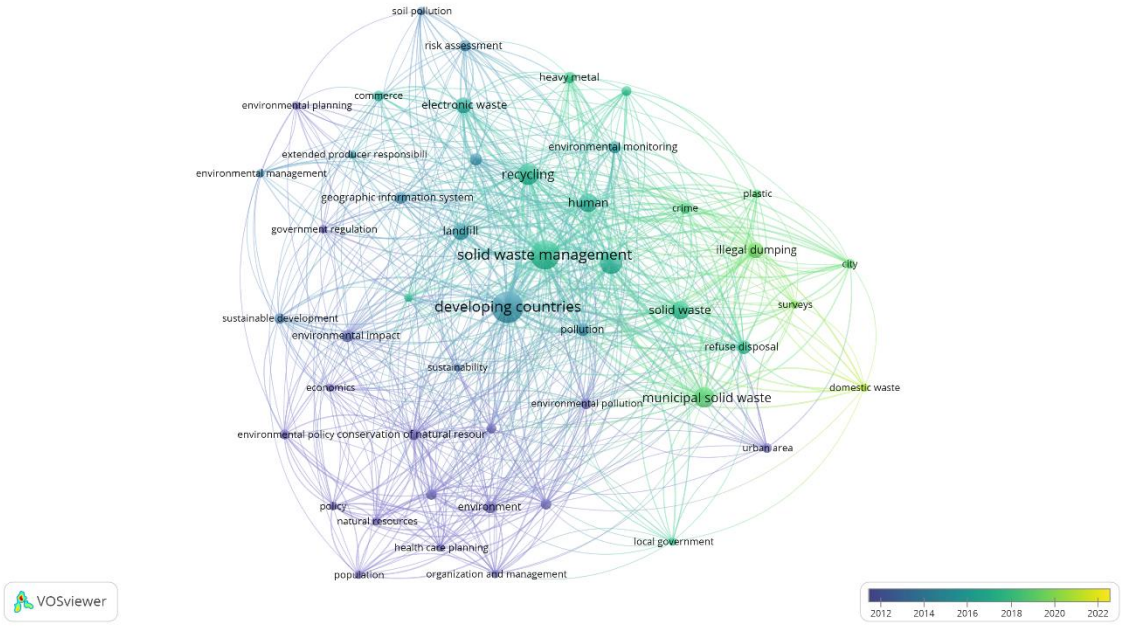

Figure 5. Overlay Map of Research Year

Based on the Figure 4., cluster 1 or red color describes Environmental Policy and Public Health Management, this cluster encompasses topics related to local government initiatives, economic considerations, and public health management in the context of environmental policy. These cluster delves into areas such as sustainable development, environmental protection, and the impact of policies on population health and natural resources.

Cluster 2 or green color describes Environmental Planning and Regulatory Compliance, this cluster focuses on the intersection of environmental planning, government regulation, and commerce. It discusses topics like extended producer responsibility, risk assessment, and waste management strategies, particularly in both developed and developing countries.

Cluster 3 or blue color describes Sustainability and Environmental Management, this cluster highlights the importance of sustainability and effective environmental management practices. This cluster covers topics such as soil pollution, hazardous waste, and the use of geographic information systems for decision-making in Illegal waste disposal sites.

Cluster 4 or yellow color describes Urban Waste Management and Public Services, this cluster addresses issues related to urban waste management and public services delivery in cities. It includes discussions on domestic waste, illegal dumping, and municipal solid waste management, along with efforts to mitigate pollution and crime associated with refuse disposal in urban areas.

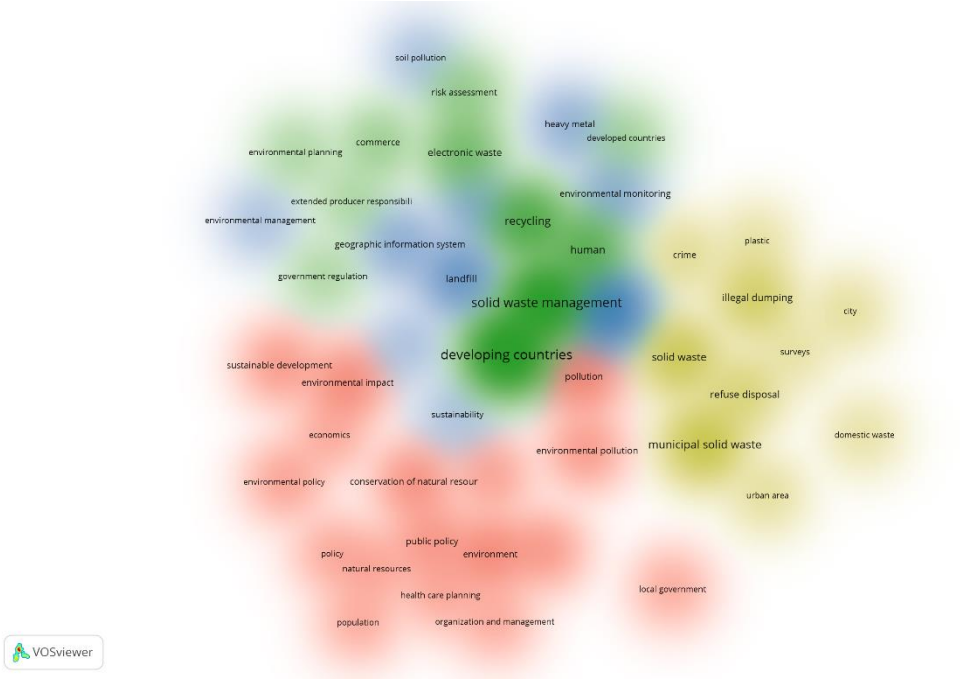

Figure 6. Research Density Map based on Cluster

The density analysis of the research data reveals concentrated periods of intense study. Based on figure 6. Research on Illegal Waste Disposal Sites (IWDS) is extensive in developing countries, focusing on understanding human behavior, recycling practices, and solid waste management within these contexts. These studies investigate the prevalence and impact of illegal waste disposal on local environments and communities. They analyze the socio-economic factors driving illegal dumping activities and explore how these practices affect public health and environmental sustainability. Researchers also examine strategies for mitigating the environmental and health risks associated with IWDS, aiming to develop effective policies and interventions to promote waste management practices and sustainable development in developing countries. Research on IWDS also extensively utilizes Geographic Information Systems (GIS). This technology helps researchers map and analyze IWDS locations, activities, and their environmental impacts with spatial accuracy. Moreover, IWDS studies often link these informal waste activities to crime rates and social issues, highlighting broader societal implications. Environmental monitoring is

another critical focus of IWDS research, as it enables the assessment of pollution levels, ecological impacts, and potential health hazards associated with these sites. By integrating GIS, crime analysis, and environmental monitoring, researchers gain comprehensive insights into the complex dynamics of IWDS, facilitating informed decision-making for effective waste management policies.

Table 3. Number of Co-Occurrences and Total Strength of The Terms Per Cluster

Cluster 1		
Items	**Occurrences**	**Total link strength**
Conservation on natural Resources	7	78
Economics	4	33
Environment	8	62
Environmental Impact	8	50
Environmental Policy	5	36
Environmental Pollution	6	50
Environmental Protection	6	69
Health care planning	4	41
Local Government	4	24
Natural Resources	4	38
Organization and Management	4	41
Policy	4	39
Pollution	9	75
Population	4	37
Public Health	5	33
Public Policy	6	63
Sustainable Development	6	45
Cluster 2		
Items	**Occurrences**	**Total link strength**
Commerce	6	38
Developed Countries	5	40
Developing Countries	47	331
Electronic Waste	13	83
Environmental Planning	4	26
Extended Producer Responsibility	4	26
Government Regulation	4	30
Human	19	151
Recycling	24	161

Risk Assessment	7	48
Solid Waste Management	47	294
Cluster 3		
Items	**Occurrences**	**Total link strength**
Decision Making	4	42
Environmental Management	4	19
Environmental Monitoring	8	73
Geographic Information System	8	56
Hazardous Waste	8	58
Heavy Metal	7	42
Landfill	15	109
Soil Pollution	4	27
Sustainability	4	12
Waste Disposal Facilities	28	192
Cluster 4		
Items	**Occurrences**	**Total link strength**
City	5	50
Crime	6	48
Domestic Waste	4	28
Illegal Dumping	14	99
Municipal Solid Waste	22	142
Plastic	4	34
Refuse Disposal	10	103
Solid Waste	18	139
Surveys	4	37
Urban Area	5	31

1.4. Objectives and Scopes

1.4.1. Research Objectives

Deli Serdang is one of the National Strategic Areas based on Indonesia Presidential Regulation 62/2011 and located in North Sumatra Province, plays a role as the gate of west Indonesia regional. It has a very strategic position as an entrance gate for tourism, business, and industry sectors. In another hand, Deli Serdang is facing environmental issues; one of them is Illegal Waste Disposal Sites (IWDS). As there

are gaps in the investigation and inventory assessment of Illegal Waste Disposal Sites (IWDS), this study has several aims or objectives to accomplish.

a. Analyzing the status of IWDS at the global and regional levels, and the factors affecting IWDS
b. Investigating and analyzing IWDS location and characteristics in Deli Serdang Regency
c. Analyzing the spatiotemporal pattern of IWDS in Deli Serdang Regency
d. Examining the appropriate policy recommendation for reducing illegal waste disposal sites in Indonesia

1.4.2. Research Scope

For the first chapter, systematic literature network analysis (SLNA) which combines bibliometric analysis (BA) was conducted to understand the study's first aim. The literature review task was done by analyzing status, and factors affecting IWDS practices were searched and analyzed through Scopus databases. For the second to the fourth chapter of this study, the study area is limited to Deli Serdang Regency, which consists of assessing the current condition of Deli Serdang MSWM, investigating the precisely locate, quantifying, and determining the extent of IWDS activity at the regency scale while also involving the community in the investigation process, analyzing spatiotemporal pattern to evaluate characteristic and countermeasures to reduce the IWDS activity. Deli Serdang Regency became the pilot study area, representing a regency in Indonesia. Indonesia has two classifications of cities: city and regency; a typical regency has a less dense population and a larger area than a city, and the availability of an efficient waste collection system covering almost all districts is still inadequate. Deli Serdang Regency is the one of National strategic Area that located in North Sumatera Province. The investigation of IWDS activities was conducted for 8 months from March 2023-November 2023. In this study, IWDS is limited to medium size piles and big size piles, small size piles are not counted in

this study. In the fifth chapter, assesses the priority of policy recommendations concerning IWDS in Indonesia.

1.5. Methodological Framework

To achieve the research goals, several steps have been taken. First, the literature review was done from a global perspective and regional perspective. The literature review employed systematic literature network analysis (SLNA), which combines bibliometric analysis (BA) and qualitative content analysis. The second methodology used is combining ground-based individual investigation and community engagement investigation methodology. Ground-based individual investigations using the transect walk method frequently called the distance sampling approach to find any IWDS activities and community engagement investigation methodology using direct interviews, focus group discussions (FGDs), and whistleblower. The direct interviews were conducted using open-ended questions. Whistleblower is a new method developed by researchers to reveal the problem of IWDS, the whistleblower mechanism provides an opportunity for individuals and communities who have sensitive or confidential information about IWDS to share this information anonymously. This method helps uncover insights that may not be revealed through standard methods. When conducting direct interviews and FGDs, researchers also carried out awareness campaigns to educate the community about the importance of reporting IWDS activities and the protections available to whistleblowers and create a hotline where individuals and the community can report information about suspected IWDS without fear of retaliation. Researchers ensure strict confidentiality and protection for whistleblowers to encourage them to come forward with information. This method successfully evaluated the IWDS activities in Deli Serdang regency. Lastly, using a literature survey data to examine appropriate policy recommendations to reducing illegal waste disposal sites in Indonesia. The research framework can be seen in Figure 7.

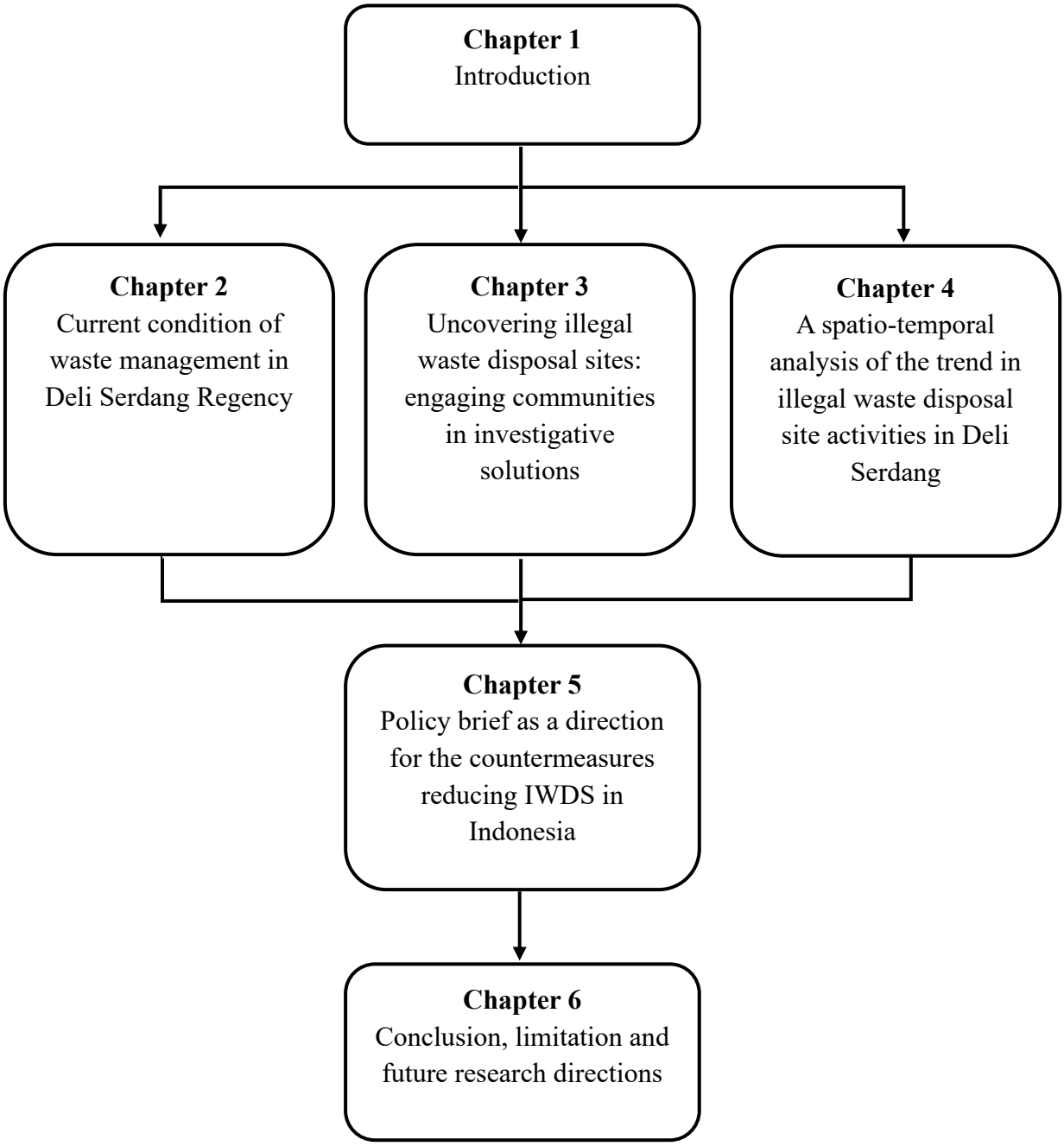

Figure 7. Research Framework

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Chapter 2 Current Condition of Waste Management in Deli Serdang Regency

2.1. Introduction

Deli Serdang is a regency located in North Sumatra province and directly adjacent to Medan city. Deli Serdang has 2 sanitary landfills. Deli Serdang is one of the National Strategic Areas based on Indonesia Presidential Regulation 62/2011. It is located on the eastern coast of Sumatra, and it consists of 22 districts and 394 villages. According to Deli Serdang Central Bureau of Statistics data, the Deli Serdang population in 2023 was 2,018,164 people, 1,014,629 men and 1,003,535 women with 456,000 households, and about four people inhabited each household. Along the northern region, the regency is bordered by the Malacca Strait, which is one of the most densely populated sea traffic lanes in the world.

Geographically, Deli Serdang Regency is located at 2°57' North Latitude to 3°16' North Latitude and 98°33' East Longitude to 99°27' East Longitude. The area of Deli Serdang Regency is 2,497.72 sq.km or 249,772 Ha. Boundary area to the north is Langkat Regency and the Malacca Strait, on the east by Serdang Bedagai Regency, on the south by Simalungun Regency and Langkat Regency and on the west by Langkat Regency, Karo Regency, and Binjai City. Located near the equator, Deli Serdang Regency has an entirely tropical climate with two major seasons: the dry season (June-September) and the rainy season (December-March), and the transitional periods between the two seasons are April-May and October-November (BPS-Statistics of Deli Serdang Regency, 2024). According to Deli Serdang Geophysical Station records, in 2023 there will be an average of 17 rainy days per month with an average rainfall volume of 188.5 mm. The greatest rainfall occurred in December, namely 367 mm. Meanwhile, the smallest rainfall occurred in April at 51 mm.

Figure 8. The map of Deli Serdang Regency

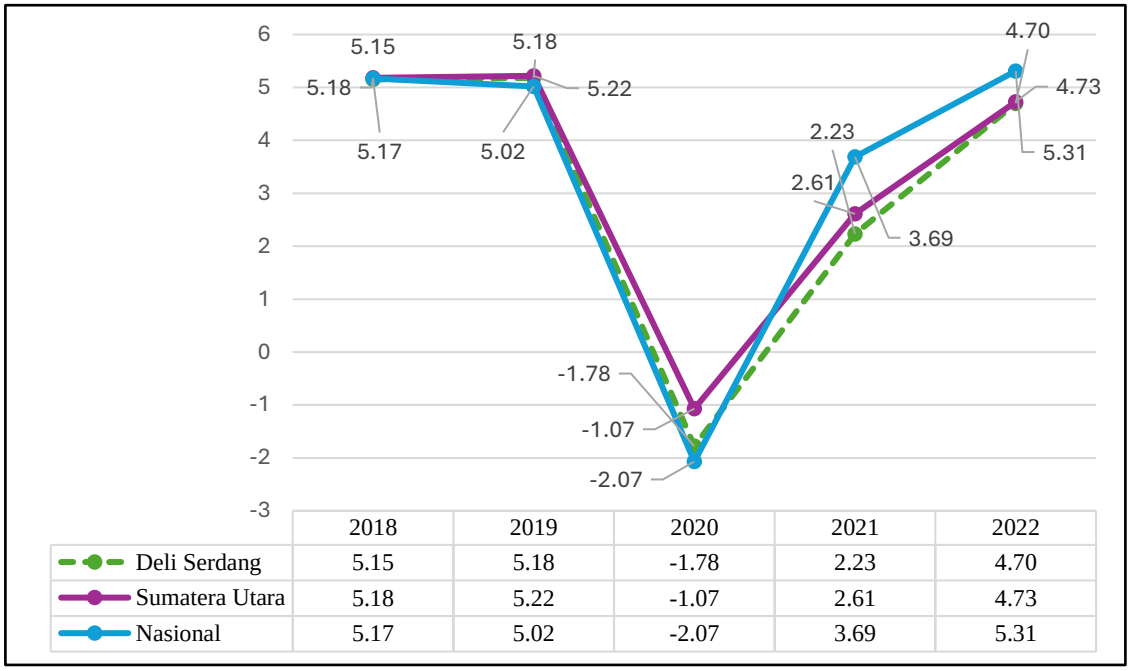
Roads play a significant role in MSWM. Accessible and well-maintained roads facilitate the transportation of waste to landfill or recycling facilities. Therefore, the condition and accessibility of roads are crucial factors to consider in the planning and implementation of effective MSWM strategies. The length of roads throughout the Regency of Deli Serdang in 2022 reached 3,932.536 kilometers. The length of roads that are under the authority of the state is 141.349 kilometers, under the authority of the province was 120.480 kilometers and the rest under the authority of the regency as much as 3,670.707kilometers (Table 4.).

Table 4. Road Length of State, Province and Regency by Road Condition in Deli Serdang Regency in 2022

Road Condition	Authorized Government to Manage			Total (km)
	State	Province	Regency	
Good	131.399	82.090	1,472.357	1,685.846
Moderate	-	10.000	57.280	67.280
Damaged	9.950	16.390	207.248	233.588
Badly Damages	-	12	323.407	335.407
Other	-	-	1,610.415	1,610.415
Deli Serdang Regency	**141.349**	**120.480**	**3,670.707**	**3,932.536**

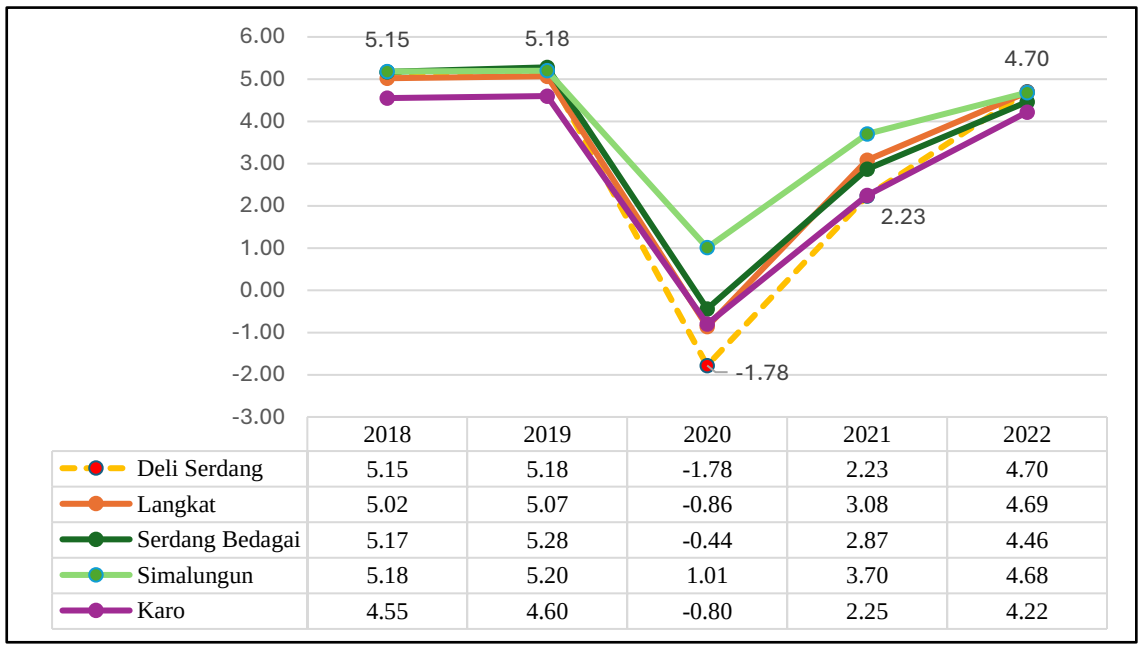
Source: Water Resources, Highways and Construction Services Agency of Deli Serdang, 2022

Deli Serdang's economic growth over the past five years has fluctuated. In 2018 and 2019, growth was recorded at 5.15 and 5.18. However, in 2020 it showed negative growth (-1.78), because most of the contribution came from the processing and service industry which was greatly impacted by the Covid-19 pandemic. However, it started to show improvement in 2021 (2.23) and 2022 by 4.70 percent. Although it is still below the growth of North Sumatra Province (4.73) and National (5.31). However, over the last two years it has shown a positive growth trend (Figure 9.). Deli Serdang Regency's economic growth is the highest compared to neighboring regency (Langkat Regency, Serdang Bedagai Regency, Simalungun Regency and Karo Regency) (Figure 10.).



	2018	2019	2020	2021	2022
Deli Serdang	5.15	5.18	-1.78	2.23	4.70
Sumatera Utara	5.18	5.22	-1.07	2.61	4.73
Nasional	5.17	5.02	-2.07	3.69	5.31

Figure 9. Deli Serdang's Economic Growth Compared By Provincial And National



	2018	2019	2020	2021	2022
Deli Serdang	5.15	5.18	-1.78	2.23	4.70
Langkat	5.02	5.07	-0.86	3.08	4.69
Serdang Bedagai	5.17	5.28	-0.44	2.87	4.46
Simalungun	5.18	5.20	1.01	3.70	4.68
Karo	4.55	4.60	-0.80	2.25	4.22

Figure 10. Deli Serdang's Economic Growth Compared By Neighboring Regency

2.2. Waste management policy

According to the 1945 Constitution of the Republic of Indonesia (UUD 1945) article 28H ‘every citizen of Indonesia has the right to a good and healthy living environment’, provides everyone's right to a good and healthy environment. The mandate of the constitution has the consequence that the government is obliged to provide public services in waste management. In order to carry out comprehensive and integrated waste management from upstream to downstream, fulfill the rights and obligations of the community and the private sector, as well as the duties and authority of the central and regional governments to carry out public services, Law 18/2008 about Waste Management was issued.

Law 18/2008 about Waste Management is the primary legal foundation for managing waste in Indonesia. This law mandates the need for fundamental changes in waste management that have been carried out. Article 1 paragraph (5) states that waste management is a systematic, comprehensive and sustainable activity. Article 19 states that waste management is divided into two main activities, waste reduction and waste handling. Article 20 describes three main activities in the implementation of waste reduction activities: limitation of waste generation, recycling and reuse of waste. The three activities are an embodiment of the principles of environmentally sound waste management called 3R (reduce, reuse, recycle). In Article 22, five main activities are described in the implementation of waste management activities, which include sorting, collecting, transporting, processing, and final processing of waste. In Article 22 outlined five primary activities in the implementation of waste management activities, including sorting, collecting, transporting, processing, and final disposal.

Waste management in Indonesia involves the central government, provincial government, local government and other parties. Each party has their own responsibility in managing waste, because to deal with waste requires a comprehensive approach that involves the community, government at both local and

national levels and the private sector. National waste management policies and strategies are the authority of the central government. Waste management norms, standards, procedures and criteria are determined by the central government. Furthermore, local governments implement these national policies and strategies in their respective regions starting from establishing regulations, managing waste from upstream to downstream and monitoring and evaluating waste management. The community is expected to participate in reducing waste and handling waste in an environmentally sound manner in accordance with local regulations. The private sector or other parties are expected to follow the provisions in managing the waste they generate.

In line with the formulation of the SDGs at the global level, Indonesia has prepared and harmonized the 2015-2019 National Medium Term Development Plan (RPJMN) and the 2020-2024 RPJMN. One of the policies in the 2020-2024 RPJMN which is in accordance with SDGs Goals No. 12 (responsible consumption and production), 3 (good health and well-being) and 11 (sustainable cities and communities) is improving the performance of waste management by the Central and Local Governments. In the 2020-2024 RPJMN, waste management is included in the National Priority VI agenda, namely "Developing the Living Environment, Increasing Disaster Resilience and Climate Change".

Government Regulation 81/2012 about Domestic Waste and Domestic Waste Equivalent Management is issued as implementing regulations Law 18/2008, as well as strengthen the legal basis for dealing with waste management in Indonesia, particularly in the regions. There are several important subject matters mandated by these government regulations, namely (Indonesia Government, 2012):

1. Providing a stronger foundation for local governments in the implementation of environmentally sound waste management from various aspects including

legal, management, operational, technical, financing, institutional, and human resources;

2. Provide clarity regarding the division of tasks and the role of all relevant stakeholders in waste management starting from ministries/institutions at the central level, provincial government, regency/city government, business, area managers to the community;
3. Providing an operational foundation for the implementation of the 3R (reduce, reuse, recycle) in waste management replacing the old waste paradigm;
4. Providing a strong legal foundation for the involvement of the business communities to take responsibility for waste management following its role.

The seriousness of the Indonesian government in waste management is manifested by the issuance of Presidential Regulation 97/2017 about National Policy and Strategy for Domestic Waste and Domestic Waste Equivalent Management, known as JAKSTRANAS. Indonesian President Regulation 97/2017 is a roadmap towards the 2025 Clean-from-Waste Indonesia. The Indonesian government is continually establishing and polishing a model plan to reduce 30% of the country's waste (from the waste source generation) and to process and manage at least 70% of the country's waste to avoid it from accumulating in landfills. This target is aimed to be achieved by the year 2025.

Based on Presidential Regulation 97/2017 the government sets strategies, targets and programs for waste reduction and waste handling. Strategies for reducing domestic waste and domestic waste equivalent include:

1. Preparation of norms, standards, procedures and criteria for reducing waste;
2. Strengthening coordination and cooperation between the central government and local governments;
3. Strengthening the commitment of executive and legislative institutions at the central and local levels in providing waste reduction budgets

4. Increasing leadership, institutional and human resource capacity in efforts to reduce waste;
5. Establishment of an information system;
6. Strengthening community involvement through communication, information and education;
7. Implementation and development of incentive and disincentive systems in waste reduction; And
8. Strengthening the commitment of the private sector through implementing extended producer responsibility (EPR) in reducing waste.

In its implementation, the Deli Serdang Government has issued several Regional Regulations and Regent Regulations regarding waste management, such as:

1. Deli Serdang Regency regulations 4/2021 about Waste Management
2. Deli Serdang Regency regulations 1/2024 about Regional Tax and Regional Retribution (including waste management retribution)
3. Regent regulation of Deli Serdang 429/2016 about The Partial Delegation of Regent's Authority to District Head in Deli Serdang Government (including the implementation of government affairs in the field of waste management)
4. Regent regulation of Deli Serdang 24A/2018 about Deli Serdang Policy and Strategy for Domestic Waste and Domestic Waste Equivalent Management (JAKSTRADA)
5. Regents Circular Letter 660/2773/2019 about The Implementation of 3R Waste Management (Reduce, Reuse, Recycle) in the Government Office
6. Regent Circular Letter 660/1928/2019 about The Obligations to Become a Customer of the Waste Bank.

2.3. Facilities and Infrastructure

On a daily basis, Deli Serdang endeavors to manage its waste disposal operations through a fleet of approximately 74 operational trucks (Table 5.), a modest figure when juxtaposed with the more robust fleet exceeding 200 trucks servicing neighboring Medan City. Within Deli Serdang's fleet, there exists a heterogeneous array of trucks, including dump trucks, container trucks, compactor trucks, and arm-roll trucks, each tailored to specific waste management functions. Despite this multifaceted approach, the current fleet grapples with the formidable challenge of accommodating the increasing volume of waste generated within Deli Serdang's jurisdiction.

To make it easier for the public, the city government provides pedicabs. Around 40 pedicabs are operating. This pedicab has the crucial role of collecting waste from the community, which is far from the communal container.

Table 5. Truck Facilities and Pedicab in Deli Serdang

No.	Sub Dictrict & Agency	Total Population	Total Truck		Truck Condition		Total Pedicab	Pedicab Condition	
			Arm-Roll Truck	Dump Truck	Good	Bad		Good	Bad
1	Environmental Agency	-	1	1	2	-	2	2	-
2	Industry and Commerce Agency	-	7	-	7	-	6	6	-
3	Sunggal	251,588	2	6	8	-	6	6	-
4	Percut Sei Tuan	423,020	8	4	10	2	4	1	3
5	Batang Kuis	68,554	1	1	1	1	2	1	1
6	Lubuk Pakam	91,858	9	-	8	1	11	8	3
7	Pantai Labu	51,578	1	-	1	-	6	1	5
8	Galang	73,583	4	-	4	-	1	-	1
9	Hamparan Perak	169,316	3	-	3	-	2	2	-
10	Deli Tua	61,860	4	-	4	-	-	-	-
11	Tanjung Morawa	235,558	4	2	5	1	4	2	2

12	Sibolangit	20,630	1	-	1	-	2	-	2
13	Labuhan Deli	69,977	2	1	3	-	2	2	-
14	Beringin	63,985	1	1	2	-	4	2	2
15	Pancur Batu	97,064	4	-	3	1	5	4	1
16	Namorambe	41,031	4	-	3	1	-	-	-
17	Patumbak	101,784	2	-	2	-	4	3	1
18	Bangun Purba	25,513	1	-	1	-	-	-	-
19	Pagar Merbau	41,146	1	-	1	-	-	-	-
20	Biru-Biru	40,848	1	-	1	-	-	-	-
21	STM Hilir	34,290	1	-	1	-	-	-	-
22	STM Hulu	14,069	1	-	1	-	-	-	-
23	Gunung Meriah	3,373	1	-	1	-	-	-	-
24	Kutalimbaru	37,539	1	-	1	-	-	-	-
Total		**2,018,164**	**65**	**16**	**74**	**7**	**61**	**40**	**21**

Figure 11. Arm-roll Truck

Figure 12. Compactor Truck

Deli Serdang has two sanitary landfills. Tadukan Raga landfill is located in Sinembah Tanjung Muda Hilir district and Namorube Julu landfill is located in Kutalimbaru district. The landfill location in Deli Serdang Regency can be seen in Figure 13.

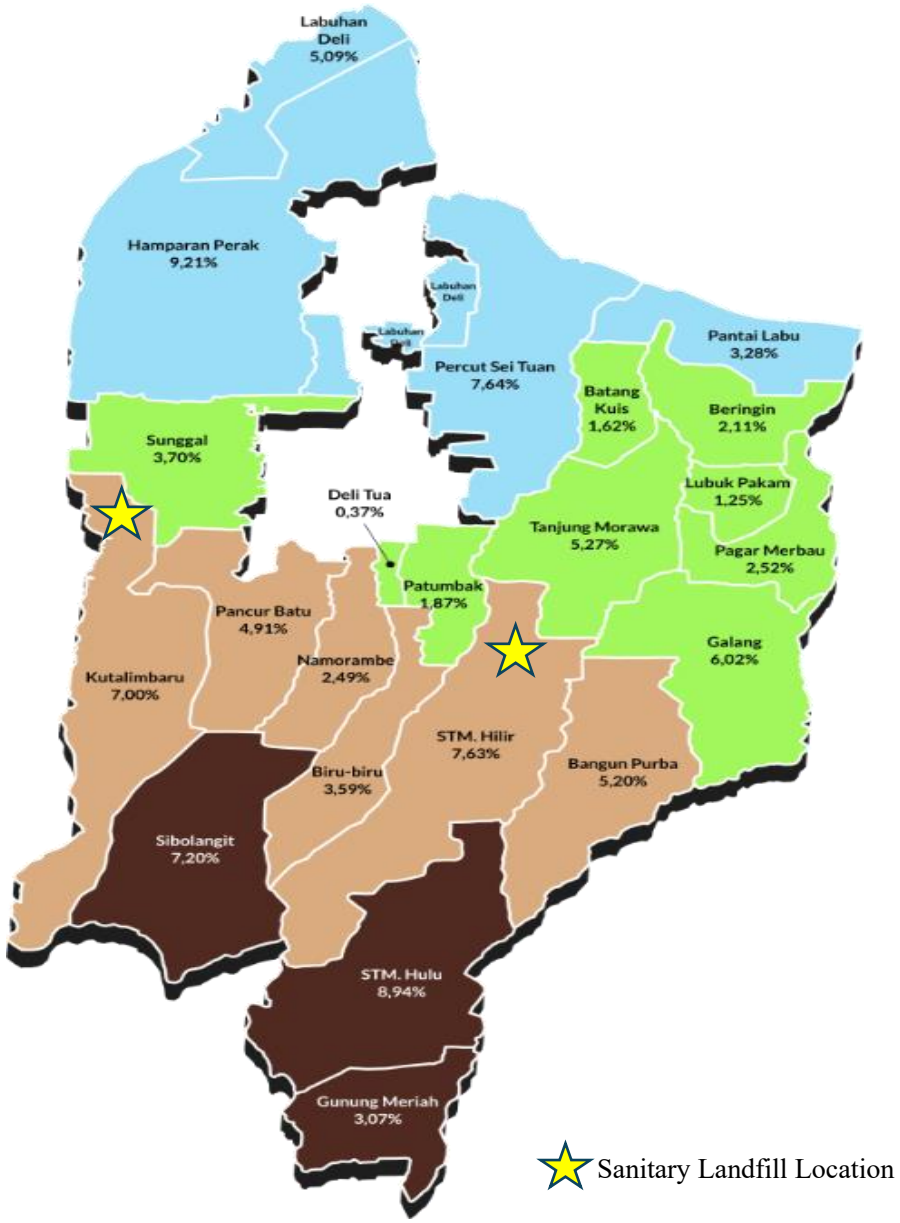


Figure 13. Landfill Location in Deli Serdang Regency

Each landfill in Deli Serdang has a bulldozer, wheel loader and excavator for operational processes. Bulldozers and wheel loaders have the function of pushing, leveling and compacting waste in places where waste storage cells have been established. The waste pile is compacted by grinding it with a bulldozer 8-10 times to obtain an optimum density of 600 -650 kg/m^3. The excavator's function is to dig and pile up the cover material to cover the waste.

Figure 14. Landfill Operational Process Facilities
(a) Wheel Loader (b) Bulldozer (c) Excavator

As the population and economic activities in Deli Serdang grow, the amount of waste produced also increases, resulting in a gradual rise in the amount of space used in landfills in the area day by day. This growing waste load adds pressure to landfill capacity, raising concerns about environmental sustainability and the effectiveness of waste management. This situation is clearly portrayed in Figure 15. and Figure 16., which depicts the changing conditions of the Tadukan Raga and Namorube Julu landfills, respectively.

Deli Serdang's landfill operation and maintenance activities include:

1. Data collection on trucks loaded with waste entering the landfill area
2. Arrangement of garbage truck traffic and at the same time directing it to and from the maneuver area.
3. Dropping waste from trucks in the maneuvering area.
4. Dropping waste from the truck at the bulk site to the landfill by bulldozer.
5. Piling and compacting waste.
6. Cover the compacted waste pile with cover material.

The environmental agency of Deli Serdang regency carries out the management and operation of the landfill in Deli Serdang. The environmental agency is also responsible for dividing active zones in landfill management. The plan for dividing active zones at the Namorube Julu landfill can be seen in Figure 17.

Furthermore, the Environmental Service oversees the stability of landfill slopes as a precautionary measure against potential landslides resulting from instability caused by shear failure or disruption of slope stability. This oversight is facilitated by the Technical Implementation Unit of the Tadukan Raga Landfill Service and the Technical Implementation Unit of the Namorube Julu Landfill Service, which conduct daily monitoring of the wastewater treatment plant (WWTP). The daily monitoring includes the leachate processing process to sustain the stability of

microorganisms in anaerobic tanks, which play a vital role in leachate processing. Additionally, sampling and analysis of river water within 200 meters from the outer boundary of the landfill are periodically conducted every six months, in compliance with relevant regulations.

Figure 15. Condition of Namorube Julu Landfill

Figure 16. Condition of Tadukan Raga Landfill

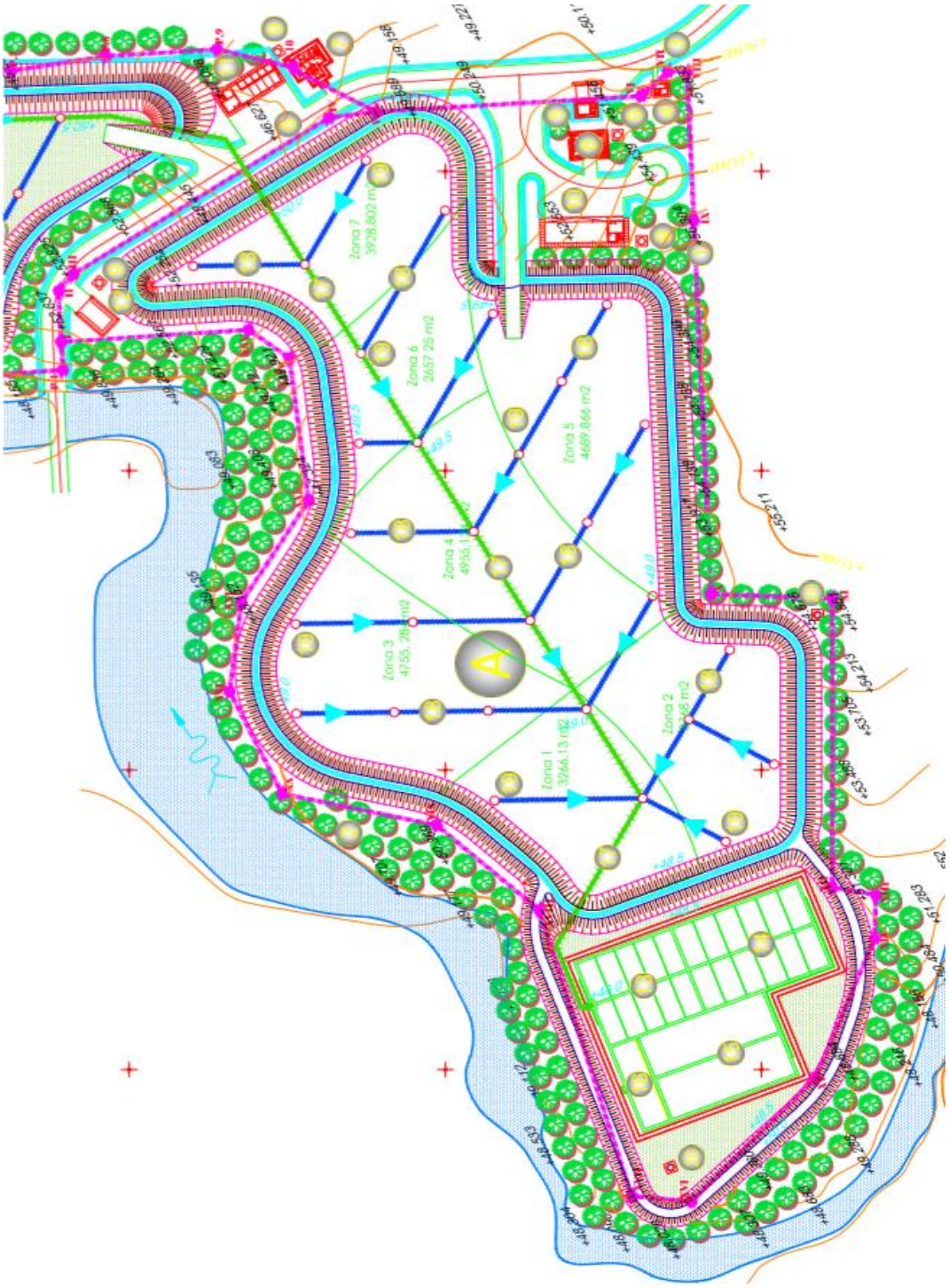


Figure 17. Namorube Julu Landfill Active Zones Plan

2.4. Waste generation

Understanding waste generation and solid waste composition might be deemed critical in planning and developing MSWM strategies (Aleluia, 2016; Jun,2011). Solid waste generation was found to be different because there were different levels of consumption patterns in different locations, respectively indicating that the factors affecting the environmental aspects of solid waste management in developing countries are the lack of environmental control systems and real impact evaluation (Ismaila, 2022) The consequences of excessive waste generation are significant and can adversely affect the environment and human health. Improper municipal solid waste management may result in pollution of land, water, and air, which contributes to climate change, habitat destruction, and disease transmission. Based on SIPSN data, in 2021, waste generation in Deli Serdang Regency reached 408,129.86 tons/year, which is still smaller than Medan city, which has a population of around 2.4 million people. Solid waste generation in the regency area in Indonesia is still smaller than in cities (Figure 18.). That can happen due to several factors: population, rate of consumption, socio-economic, climatic conditions, food habits, lifestyle, economic activities, level of technology, urbanization, culture and tradition, literacy level, local regulations related to waste, usage behavior, and recoverability.

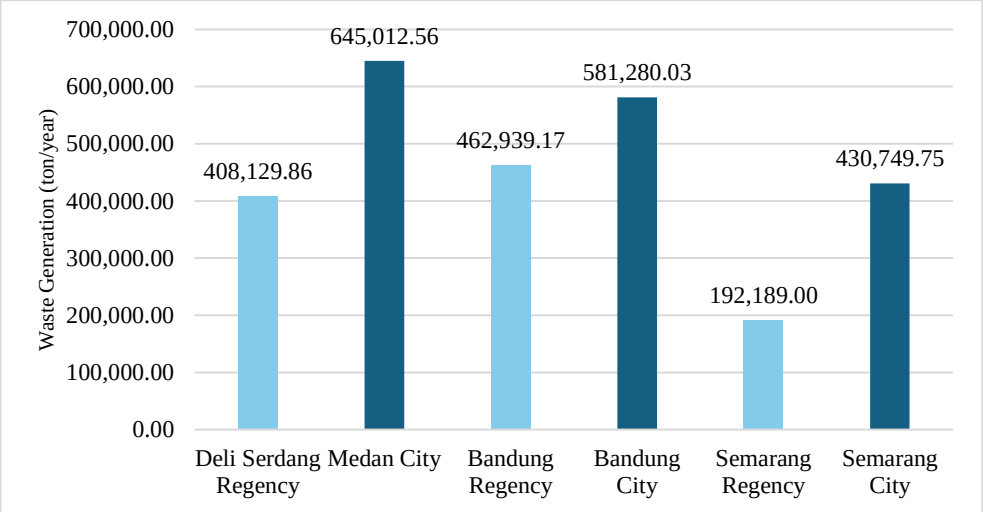


Figure 18. Waste generation regencies vs. cities in Indonesia

2.5. Source of waste

MSW is typically generated from a range of sources where various human activities occur. According to various studies, households generate most of the MSW in developing countries (55-80%), followed by market or commercial sectors (10-30%) (Aliyu, 2010). composed of varied amounts created by industry, roadways, institutions, and several other elements. Data on waste sources can help define the goal of MSWM. Based on SIPSN data 2021, (Figure 19.) shows the proportion of waste sources in Deli Serdang Regency and Medan city. The sources of waste varied slightly between the regency area and the city area. Households are the largest waste generators in Deli Serdang regency and Medan city at 43%, and differences can be seen from other sources, such as the market. Traditional markets in regency areas generate more waste than those in city areas because traditional markets are frequented in city areas, and residents in city areas prefer to visit supermarkets and contemporary marketplaces. A similar effect is found for offices in cities that create a higher proportion of solid waste than offices in regencies. Due to the number and complexity of operations in city commercial areas, city commercial areas create a greater percentage of MSW than regency commercial areas.

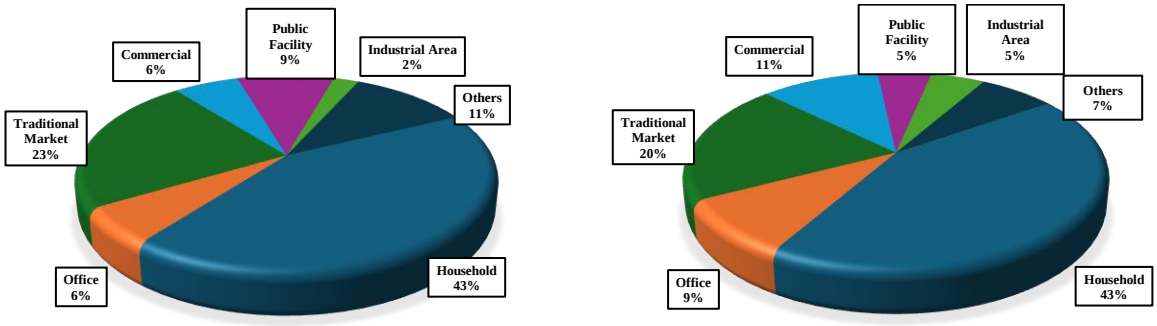


Figure 19. MSW sources in Deli Serdang (a) and Medan (b)

2.6. Waste composition

Waste composition information is critical for MSWM planning and decision-making (Saidan et al.,2017). (Figure 20.) shows the differences in the composition of solid waste in regency and city areas. The fundamental difference in waste composition between regencies and cities is the percentage of food waste. City areas produce more food waste because consumption patterns and lifestyles differ from those of regency areas. In Deli Serdang, a lot of food waste is still processed back into compost and used as animal feed by most of the population working as farmers and ranchers. Hence, the food waste composition in Deli Serdang regency is less than in Medan city.

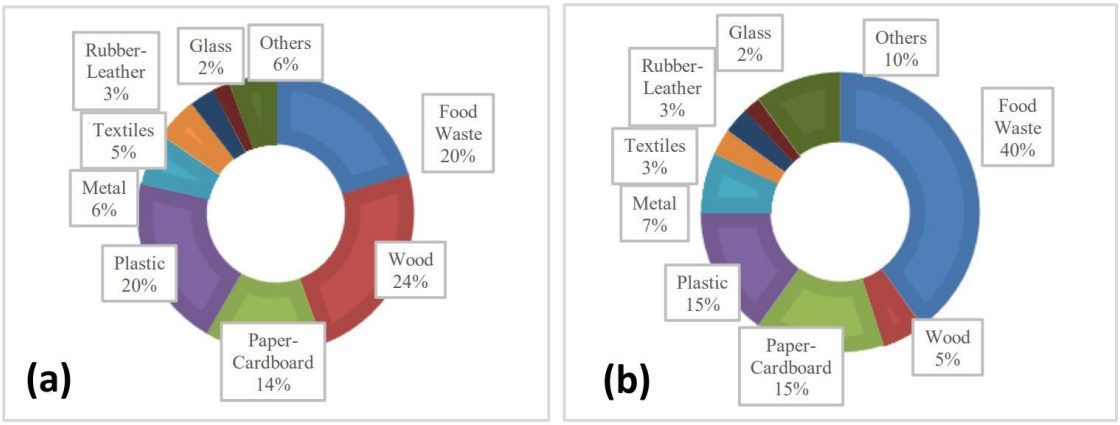


Figure 20. MSW composition in Deli Serdang (a) and Medan (b)

2.7. Waste collection and transportation system

Previous research found that improper waste collection systems, bad route design, a lack of knowledge regarding collection schedules, inadequate infrastructure, poor roads, and a lack of waste collection facilities all had an impact on waste collection and transportation practices (Vallakonda et al., 2016, Mohee et al., 2015, Pitchayanin, 2016). In general, Indonesia's waste collection and transport systems are quite similar. The frequency of transfers and the size and type of trucks are determined by the amount of waste generated and the local government's financial resources.

MSWM in Deli Serdang is managed by the local government. At the source, there are no distinct types of MSW separated, they are all put into a bag and dumped in solid waste facilities. MSWs are collected every day in all Deli Serdang regency areas. In Medan city, those responsible for waste collection and transportation are the Cleanliness and Gardening Agency, different from Deli Serdang Regency. In Deli Serdang, the head of districts (*Camat*) is responsible for waste collection and transporting from household to the landfill. That was done because Deli Serdang has a very wide area, so the placement of truck depots at each district office is considered more efficient for transporting waste from households to landfills.

Waste management in Deli Serdang Regency is meticulously organized, with a clear division of responsibilities among various regional work units as outlined in Deli Serdang Regency Regional Regulation 3/2016 about the Formation and Structure of Regional Apparatus. District plays a pivotal role in the collection and transportation of waste from households and other sources to designated disposal sites. Additionally, districts are tasked with collecting waste fees, ensuring the sustainable financing of waste management efforts. The final stage of waste processing is overseen by the Deli Serdang Environmental Agency, which manages the operational and maintenance processes of landfills.

In Deli Serdang, MSW is collected by door-to-door trucking service, as shown in (Figure 21.), from households directly to the landfill; from households transported to the communal container and then transported to the landfill; and from households transported to TPS3R then the residual waste is transported to the landfill

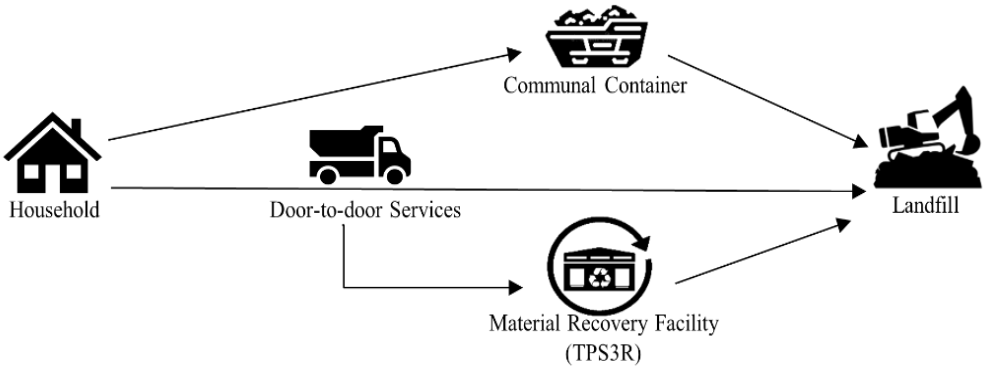


Figure 21. Waste collection and transportation system in Deli Serdang Regency

2.8. Waste management cost and budget

Waste management costs encompass a broad spectrum of expenses associated with the collection, transportation, processing, and disposal of waste materials. The funding and financing aspects of waste management are considered to have an important role in ensuring the implementation of the planned waste management system.

The 2020-2024 National Medium Term Development Plan (RPJMN) of Indonesia has included environmental issues which include waste management as a national priority. The inclusion of waste management matters in the RPJMN marks a significant step towards elevating its status to a national priority in Indonesia. Historically, waste management was often considered a mainstream issue rather than a focal point of national development strategies. However, despite its newfound prioritization in the RPJMN, there remains a critical gap between policy objectives and budget allocations. The budget earmarked for waste management has not seen a proportional increase commensurate with its elevated status, posing a challenge to effectively implement comprehensive waste management solutions nationwide. This discrepancy underscores the need for greater financial commitment and strategic allocation of resources to address the complex challenges of waste management in Indonesia.

The budget required for waste management is very large while the government budget availability is still low. On average, regency and city governments in Indonesia spend only 0.7% of their Local Government Budgets Fund (APBD) budget on waste management: city governments allocate around 2% of APBD, while regency governments allocate only 0.4% (Fitra dan Systemiq, 2019).

In Indonesia, the allocation of local government budget funds reveals a significant challenge for prioritizing waste management amidst competing financial demands. Approximately 80% of APBD is typically allocated for personnel expenditures and essential services such as economy, education, infrastructure, health, and population management. These allocations are crucial for maintaining basic governmental functions and public services. However, this leaves only 20% of the budget to cover a diverse array of 33 other matters, including waste management.

According to (Kompas Research and Development, 2022) the ratio of waste management costs and local government budget funds in Deli Serdang Regency is only 1.3%, as shown in Table 6.

Table 6. Proportion of Waste Management Budgeting in Indonesia

City/Regency	Waste Management Cost (Rp. Billion)	Local Government Budgets Fund (APBD)	Ratio Waste Management Cost and Local Government Budgets Fund
Surabaya City	368	8,111	4.5%
Tangerang City	109	3,648	3.0%
DKI Jakarta	1,400	57,136	2.5%
Semarang City	117	5,093	2.3%
Bandung City	121	7,117	1.7%
Palembang City	52	4,164	1.2%
Cirebon Regency	66	3,579	1.9%
Deli Serdang Regency	***42***	***3,335***	***1.3%***
Pandeglang Regency	12	1,677	0.8%
Sumenep Regency	17	2,407	0.7%

Sources: Litbang Kompas, 2022

2.9. Waste management problems in Deli Serdang

MSWM in Indonesia is increasingly complex for various reasons. The quantity of MSW is expected to increase substantially due to an increasing population and rapid urbanization. There are still many municipalities that do not have their own landfill, this generally occurs in cities due to the unavailability of land. Developing a phased technical and legal framework for waste management is necessary as a first step in addressing MSWM issues. In addition to implementing MSWM policies, a legal framework is also required. Many studies try to document how an adequate legal framework positively contributes to the development of an integrated municipal solid waste management system. A well-defined legal framework can aid effective implementation. The legal framework should also include an effective law enforcement system.

In general, the coverage of services provided by municipalities in Indonesia is insufficient, notably in low-income and/or slum neighborhoods with limited roadways or in remote suburban areas (Wibisono et al., 2020) Deli Serdang has a very wide area, which makes the efficiency of waste collection and waste transportation must be a top priority for the Deli Serdang government in carrying out MSWM. The efficiency of waste collection and transportation must be improved by increasing the coverage of collection areas (Graeme et.al., 2015), and cost-effective transportation with a scheduled collection system (Raharjo et al., 2017). Increasing the coverage of the collection area can reduce the amount of waste disposed of improperly, such as illegal dumping and open waste burning.

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Chapter 3 Uncovering Illegal Waste Disposal Sites: Engaging Communities in Investigative Solutions

3.1. Introduction

Globally, approximately two billion individuals lack access to proper waste management services. In developing countries, the challenge is evident, with urban areas only managing to collect 48% of waste, while rural areas fare even worse, with a mere 26% of waste being collected (Kaza et al., 2018). Inadequate solid waste management (SWM) infrastructure, such as insufficient waste collection centers and waste transportation systems, coupled with low collection efficiency, compel households to resort to illegal dumping of their daily generated waste on city streets and in open spaces (Fariz et al., 2023). Illegal dumping, also known as fly-tipping, fly-dumping, or indiscriminate waste disposal, refers to the unauthorized and unlawful act of discarding waste. This activity involves disposing of waste materials in locations not designated or approved for waste disposal, such as public areas, open spaces, or natural environments (D'Amato et al., 2018).

Over the past decades, illegal waste disposal sites (IWDS) have become a chronic and severe environmental concern worldwide (Niyobuhungiro & Schenck, 2022). IWDS is an ongoing, costly waste management problem to control and solve. IWDS usually manifests inadequate waste management systems, suggesting inefficiency, but it is not excluded within well-managed waste management systems.

IWDS has resulted in significant contamination of soil and groundwater, with potentially severe environmental and public health consequences (Baird et al., 2014; Bartkowiak et al., 2016; Triassi et al., 2015; Vaverková et al., 2019). However, the true extent of these impacts is often underestimated, as highlighted by (Ramadan et al., 2022) chain of custody records typically commence at the point of waste collection or landfill. However, in cases where waste is disposed of informally or

illegally, such as through dumping or burning, there is a notable absence of records documenting its existence. This lack of documentation poses significant challenges in tracking and managing waste streams effectively, as it hinders efforts to monitor and regulate the disposal process (Fariz et al., 2024). Additionally, the absence of a comprehensive chain of custody for illegally disposed waste undermines accountability and may exacerbate environmental and public health risks associated with improper waste disposal practices.

Removal of IWDS bears a cost and makes it necessary to carry out remediation (Ishii et al., 2013). Although efforts have been made to clean up contaminated sites to mitigate their impact on the surrounding environment, the post-remediation land use of these sites has yet to be thoroughly examined (Ishii et al., 2013). As an example, (Ichinose & Yamamoto, 2011) highlights data from the Environment Agency of the UK, which suggests that the annual cost of clearing up IWDS ranges between GBP 100 million and GBP 150 million. This substantial financial expenditure underscores the significant economic burden associated with managing IWDS and emphasizes the importance of implementing effective measures to address IWDS practices.

Research on IWDS has been conducted extensively in both developing (Khumalo et al., 2021; Nagpure, 2019; Niyobuhungiro & Schenck, 2021) and developed countries (Du et al., 2023; Hidalgo et al., 2019; Karimi & Ng, 2022; Kubasek & Hrebicek, 2013; Quesada-Ruiz et al., 2019; Tasaki et al., 2007). Previous studies have identified various factors that influence the emergence of IWDS. These factors include the availability and accessibility of waste disposal facilities (Fariz et al., 2023), population density (Syafrudin et al., 2023), levels of poverty (Matsumoto & Takeuchi, 2011), surveillance and enforcement of waste management regulations (Tasaki et al., 2007), and disposal fees (Ichinose & Yamamoto, 2011).

Numerous researchers have endeavored to devise and implement diverse methodologies for monitoring (Tasaki et al., 2007), mapping (Glanville & Chang, 2015a; Karimi & Ng, 2022), and identifying locations (Seror & Portnov, 2018) of IWDS using remote sensing technologies. However, the results have often yielded potential locations rather than pinpointing the precise IWDS locations with optimal accuracy (Glanville & Chang, 2015b). Despite employing sophisticated remote sensing techniques, such as satellite imagery (Jakiel et al., 2019; Khumalo et al., 2021) and geographic information systems (GIS) (Biotto et al., 2009), challenges persist in accurately identifying IWDS due to factors like limited resolution, complex terrain, and the clandestine nature of IWDS or illegal dumping activities (Glanville & Chang, 2015b). Consequently, further refinement and integration with ground-based investigations are needed to enhance the effectiveness of IWDS detection and management strategies.

(Nagpure, 2019) have conducted field investigations to locate IWDS. However, there is a gap in studies that cover the entire study area and involve community participation in identifying IWDS locations. Community involvement is crucial in identifying IWDS issues, as local knowledge can provide valuable insights into the location and extent of illegal dumping activities (Schenck et al., 2022; Tompson & Chainey, 2011). Achieving a thorough understanding of IWDS issues requires collaboration and engagement from all stakeholders, including community members, government agencies, and researchers. Integrating community participation can enhance the accuracy of site identification and inform targeted interventions to address the problem effectively

IWDS poses various risks for governments, highlighting the need for cost-effective and efficient monitoring and mapping solutions to enhance management outcomes (Fujikura, 2011; Šedová, 2016). Addressing a gap in the current study, this research method aimed to precisely locate, quantify, and determine the extent of IWDS at the

city scale while also involving the community in the investigation process. The current study also aims to gain insight into the characteristics and surroundings of IWDS, including their relationship with land use patterns in the surroundings. This approach will facilitate a better understanding of IWDS dynamics and inform the evaluation of waste management effectiveness. Additionally, it will enable the design of targeted policies to mitigate IWDS practices and address environmental inequality.

3.2. Materials and Methods

The research was conducted over eight months, spanning from March 2023 to November 2023, within the Deli Serdang Regency. Deli Serdang is designated as one of the National Strategic Areas as per Indonesia Presidential Regulation 62/2011. Situated along the eastern coast of Sumatra, it encompasses an area of approximately 2,497.72 sq.km or 249,772 hectares, comprising 22 districts and 394 villages. (Figure 22.) shows the map of Deli Serdang Regency. According to data from the Deli Serdang Central Bureau of Statistics, the population of Deli Serdang in 2023 was 1,941,374 individuals, with 983,675 men and 970,311 women residing in the area. This population was distributed across 453,533 households, with an average of approximately four individuals per household.

The research integrates four methodologies to engage community participation: interviews, focus group discussions (FGDs), whistleblower reports, and transect walks. These interconnected methods collectively lead to the identification of IWDS.

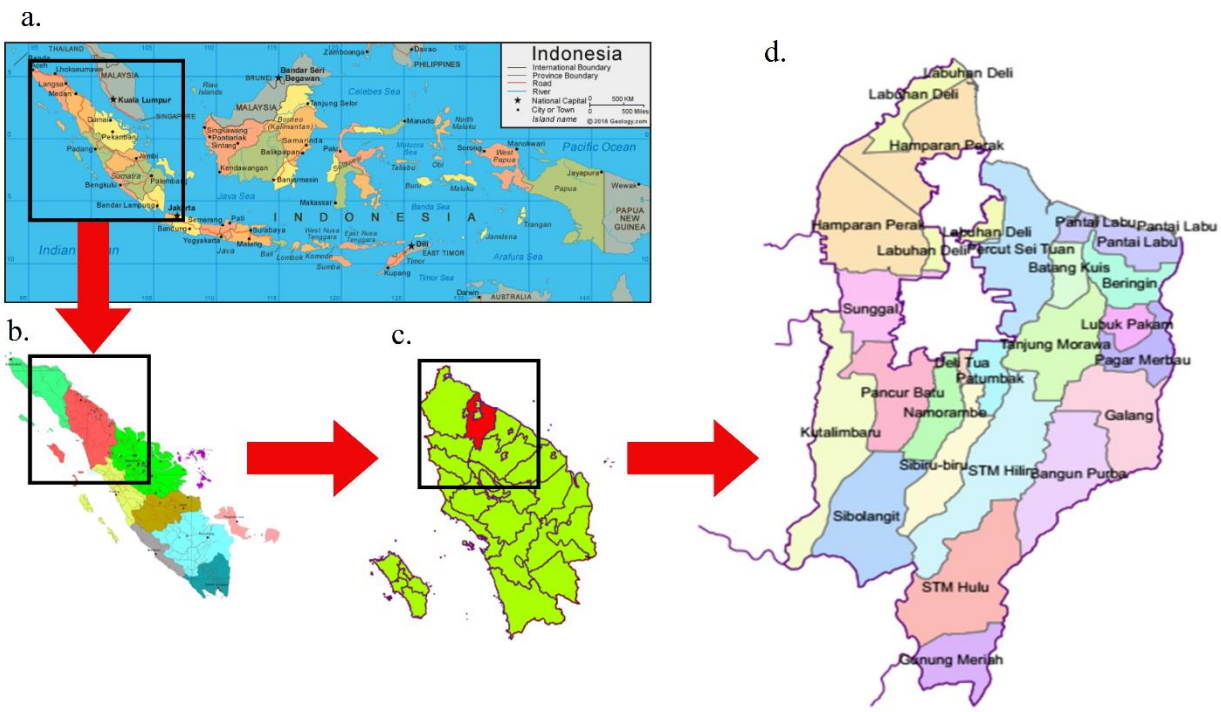

Figure 22. The map of study area: (a) Indonesia, (b) Sumatera Island, (c) North Sumatera, (d) Deli Serdang Regency

3.2.1. Interview

In the current study, direct interviews were conducted using open-ended questions. Direct interviews, also known as personal interviews or face-to-face interviews, are a method of collecting primary data in which the researcher interacts directly with the respondent to gather information (Taherdoost, 2022; Utibe Monday, 2020). In the current study, direct interviews were conducted with stakeholders related to waste management problems in the Deli Serdang Regency, such as environmental agencies, district governments, waste management personnel, environmental activists, academics and the community.

Direct interviews with the community were conducted using the open-ended question method to elicit elaborate and descriptive answers from the interviewees (Haddock & Zanna, 1998; Hansen & Świderska, 2023). This method aims to uncover the interviewee's perspectives, experiences, and opinions, providing rich and nuanced data for analysis. In conducting this direct interview, the researcher typically begins with a general question or topic and allows the conversation to flow naturally. Follow-up questions are based on the interviewee's responses, allowing for further exploration and clarification of key points. This methodology allowed the researcher to comprehensively explore the interviewees' thoughts, emotions, and experiences, resulting in a deeper comprehension of the subject matter.

Figure 23. Direct Interview to the Community

Figure 24. Direct Interview to the Central, Provincial and Local Government

3.2.2. Focus Group Discussion

FGDs is also carried out in the current study. This method where a group of participants convene to discuss a specific topic or issue in a structured yet interactive setting through group interaction and dialogue (Aitsidou et al., 2024; Basnet, 2018). This FGDs was carried out at community associations and the village office. In the FGDs, participants from various backgrounds were gathered to discuss openly the issue of illegal waste dumping. This discussion facilitates the exchange of ideas, experiences and views from various parties involved, thereby helping to understand the problem holistically.

Figure 25. Focus Group Discussion in the Community

3.2.3. Whistleblower

This method is a new method developed by researchers to reveal the problem of IWDS. IWDS is a susceptible issue, so a method is needed that allows individuals and the community to report this matter without feeling afraid or intimidated. The whistleblower mechanism provides an opportunity for individuals and communities who have sensitive or confidential information about IWDS to share this information anonymously (Vandekerckhove & Phillips, 2019). This method helps uncover insights that may not be revealed through standard methods (Mesmer-Magnus & Viswesvaran, 2005; Park et al., 2008).

When conducting direct interviews and FGDs, researchers also carried out awareness campaigns to educate the community about the importance of reporting IWDS activities and the protections available to whistleblowers and create a hotline where individuals and the community can report information about suspected IWDS without fear of retaliation. Researchers ensure strict confidentiality and protection for whistleblowers to encourage them to come forward with information. This collaborative approach empowers individuals and the community to play an active role in protecting the environment and upholding the rule of law.

3.2.4. Transect Walk

In the current study researchers also carried out individual investigations using the transect walk method frequently called the distance sampling approach. The transect walk method, as employed by (Nagpure et al., 2015) was adapted to assess the incidence of IWDS in various neighborhoods of Deli Serdang, Indonesia. In this approach, researchers systematically traversed predetermined transect routes, like streets or roads within the city, and recorded instances of IWDS observed along these routes (Das et al., 2018; Nagpure et al., 2015; Ramaswami et al., 2016). During the transect walk, researchers meticulously documented each occurrence of IWDS visible

within the proximity of the street or road (Das et al., 2018). This method involved visually inspecting both the immediate roadside areas and nearby open spaces (Ramaswami et al., 2016). Data collection was conducted in a consistent and standardized manner to ensure accurate recording of the location, extent, and characteristics of the dumped waste piles encountered along the transect routes. By using the transect walk method, researchers were able to survey different neighborhoods of Deli Serdang systematically. This approach facilitated the collection of spatially explicit data on the distribution and magnitude of the problem, thereby informing efforts to address and mitigate the environmental and public health impacts associated with IWDS.

3.3. Results and Discussion

3.3.1. IWDS Per Unit Area

From the investigation conducted across all areas of Deli Serdang, a total of 120 IWDS with a total area 164,194.87 sq.m were found (Table 7.). However, these sites were not evenly distributed across all districts within Deli Serdang. These sites were spread out among only 12 out of the 22 districts in Deli Serdang (Table 8.). This result suggests that IWDS activities are more concentrated in certain districts compared to others (Ballatore et al., 2022). Identifying these districts with higher incidences of IWDS can aid in the allocation of resources and implementation of targeted interventions to address the issue effectively (Joo & Kwon, 2015; Kim et al., 2008).

Table 7. Illegal Waste Disposal Sites Area from Community Engagement and Ground-Based Individual Investigation

IWDS	Area (sq.m)	Data Sources	IWDS	Area (sq.m)	Data Sources	IWDS	Area (sq.m)	Data Sources	IWDS	Area (sq.m)	Data Sources
1	2,509.08	Interview, FGDs	**31**	1,899.41	Whistleblower	**61**	299.01	Transect Walk	**91**	4,467.95	Interview
2	6,778.10	Interview, FGDs, Whistleblower	**32**	2,079.04	Interview	**62**	1,578.61	Transect Walk	**92**	2,259.81	Interview, Whistleblower
3	1,227.26	Interview, FGDs, Whistleblower	**33**	11,792.81	Interview, FGDs	**63**	166.06	Transect Walk	**93**	820.86	Interview, Whistleblower
4	5,377.80	Interview, FGDs	**34**	1,333.90	Interview, FGDs	**64**	3,189.64	Transect Walk	**94**	509.65	Interview
5	2,516.62	Interview, FGDs Whistleblower	**35**	2,187.41	Transect Walk	**65**	1,258.99	Transect Walk	**95**	721.18	Interview
6	4,779.40	Interview, FGDs	**36**	98.95	Transect Walk	**66**	50.81	Transect Walk	**96**	149.41	Transect Walk
7	5,831.67	Interview, FGDs, Whistleblower	**37**	5,718.60	Transect Walk	**67**	115.62	Transect Walk	**97**	138.46	Transect Walk
8	82.85	FGDs	**38**	237.23	Transect Walk	**68**	31.71	Transect Walk	**98**	296.04	Transect Walk
9	20.40	FGDs	**39**	720.83	Transect Walk	**69**	66.61	Transect Walk	**99**	53.49	Transect Walk
10	70.93	Interview	**40**	1,294.94	Whistleblower	**70**	123.28	Transect Walk	**100**	161.32	Transect Walk
11	47.49	Interview	**41**	104.85	Whistleblower	**71**	38.80	Transect Walk	**101**	2,213.22	Transect Walk
12	1,083.91	Interview, Whistleblower	**42**	3,307.61	Interview, FGDs	**72**	59.51	Transect Walk	**102**	44.62	Transect Walk
13	30.83	Interview	**43**	3,904.19	Whistleblower	**73**	254.60	Transect Walk	**103**	21.41	Transect Walk
14	468.06	Interview, Whistleblower	**44**	3,104.42	Whistleblower	**74**	472.79	Transect Walk	**104**	12.51	Transect Walk
15	430.40	Whistleblower	**45**	399.97	Interview	**75**	1,203.40	Transect Walk	**105**	351.01	Transect Walk
16	1,783.14	FGDs	**46**	637.92	Interview	**76**	94.29	Transect Walk	**106**	151.22	Transect Walk
17	4,441.27	Whistleblower	**47**	597.17	Interview	**77**	160.06	Transect Walk	**107**	67.87	Transect Walk
18	650.04	Transect Walk	**48**	331.76	Transect Walk	**78**	46.80	Transect Walk	**108**	372.65	Transect Walk
19	675.16	Transect Walk	**49**	703.52	Transect Walk	**79**	41.62	Transect Walk	**109**	127.71	Transect Walk
20	466.67	Transect Walk	**50**	2,858.81	Transect Walk	**80**	197.26	Transect Walk	**110**	320.06	Transect Walk
21	507.73	Transect Walk	**51**	131.51	Transect Walk	**81**	87.84	Transect Walk	**111**	732.88	Transect Walk
22	468.07	Interview	**52**	1,599.62	Transect Walk	**82**	853.28	Interview, Whistleblower	**112**	511.90	Transect Walk
23	834.43	Whistleblower	**53**	308.53	Transect Walk	**83**	1,291.02	Interview, Whistleblower	**113**	617.42	Transect Walk
24	634.72	Interview	**54**	1,378.74	Transect Walk	**84**	859.16	Transect Walk	**114**	411.29	Transect Walk
25	2,960.89	Interview, Whistleblower	**55**	644.57	Transect Walk	**85**	1,008.98	Transect Walk	**115**	277.56	Transect Walk
26	3,158.90	Whistleblower	**56**	6,511.88	Transect Walk	**86**	224.87	Transect Walk	**116**	60.09	Transect Walk
27	426.02	Whistleblower	**57**	95.51	Transect Walk	**87**	193.67	Transect Walk	**117**	3,323.55	Transect Walk
28	3,817.24	Whistleblower	**58**	1,309.33	Transect Walk	**88**	247.16	Transect Walk	**118**	456.42	Transect Walk
29	1,539.83	Whistleblower	**59**	96.00	Transect Walk	**89**	101.63	Transect Walk	**119**	595.70	Transect Walk
30	1,143.40	Whistleblower	**60**	47.51	Transect Walk	**90**	19,296.20	Transect Walk	**120**	136.06	Transect Walk

Table 8. Illegal Waste Disposal Sites Area in each District in 2023

DISTRICT	IWDS Amount	AREA (sq.m)
Biru-Biru	1	820.86
Delitua	2	3,639.37
Hamparan Perak	4	25,372.49
Labuhan Deli	12	7,164.31
Namorambe	1	2,858.81
Pagar Merbau	1	166.06
Pancurbatu	7	13,898.40
Patumbak	10	11,705.04
Percut Sei Tuan	56	55,896.52
Senembah Tanjung Muda Hilir	2	1,309.80
Sunggal	10	25,028.35
Tanjung Morawa	14	16,334.85
TOTAL	**120**	**164,194.87**

The results also show that in the Percut Sei Tuan district, the most IWDS were found at 56 locations with a total area of 55,896.52 sq.m (Figure 26.), followed by the Tanjung Morawa district with 14 locations with a total area of 16,334.85 sq.m and the Labuhan Deli district with 12 locations with a total area of 7,164.31 sq.m. However, in the Hamparan Perak district, the largest IWDS location was found at 19,296.20 sq.m (Figure 27.) and in the Sunggal district, the second largest IWDS area of 11,792.81 sq.m was found (Figure 28.).

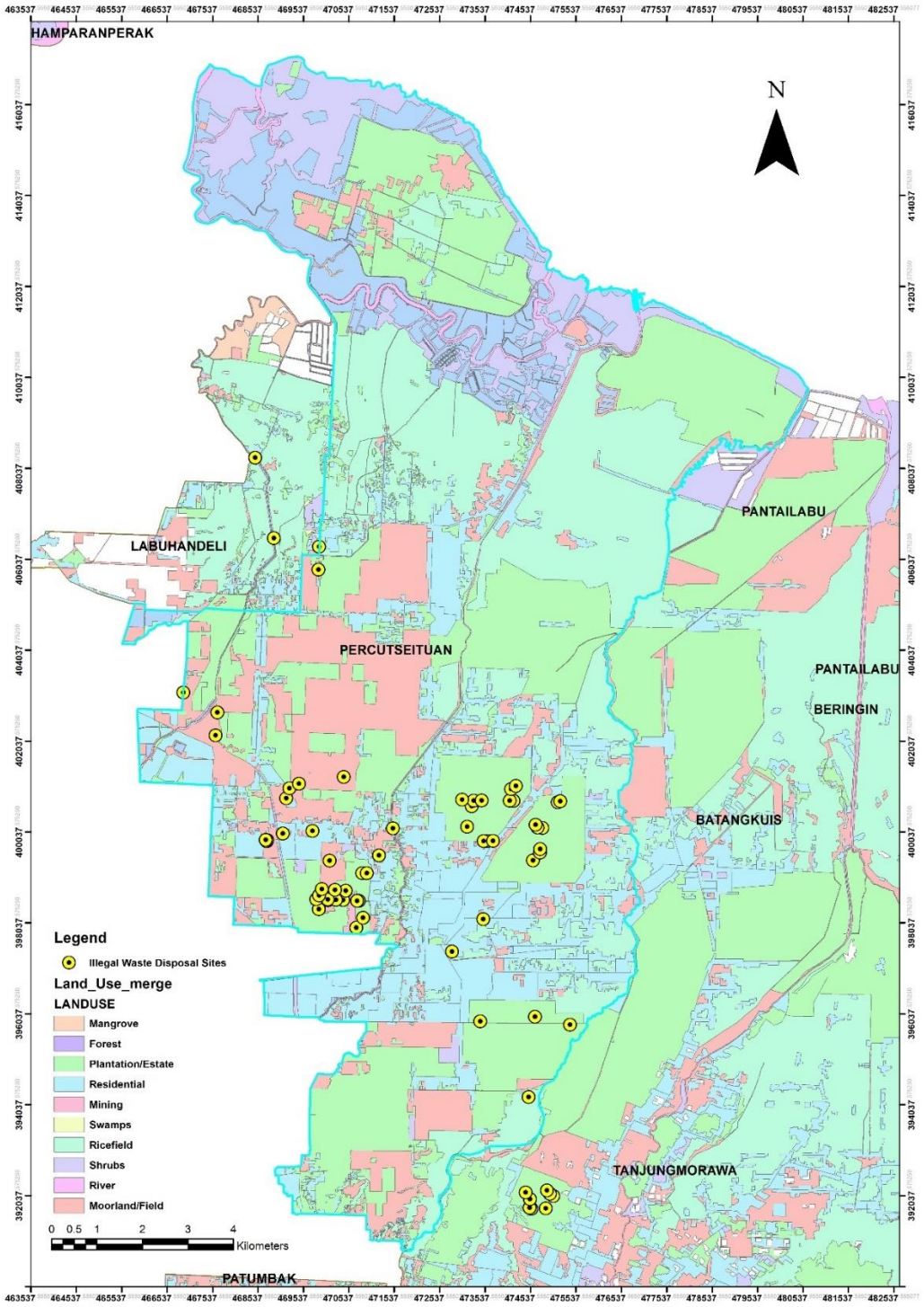

Figure 26. Illegal Waste Disposal Sites at Percut Sei Tuan District

Figure 27. The Largest Illegal Waste Disposal Sites

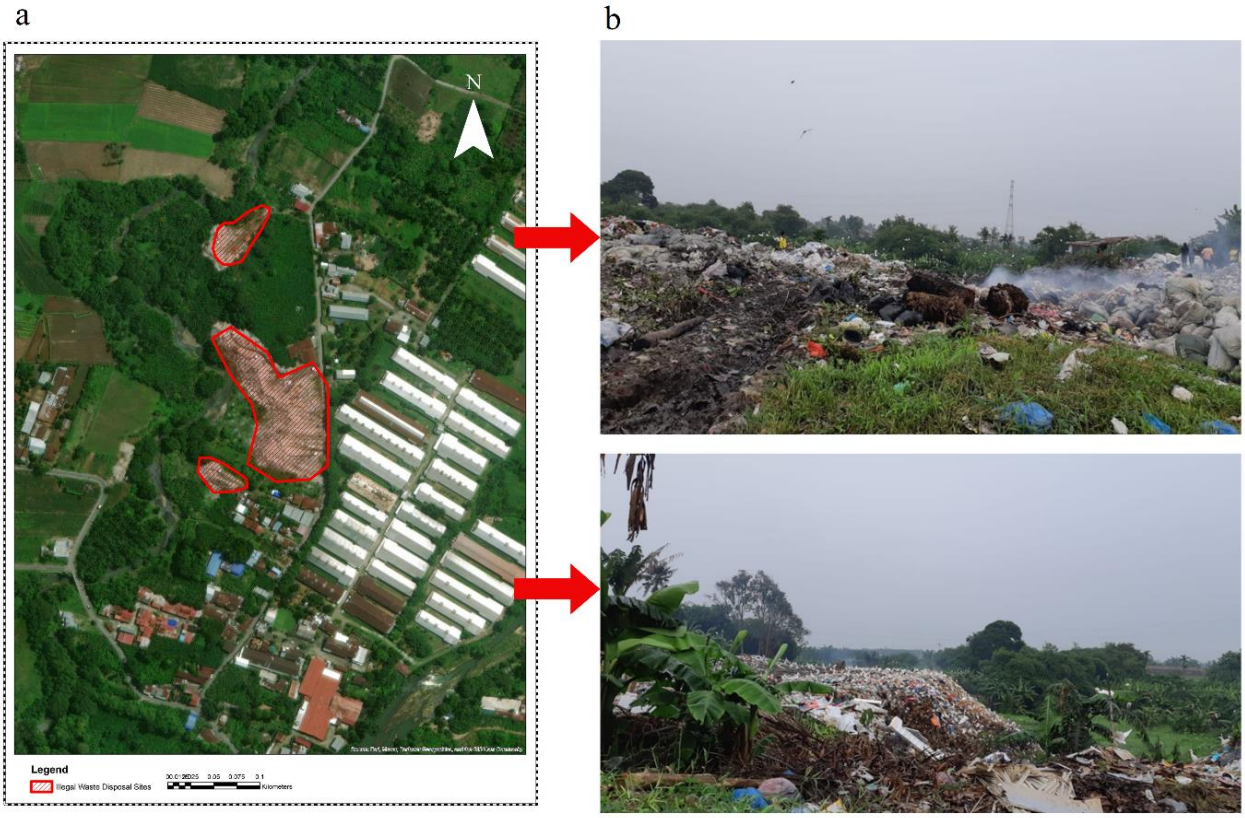

Figure 28. (a) Second Largest IWDS Location (b) IWDS field conditions

The research results show that the characteristics of IWDS in Deli Serdang can be divided into 3 cluster categories: 1) Low Incidence Small Area Affected, 2) Moderate Incidence Moderate Area Affected, 3) High Incidence Large Area Affected (Figure 29.).

1) Low Incidence, Small Area Affected

   Biru-Biru, Namorambe, Pagar Merbau, Senembah Tanjung Muda Hilir.

   These districts have a low number of IWDS and a relatively small total affected area (less than 10,000 sq.m). IWDS is sporadic or localized in these areas.

2) Moderate Incidence, Moderate Area Affected

   Delitua, Labuhan Deli, Patumbak, Sunggal

These districts show a moderate number of IWDS and a moderate total affected area (between 7,000 and 25,000 sq.m). IWDS appears to be more prevalent compared to Cluster 1, but the impact is less extensive than in Cluster 3.

3) High Incidence, Large Area Affected

Hamparan Perak, Pancurbatu, Percut Sei Tuan, Tanjung Morawa

These districts have a high number of IWDS and a large total affected area (over 13,000 sq.m). The widespread presence of IWDS has a significant environmental impact in these areas.

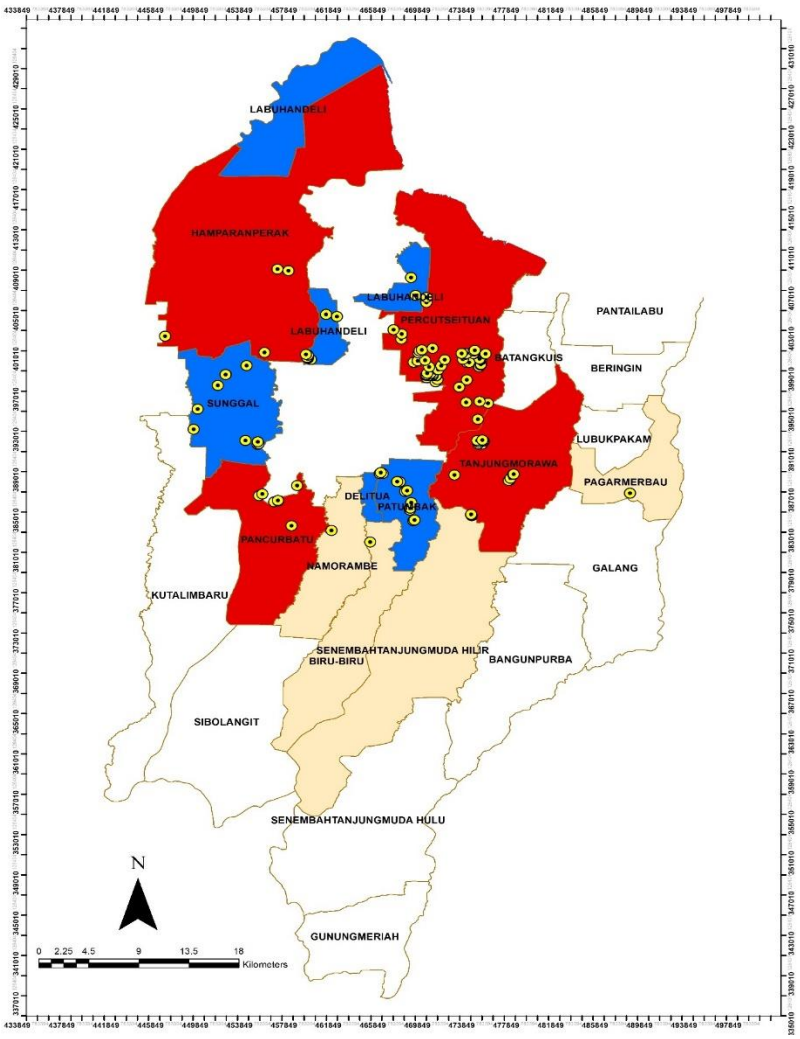

Figure 29. The Map of Illegal Waste Disposal Sites Cluster

3.3.2. IWDS Based on Land Use

IWDS in Deli Serdang is found in 5 land use categories (Figure 30.). Majority of IWDS are found in plantation/estate areas 75 locations 141,527.84 sq.m (62,5%), moorland/field area 21 locations 12,637.16 sq.m (17,5%), residential area 14 locations 4,630.97 sq.m (11,68%), ricefield area 5 locations 4,313.94 sq.m (4,16%) and shrubs area 5 locations 1,384.62 sq.m (4,16%) (Figure 31.).

This statistical shed light on the distinctive characteristics of IWDS in Deli Serdang that 80% of illegal waste disposal sites (IWDS) were identified within plantation/estate and moorland/field areas. The defining characteristics of IWDS in Deli Serdang reveal a complex landscape of concealment, invisibility, and distance from main thoroughfares, all contributing to the formidable challenge of their detection. These sites are strategically positioned in hidden areas, shielded from casual observation, and often tucked away in remote locales, far removed from the visibility afforded by bustling roadways (Faria et al., 2023; Jordá-Borrell et al., 2014; Seror & Portnov, 2018). Such deliberate placement underscores the clandestine nature of these operations, making them exceedingly difficult for authorities and environmental agencies to identify and address effectively (Matos et al., 2012; Quesada-Ruiz et al., 2019; Tasaki et al., 2007). This intricate interplay of geographic seclusion and covert placement underscores the gravity of the issue, necessitating comprehensive strategies and heightened vigilance in combating illegal waste disposal practices.

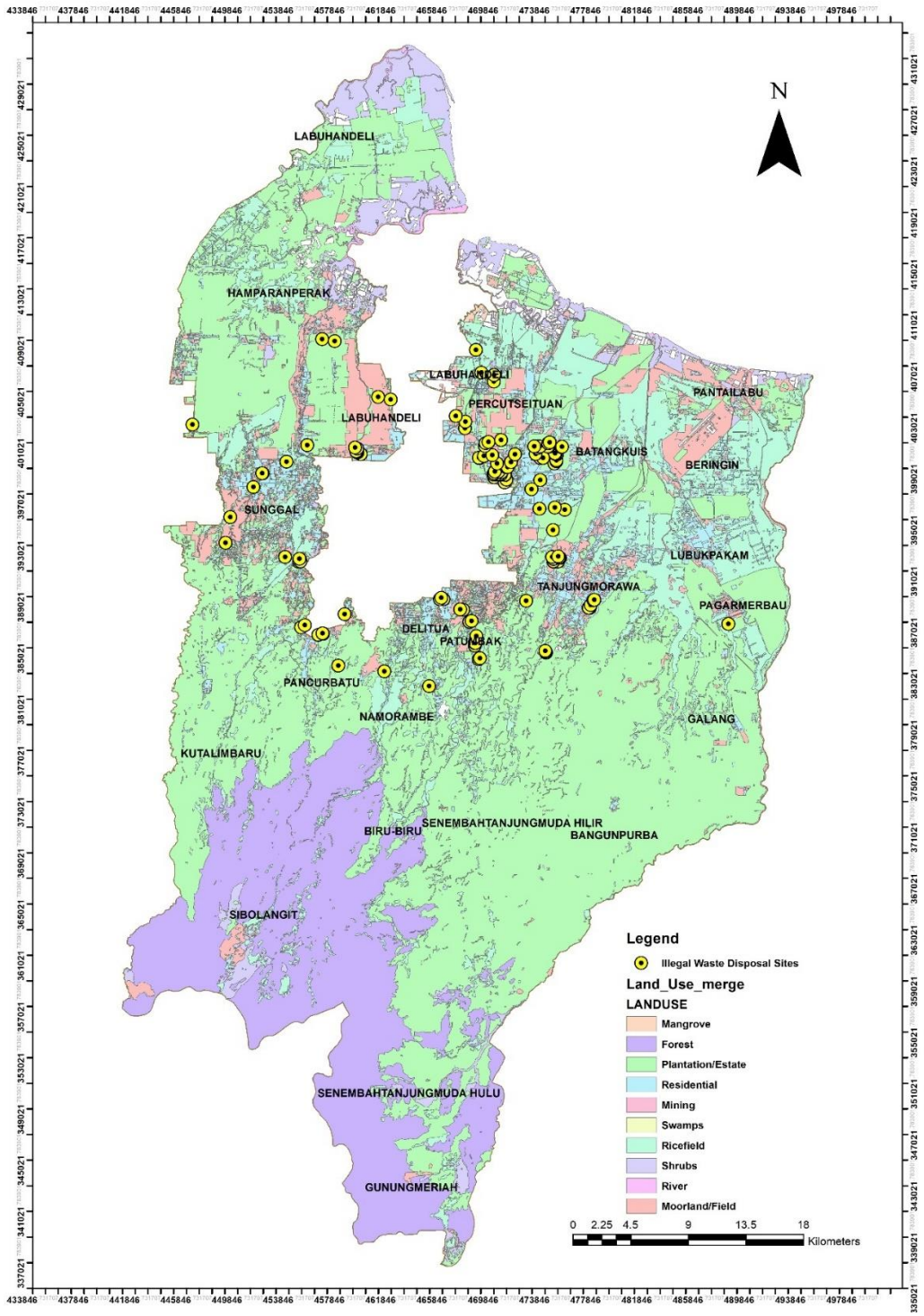

Figure 30. The Map of Illegal Waste Disposal Sites Distribution based on Land Use

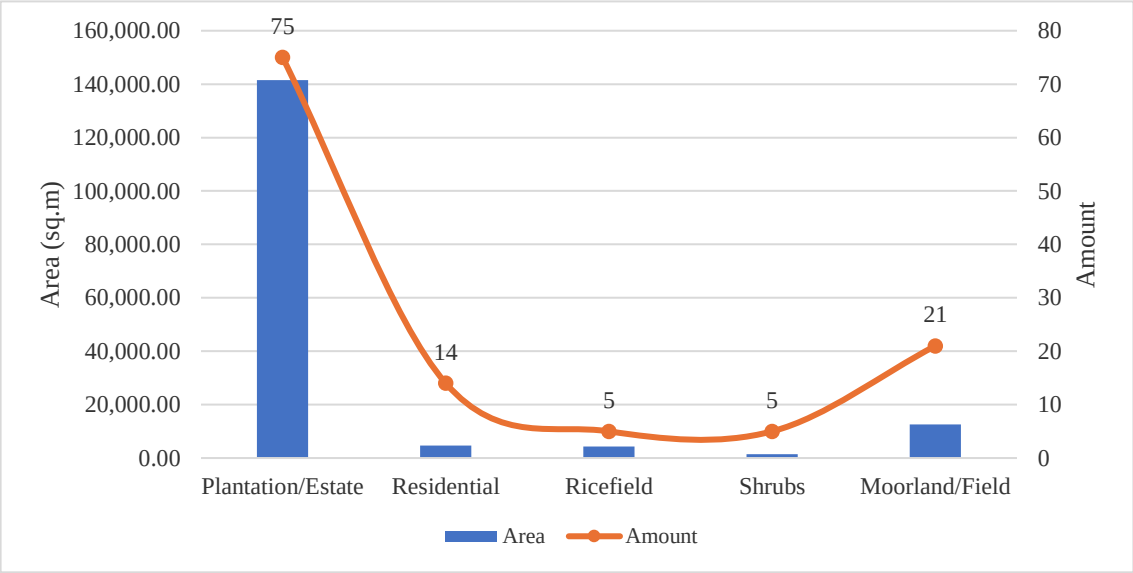

Figure 31. Illegal Waste Disposal Sites Location Trend based on Land Use

3.3.3. IWDS Discovered through Community Engagement

IWDS are often strategically located in remote or secluded areas, away from public view or areas frequented by authorities (Aluko et al., 2022; Tompson & Chainey, 2011; Torres & Fraternali, 2021; Yang et al., 2019). Perpetrators of IWDS may camouflage their activities by dumping waste in areas that blend in with the natural surroundings, such as dense vegetation or abandoned lots (Du et al., 2021). This camouflage makes it hard to distinguish between legal and illegal dumping activities (Tompson & Chainey, 2011). IWDS activities frequently occur under the cover of darkness, making it challenging for authorities to detect them in real-time. Perpetrators take advantage of the darkness to evade detection and minimize the risk of being caught (D'Amato et al., 2018; Di Fiore et al., 2017; Du et al., 2021; Triassi et al., 2015). Some IWDS operations are mobile, with perpetrators moving from one location to another to avoid detection. This mobility makes it challenging for authorities to track and monitor IWDS activities effectively. Community may hesitate to report illegal waste disposal activities due to fear of retaliation, lack of trust in

authorities, or concerns about their own safety (Dlamini et al., 2017; Hidalgo et al., 2019; Tompson & Chainey, 2011). This underreporting further complicates efforts to detect and address IWDS.

The data reveals a significant contribution of individual and community engagement to the discovery of IWDS. Out of the 120 identified locations, 54 locations (45%) were unearthed through methods such as direct interviews, FGDs and information provided by whistleblowers. Moreover, the impact of community engagement becomes even more apparent when considering the total area of IWDS discovered through these participatory methods. Community engagement led to the identification of sites covering a total area of 93,842.72 sq.m, representing a substantial 57.15% of the overall area uncovered (Figure 32.).

This research shows that community engagement participation has excellent potential for developing new IWDS monitoring and reporting methods based on community engagement. These findings highlight the invaluable role played by community members and individuals in enhancing the scope and effectiveness of IWDS detection efforts. By tapping into local knowledge, insights, and concerns, researchers can access previously unknown areas of illegal waste disposal, thereby bolstering environmental monitoring initiatives. Engaging with the community raises awareness about the issue and encourages residents to report suspicious activities or locations to authorities.

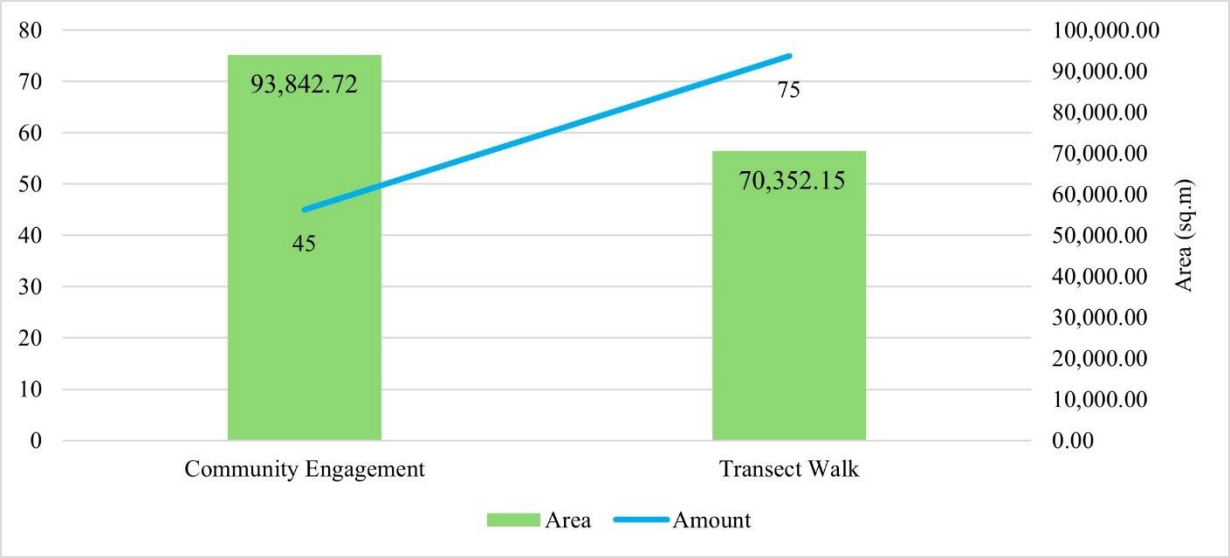

Figure 32. Illegal Waste Disposal Sites Community Engagement vs Transect Walk

3.4. Conclusion

The current study developed a new field method to find the actual location of IWDS in Deli Serdang, Indonesia. This research was conducted by combining individual investigation methodology with community engagement methodology. The community engagement methodology uses three methods: direct interviews with the open-ended method, FGDs, and the whistleblower method. The results show that this methodology can effectively and accurately determine the actual location of IWDS. This result is beneficial for the authorities in finding out the location of the IWDS and knowing the characteristics of the IWDS condition. The data from this research could be a guide for authorities in handling and making a policy regarding IWDS. This research also shows that community-based monitoring and reporting methods can be more cost-effective than traditional surveillance methods. By leveraging the power of community networks and grassroots organizations, authorities can access a wealth of information at minimal cost, making IWDS monitoring efforts more sustainable and

scalable. IWDS are a complex problem, and there is no 'one-size-fits-all' solution that cannot be solved with a simple singular blueprint and top-down solutions.

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Chapter 4 A Spatio-Temporal Analysis of Illegal Waste Disposal Site Activities in Deli Serdang

4.1. Introduction

Illegal waste disposal sites (IWDS) present a significant and multifaceted challenge for countries worldwide (D'Amato & Zoli, 2012; Niyobuhungiro & Schenck, 2022; Ruffell & Dawson, 2009). This pervasive issue not only poses threats to environmental integrity but also imposes substantial financial burdens on governments (Agya et al., 2024; Matsumoto & Takeuchi, 2011; Yang et al., 2019). The costs associated with detecting and mitigating IWDS are considerable, encompassing expenses for surveillance, cleanup operations, and the implementation of preventive programs (Kubasek & Hrebicek, 2013; Matsumoto & Takeuchi, 2011; Youme et al., 2021). In Indonesia, as in many other nations, IWDS takes various forms, ranging from unauthorized dumping to improper handling of hazardous materials (Fariz et al., 2024; Ramadan et al., 2022). These activities not only degrade natural habitats and contaminate water sources but also hinder progress towards sustainable development goals and environmental conservation efforts.

IWDS represents a pressing environmental and public health issue globally (Mazza et al., 2015; Triassi et al., 2015), driven by economic incentives to avoid waste disposal costs (Dlamini et al., 2017; Jordá-Borrell et al., 2014; Quesada-Ruiz et al., 2019). This illicit practice has been on the rise alongside increasing waste volumes, facilitated by its covert nature which often evades initial detection efforts (Du et al., 2023; Joo & Kwon, 2015; Yang et al., 2019). The long-term accumulation of IWDS not only threatens local economies and ecosystems but also poses significant health risks. Studies have shown that people living around IWDS are more likely to develop cancer (Aluko et al., 2022; Mazza et al., 2015; Triassi et al., 2015).

Detection of IWDS is a central environmental issue in both developed and developing countries (Glanville & Chang, 2015a; Massarelli, 2018; Yan et al., 2014). Monitoring IWDS is a highly complex task (Ichinose & Yamamoto, 2011; Karimi & Ng, 2022; Torres & Fraternali, 2021). Initially, due to its clandestine nature, perpetrators of IWDS actively seek to conceal their activities, making detection challenging for stationary monitoring facilities. This difficulty is particularly pronounced in sparsely populated regions (Biotto et al., 2009; Silvestri & Omri, 2008) like Deli Serdang, where IWDS incidents may go unnoticed for extended periods. Furthermore, the dynamics of IWDS locations and opportunities fluctuate over time, necessitating continuous advancements in detection capabilities (Biotto et al., 2009; Hidalgo et al., 2019). This dynamic nature further complicates regulatory efforts aimed at timely identifying and addressing IWDS activities.

Geospatial and remote sensing (RS) technologies have experienced extraordinary development, becoming increasingly accessible and integral to everyday life. When combined with Geographic Information Systems (GIS), these technologies play crucial roles across multiple stages of Municipal Solid Waste Management (MSWM) (Glanville & Chang, 2015b; Karimi & Ng, 2022). They are employed in tasks such as optimizing waste collection routes, assessing dumping site's size and capacity, and detecting and monitoring landfill fires.

RS technologies contribute by providing real-time or near-real-time data on waste accumulation, site conditions, and environmental impacts (Glanville & Chang, 2015b; Silvestri & Omri, 2008; Yan et al., 2014). Satellite imagery and aerial surveys enable precise mapping and analysis, facilitating proactive management strategies to mitigate environmental risks associated with waste disposal (Dabholkar et al., 2017; Di Fiore et al., 2017; Du et al., 2021). GIS enhances these capabilities by integrating spatial data to optimize logistical operations, improve efficiency in waste transportation, and support decision-making processes for sustainable waste

management practices (Seror & Portnov, 2018; Sodoke et al., 2022; Tasaki et al., 2007).

Simple essential tools and applications such as Google Maps, Bing Maps, Google Earth, and Google Earth Pro are valuable resources for climate and environmental research, leveraging their access to high-resolution satellite imagery. Google Earth Pro, a virtual globe software, amalgamates a comprehensive array of remotely sensed and modelled images from diverse satellite and aircraft datasets captured at various intervals. Within Google Earth Pro, users can zoom in to resolutions ranging from 1 to 15 meters per pixel, facilitating the identification and examination of geographic features like river basins, canyons, agricultural landscapes, mountains, and their corresponding elevations. Google Earth Pro is a highly effective tool for generating data in regions lacking high-quality RS data. It facilitates the identification of IWDS within urban areas and surrounding regions, offering insights into the changing patterns of IWDS activities over time.

The objective of this study was to analyze changes in the shape and size of the IWDS over a period of time and to evaluate problems related to IWDS activities. This study also aims to determine the spatial and temporal pattern distribution of IWDS activities based on land use.

4.2. Material and Methods

The study area faces significant waste management challenges, with Deli Serdang generating an estimated 1.097 tons of waste per day or approximately 400,716 tons annually (Fariz et al., 2023). Of this total waste generation, only 62.72% is effectively managed by formal waste management systems, leaving approximately 37.28% unmanaged (Fariz et al., 2023). This unmanaged waste presents a potential for the emergence of IWDS activities.

To analyze the dynamics of IWDS pattern from 2021 to 2023, a time-series approach was employed, comparing satellite images of identified IWDS locations at different intervals. Historical satellite images were accessed and analyzed using the historical imagery feature in Google Earth Pro software (version 7.3.6.9796 (64-bit)). A total of 124 IWDS were selected for detailed study based on their prevalence and accessibility within Deli Serdang Regency.

Using ArcGIS 10.8 software, polygons were drawn around each IWDS to calculate both the area and perimeter of these sites. The area measurement was prioritized over perimeter due to the irregular shapes and fragmented nature of IWDS, providing a more accurate estimate of their size and spatial impact. This method facilitated a comprehensive time-based comparison of IWDS, allowing researchers to track changes in site extent and distribution over the study period.

4.3. Result and Discussion

4.3.1. IWDS Distribution Pattern

From a time-series analysis at the same IWD location spanning from 2021 to 2023 across 124 locations, it has been observed that there is a notable increase in the number of IWDS in Deli Serdang. As Shown in Table 9., the data reveals that in 2021 there were 98 IWDS locations in Deli Serdang, which increased to 112 in 2022 and 120 in 2023. This consistent rise indicates a clear upward trend in the prevalence of IWDS in the region over the three years.

Table 9. IWDS Distribution from 2021 to 2023

DISTRICT	2021	2022	2023
BIRU-BIRU	0	0	1
DELITUA	2	2	2
HAMPARAN PERAK	4	4	4
LABUHAN DELI	12	12	12
NAMORAMBE	1	1	1
PAGAR MERBAU	0	0	1
PANCUR BATU	6	7	7
PATUMBAK	9	10	10
PERCUT SEI TUAN	43	51	56
SENEMBAHTANJUNGMUDA HILIR	1	2	2
SUNGGAL	9	9	10
TANJUNG MORAWA	11	14	14
TOTAL	**98**	**112**	**120**

The results show a comprehensive overview of the prevalence of IWDS across various districts from 2021 to 2023. The study shows that the proliferation of IWDS in Deli Serdang from 2021 to 2023 underscores a pressing environmental challenge. Each year, the number of identified IWDS has steadily increased, reflecting not only the persistence of illegal dumping but also the evolving landscape of waste management issues in the region.

This study also shows that there is a fluctuating increase in the area of IWDS in Deli Serdang as shown in Table 10. The data from Table 10. illustrates a fluctuating increase in the area occupied by IWDS across various districts in Deli Serdang from 2021 to 2023. Each district shows changes in the total area of IWDS over the three-year period. In 2021, notable areas of IWDS were identified in several districts, with significant figures such as Hamparan Perak occupying 18,505.16 sq.m, Percut Sei Tuan with 32,007.06 sq.m, and Sunggal with 22,661.66 sq.m.

By 2022, there was a general increase in the area of IWDS across most districts. Notably, Percut Sei Tuan saw a substantial rise to 56,639.70 sq.m, reflecting a

significant expansion of illegal dumping activities in that area. Similarly, districts like Sunggal and Tanjung Morawa also experienced considerable increases in IWDS areas.

Table 10. IWDS Area (sq.m) in Each District

DISTRICT	2021	2022	2023
BIRU-BIRU	-	-	820.86
DELITUA	2,778.03	2,830.45	3,639.37
HAMPARANPERAK	18,505.16	23,676.95	25,372.49
LABUHANDELI	6,303.76	7,481.88	7,164.31
NAMORAMBE	944.49	3,095.81	2,858.81
PAGARMERBAU	-	-	166.06
PANCURBATU	10,043.21	17,953.40	13,898.40
PATUMBAK	8,482.86	9,602.18	11,705.04
PERCUTSEITUAN	32,007.06	56,639.70	55,896.52
SENEMBAHTANJUNGMUDA HILIR	1,229.43	1,333.40	1,309.80
SUNGGAL	22,661.66	23,124.25	25,028.35
TANJUNGMORAWA	12,182.54	21,878.13	16,334.85
TOTAL	**115,138.197**	**167,616.147**	**164,194.87**

In 2023, while the total IWDS area slightly decreased compared to 2022, many districts maintained substantial areas dedicated to IWDS activities. Percut Sei Tuan, for instance, still reported a significant IWDS area of 55,896.52 sq.m. Other districts like Hamparan Perak and Sunggal also retained large IWDS areas, demonstrating persistent environmental challenges despite fluctuations in total area across different districts in Deli Serdang.

From 2021 to 2023, Percut Sei Tuan consistently became the most significant area for illegal waste disposal sites (IWDS) in Deli Serdang. In 2021, the IWDS area in Percut Sei Tuan was recorded at 32,007.06 sq.m. This area substantially increased in 2022, reaching 56,639.70 sq.m., indicating a significant escalation in illegal dumping activities. By 2023, although there was a slight decrease, the IWDS area remained substantial at 55,896.52 sq.m. Concurrently, IWDS locations increased from 51 in

2022 to 56 in 2023, underlining the persistent and growing issue of illegal waste disposal in Percut Sei Tuan. This data underscore Percut Sei Tuan as a focal point for illegal waste disposal in the Deli Serdang.

The largest IWDS location identified in Deli Serdang was in Hamparan Perak (Figure 33.). In 2021, the IWDS measured 14,566.53 sq.m. These IWDS activities expanded to 16,713.04 sq.m. in 2022 and increased to 19,296.20 sq.m. by 2023, and the second largest IWDS location was in Sunggal (Figure 34.), which exhibited substantial growth over the years. Figure 35. shows the comparative trends in IWDS areas across various locations from 2021 to 2023. Examining the progression of IWDS trends using time-series analysis over the past three years provides valuable insights into environmental sustainability and regulatory compliance. Figure 36. presents data from 2021 to 2023, outlining fluctuations and patterns in IWDS activities. These figures highlight a concerning rise in IWDS activities. Understanding these dynamics is crucial for authorities to identify hotspots, assess the effectiveness of interventions, and propose evidence-based solutions to combat IWDS activities.

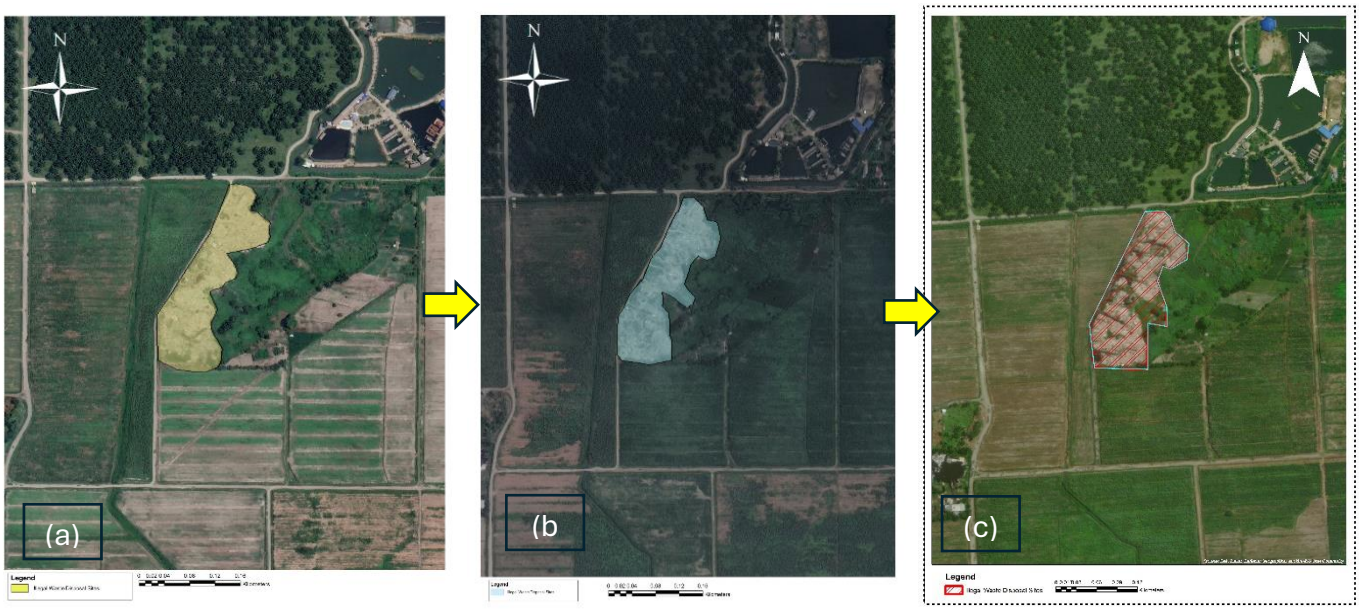

Figure 33. The Largest IWDS Location Temporal Pattern

(a) 2021 (b) 2022 (c) 2023

Figure 34. The Second Largest IWDS Location Temporal Pattern

(a) 2021 (b) 2022 (c) 2023

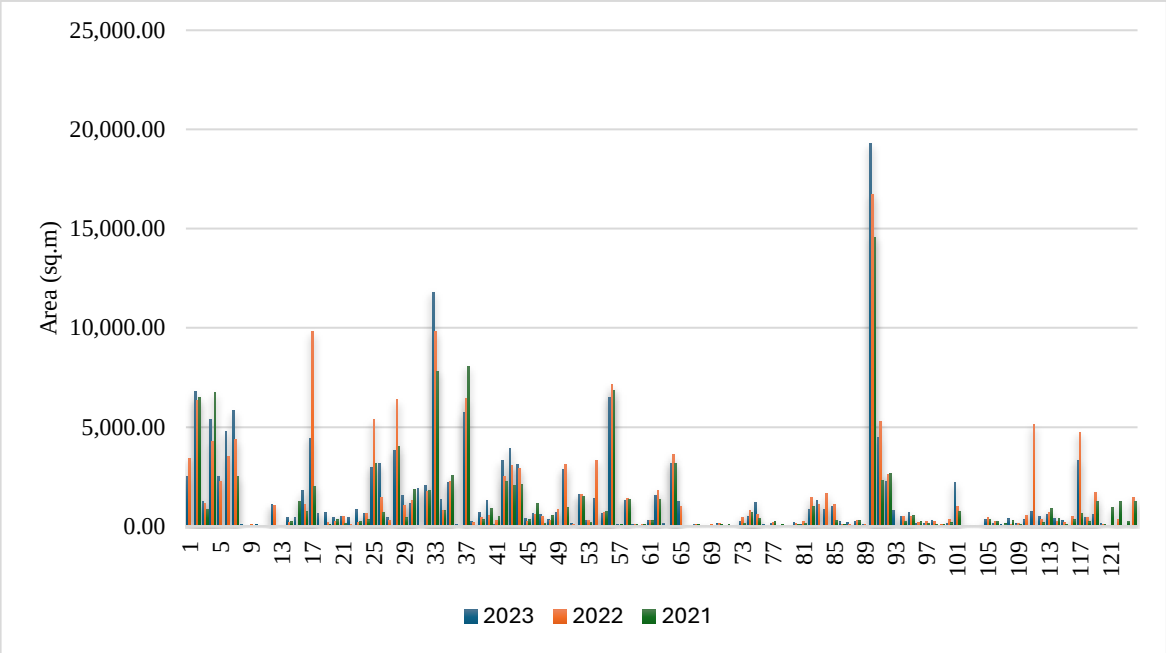

Figure 35. The Comparative Trends of IWDS Areas

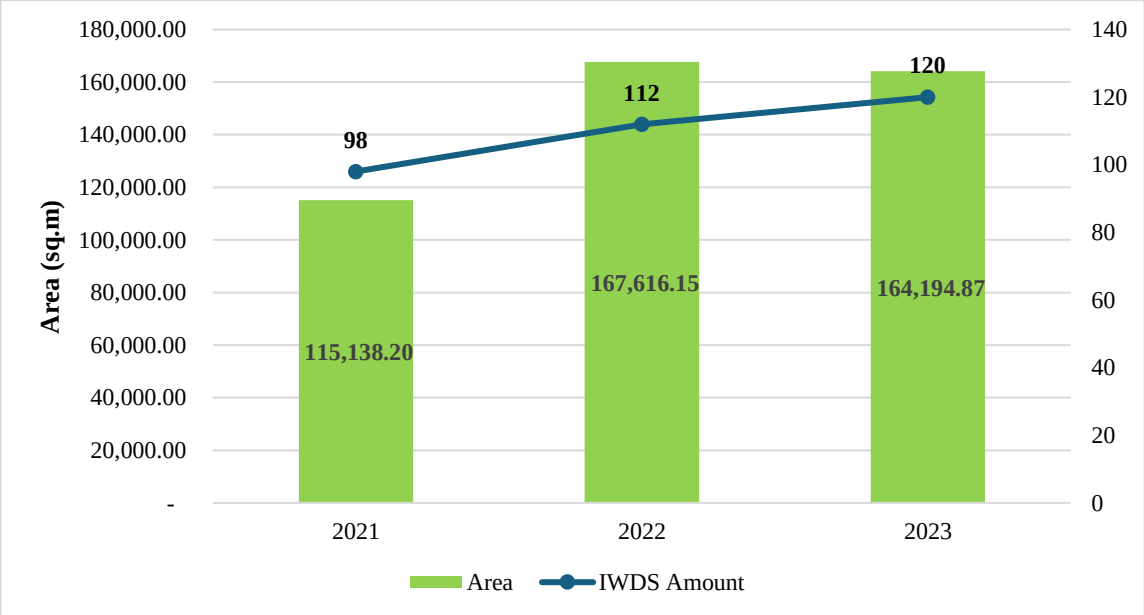

Figure 36. The IWDS Trends from 2021 to 2023

4.3.2. IWDS Distribution Based on Land Use

This study shows that illegal waste disposal sites (IWDS) in Deli Serdang are categorized across five distinct land use types. Understanding the spatial and temporal patterns of IWDS activity within these land use categories is crucial for effective management and mitigation strategies(Khumalo et al., 2021; Kim et al., 2008; Muindi et al., 2022) . Authorities can identify high-risk areas and trends over time by analyzing how IWDS are distributed across different land uses. This data enables the implementation of targeted preventive measures tailored to each land use category, such as enhanced monitoring, stricter enforcement of regulations, and community engagement initiatives.

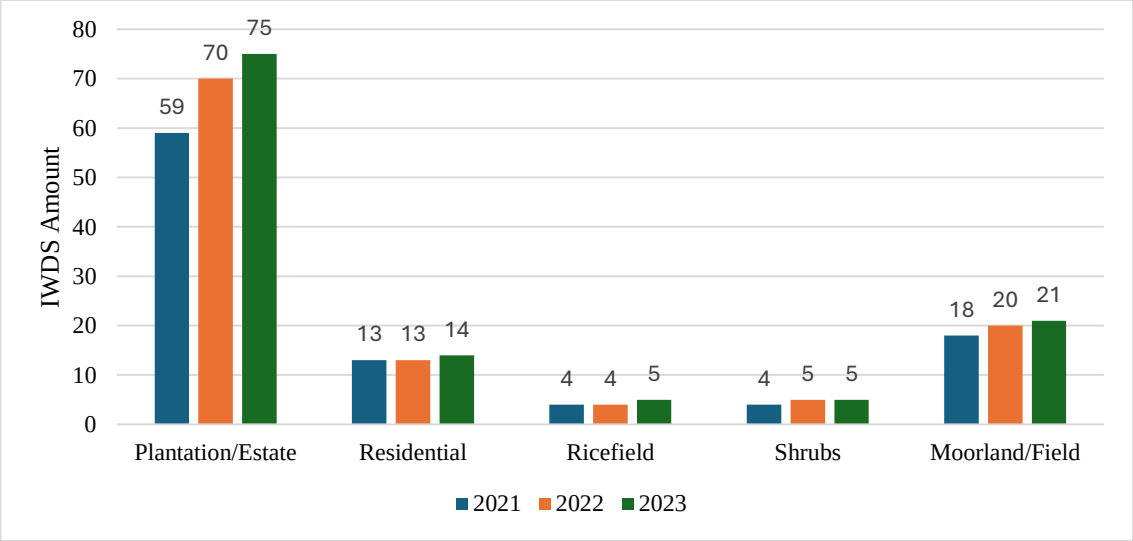

Figure 37. IWDS Distribution Based on Land Use

Figure 37. provides a comprehensive overview of IWDS across various land use categories in Deli Serdang from 2021 to 2023. Plantation/estate areas consistently recorded the highest number of IWDS incidents each year. This pattern is primarily due to the secluded and often remote nature of IWDS locations (D'Amato et al., 2018; Nagpure, 2019; Tasaki et al., 2007), making plantations ideal locations for illegal

waste dumping. The covert nature of IWDS activities aligns with their tendency to occur in hidden or less accessible areas, which complicates detection by authorities. As a result, plantation/estate emerge as prominent sites for illegal waste disposal, reflecting challenges in monitoring and enforcing waste management regulations in such remote or densely vegetated environments.

Residential areas, in contrast, exhibited consistent IWDS occurrences with minor fluctuations from 2021 to 2023. This stability suggests that waste management practices within residential zones may already be effectively regulated or that there exists a high level of community awareness and compliance with waste disposal regulations. The relatively stable number of IWDS incidents in residential areas indicates a potential success in implementing and maintaining waste management practices that mitigate illegal dumping activities.

In rice fields, there was a gradual increase in IWDS incidents from 4 in 2021 to 5 in 2023. Similar patterns were observed in shrublands, where IWDS incidents increased from 4 in 2021 to 5 in 2022 and 2023, reflecting ongoing challenges in managing waste in natural and semi-natural landscapes.

Moorland/field areas have shown a noticeable increase in IWDS incidents, with numbers rising from 18 in 2021 to 21 in 2023. This trend highlights the tendency for IWDS to occur in natural environments rich in vegetation, which effectively hides these activities, thereby complicating detection and access efforts. Moreover, the clandestine nature of IWDS contributes to a lack of public awareness regarding these illegal activities, known only to a limited number of individuals engaged in such practices. This covert behavior further obstructs efforts to address and mitigate the environmental and social consequences associated with IWDS in Deli Serdang. Table 11. shows the IWDS area based on land use.

Table 11. The IWDS Area Based on Land Use

Land Use Category	2021 IWDS Amount	2021 IWDS Area (sq.m)	2022 IWDS Amount	2022 IWDS Area (sq.m)	2023 IWDS Amount	2023 IWDS Area (sq.m)
Plantation/Estate	59	99,858.88	70	148,248.21	75	141,527.84
Residential	13	4,109.25	13	3,400.86	14	4,630.97
Ricefield	4	2,521.81	4	2,641.14	5	4,313.94
Shrubs	4	1,461.85	5	1,273.01	5	1,384.62
Moorland/Field	18	7,466.07	20	12,325.44	21	12,637.16

In 2021, Plantation/Estate areas in Deli Serdang reported the highest incidents of IWDS, totaling 99,858.88 sq.m. This area shows a significant increase to 148,248.21 sq.m. in 2022, indicating a substantial escalation in IWDS activities within these concealed and densely vegetated environments. By 2023, although there was a slight decrease, the area remained considerable at 141,527.84 sq.m., underscoring the persistent nature of IWDS in plantation/estate settings despite efforts to mitigate such activities.

Residential areas have shown a fluctuating trend in illegal waste disposal sites (IWDS) incidents from 2021 to 2023. Initially starting at 4,109.25 sq.m in 2021, the affected area decreased to 3,400.86 sq.m in 2022, before increasing to 4,630.97 sq.m in 2023. This variability indicates ongoing challenges in managing waste disposal within residential zones. Factors contributing to these fluctuations could include changes in population density, urban development activities, and shifts in waste management policies or practices. The rise in 2023 highlights a potential escalation

in IWDS activities, possibly due to increased urbanization pressures or inadequate waste management infrastructure.

Ricefield areas witnessed fluctuating IWDS incidents from 2,521.81 sq.m. in 2021 to 2,641.14 sq.m. in 2022, before experiencing a notable increase to 4,313.94 sq.m. in 2023. This variability indicates potential challenges in monitoring and regulating waste disposal in agricultural landscapes, influenced by seasonal agricultural practices and accessibility.

Shrubs areas maintained relatively stable IWDS occurrences across the years, ranging from 1,461.85 sq.m. in 2021 to 1,384.62 sq.m. in 2023. The consistent nature of these incidents highlights the persistent challenge of detecting and addressing illegal dumping activities in shrub-covered environments, where the dense vegetation provides ample cover for illegal practices.

Moorland/Field areas exhibited a consistent upward trend in IWDS incidents, increasing from 7,466.07 sq.m. in 2021 to 12,325.44 sq.m. in 2022 and further to 12,637.16 sq.m. in 2023. This pattern underscores the propensity for IWDS to occur in natural and less accessible terrains, characterized by dense vegetation that complicates both detection and mitigation efforts.

Illegal waste disposal sites are strategically positioned in remote and obscure locations, intentionally hidden from casual observation and regulatory oversight (Faria et al., 2023; Jordá-Borrell et al., 2014; Seror & Portnov, 2018). These sites are often situated away from main roads and urban centers, making them challenging for authorities and environmental agencies to detect and monitor effectively (Glanville & Chang, 2015a; Matos et al., 2012; Tasaki et al., 2007). The deliberate choice of such secluded areas underscores the clandestine nature of illegal waste disposal operations, which evade legal scrutiny and environmental regulations. This poses significant environmental and public health risks, as unregulated waste disposal can lead to soil

contamination, groundwater pollution, and air quality deterioration (Carriero et al., 2018; Triassi et al., 2015; Vaverková et al., 2019). Addressing these challenges requires robust enforcement measures, enhanced surveillance technologies, and community engagement to prevent and mitigate the adverse impacts of IWDS. Efforts to combat these practices must be multifaceted, integrating spatial analysis tools and collaborative strategies among stakeholders to ensure effective environmental stewardship and sustainable development

4.4. Conclusion

A time-series analysis of 124 illegal waste disposal sites (IWDS) in Deli Serdang Regency has been conducted using historical satellite images from Google Earth Pro and ArcGIS 10.6 software. This study employed spatio-temporal data to analyze IWDS locations across different time periods. The results indicate an increase in IWDS locations in Deli Serdang from 98 in 2021 to 112 in 2022 and 120 in 2023. Concurrently, the total area IWDS in Deli Serdang also rose from 115,138.1971 sq.m in 2021 to 164,194.87 sq.m in 2023. The study highlights plantation/estate areas as the most prevalent locations for IWDS in Deli Serdang, with a rise in the number of IWDS from 59 in 2021 to 70 in 2022 and 75 in 2023. Moorland/field areas also exhibited increased IWDS incidents, from 18 in 2021 to 20 in 2022 and 21 in 2023. This pattern underscores the characteristics of IWDS in Deli Serdang, which is situated in densely vegetated and difficult-to-access locations. These aid in concealing illegal activities and complicating detection efforts by the authorities.

The methodology employed in this study can be expanded to encompass entire cities or even multiple cities over specific time periods. Adopting technology-driven monitoring and detection systems for IWDS represents a crucial step forward for authorities worldwide. By harnessing the power of geospatial, remote sensing, GIS, and advanced data analytics, authorities can significantly enhance their ability to detect, monitor, and mitigate IWDS activities promptly and efficiently.

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Chapter 5 Policy Brief as A Direction for The Countermeasures Reducing IWDS in Indonesia

5.1. Introduction

Waste management facilities in Indonesia encompass a diverse array of establishments tailored for both organic and inorganic waste. These facilities include unit waste banks and central waste banks, which play pivotal roles in waste segregation and collection. There are also neighborhood-scale composting facilities, compost houses, and organic processing centers to process organic waste efficiently. For more comprehensive waste management, Indonesia also utilizes Material Recovery Facilities (TPST, TPS3R), Recycling Centers (PDU), and Intermediate Treatment Facilities (ITF). These facilities are crucial for sorting recyclable materials and facilitating their reuse, contributing significantly to waste reduction efforts. For instance, Jakarta has 5 central waste banks, over 700 TPS3R units (Recycling and Waste Processing Sites), and 40 compost houses. In West Java, the numbers are notably higher, with 40 central waste banks, more than 600 TPS3R units, and over 100 compost houses. This widespread infrastructure underscores Indonesia's commitment to improving waste management practices nationwide, effectively addressing environmental sustainability and public health concerns. However, illegal waste dumping sites (IWDS) are still found in big cities in Indonesia.

IWDS have indeed become a chronic and severe environmental issue both globally and in Indonesia. These sites pose ongoing and costly challenges in waste management, requiring concerted efforts to effectively control and resolve (Du et al., 2023; Hidalgo et al., 2019; Karimi and Ng, 2022; Kubasek and Hrebicek, 2013; Quesada-Ruiz et al., 2019; Tasaki et al., 2007). IWDS often arise due to unauthorized dumping and improper waste management practices, which can lead to environmental pollution, soil and water contamination, and risks to public health. To address this

issue, it will be necessary to develop some strategies to reduce the impact of this harmful practice.

Figure 38. Illegal Waste Disposal Sites Practice in Indonesia

This chapter aims to analyze some stakeholder initiatives and challenges to stop IWDS's practice of municipal waste and suggest strategic actions and recommendations for Indonesia to reduce the practice. Therefore, strength-weakness-opportunity-threat (SWOT) and Grand Strategy Matrix analysis tools were used to prioritize the strategic actions that have been developed.

5.2. Materials and Methods

5.2.1. Data Collection

To develop the SWOT factors, The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) methodologies in Chapter 1 were used. The lowest weight of total link strength and occurrences from analysis results using VOSviewer for various research labels used to develop SWOT factors. By analyzing this chart (Figure 39.), the potential research gaps and areas that may require more focus can be identified. More frequent and diverse studies could fill this gap.

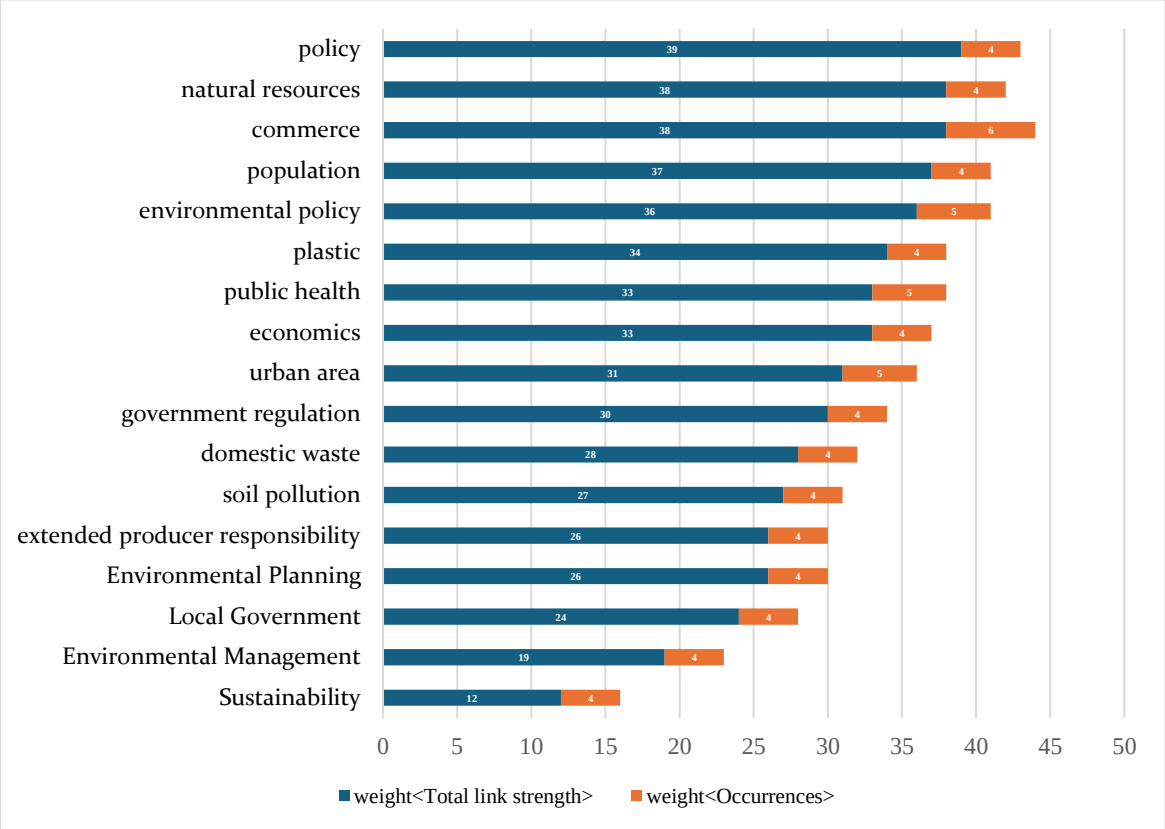

Figure 39. Weight of Total Link Strength and Occurrences by Label

5.2.2. Qualitative Content Analysis

Qualitative content analysis was used to identify the definition of the SWOT factors from the documents or metadata collected. This analysis consists of summarization and reorganization of the developed SWOT factors (Budihardjo et al., 2021). Therefore, descriptive analyses were also employed to identify stakeholder initiatives to reduce IWDS. In this part, there are 5 manuscripts that were in-depth studied which related to initiatives to reduce IWDS. The Grand Strategy Matrix analysis tool is used to determine the position of IWDS quadrant. There were 5 experts were invited to answer the SWOT questionnaire, respectively.

5.3. Result and Discussion

The factors, challenges, and strategies to reduce the IWDS are analyzed using SWOT methods and Grand Strategy Matrix tools quadrant. As can be seen in Table 12. and Table 13., the SWOT factors and their normalized weight were developed based on the terms generated in the bibliometric analysis. Therefore, the rank was generated from expert judgment. The results showed that strength and opportunity dominate over weakness and threat. It is also found that the overall result of the internal and external factor analysis summary (IFAS-EFAS) scores -0.3 and 0.4 respectively.

Table 12. SWOT Factors in the Internal Factor Analysis Summary

IFAS (Internal Factor Analysis Summary)			
Internal Factors	**Weight**	**Rating**	**Weighted Score**
Strength			
Geographical area (S1)	0.2	3	0.6
Cheaper operational cost (S2)	0.3	4	1.2

Waste can be a renewable source of energy and revenue (S3)	0.3	5	1.5
The abundance of human resources (S4)	0.2	3	0.6
Total Strength	1		3.9
Weakness			
Gaps in regulation, policy, law enforcement, and program or plan (W1)	0.3	4	1.2
Insufficient waste management infrastructures and services (W2)	0.3	4	1.2
Lack of capacity of the local authorities (W3)	0.2	4	0.8
Limited financial and technical resources (W4)	0.2	5	1
Total Weakness	1		4.2
Net IFAS score = 3.9-4.2 = -0.3			

Table 13. SWOT Factors in the External Factor Analysis Summary

EFAS (External Factor Analysis Summary)			
External Factors	**Weight**	**Rating**	**Weighted Score**
Opportunity			
Employment creation potential (O1)	0.35	5	1.75
Potential alternative energy generation from waste conversion (O2)	0.15	4	0.6
Potential alternative location of waste facilities (O3)	0.35	5	1.75
Potential markets for recycling are increasing (O4)	0.15	5	0.75
Total Strength	1		4.85
Threat			
Lack of environmental behavior, awareness, attitude, and participation of the residents (T1)	0.25	4	1
Public health (T2)	0.25	5	1.25
Environmental pollution (T3)	0.35	5	1.75
Unsystematic coherence and	0.15	3	0.45

political instability between regional, national, and local authorities (T4)			
Total Weakness	1		4.2
Net EFAS score = 4.85-4.2 = 0.4			

According to the Grand Strategy Matrix, the position of Illegal Waste Disposal Sites (IWDS) in Indonesia is in quadrant II with an aggressive maintenance approach (Figure 40.). Quadrant II shows IWDS in Indonesia uses a Weakness-Opportunity (WO) strategy, in this matrix indicates that the issue of IWDS needs to be actively addressed with intensive maintenance and preventive strategies to control its negative impacts. This aggressive approach involves enhanced monitoring, strict enforcement of regulations, and intensive efforts in community education and participation to promote responsible waste management practices. Thus, Indonesia aims to achieve more effective resolution of IWDS issues, improve environmental quality, and advance sustainable development.

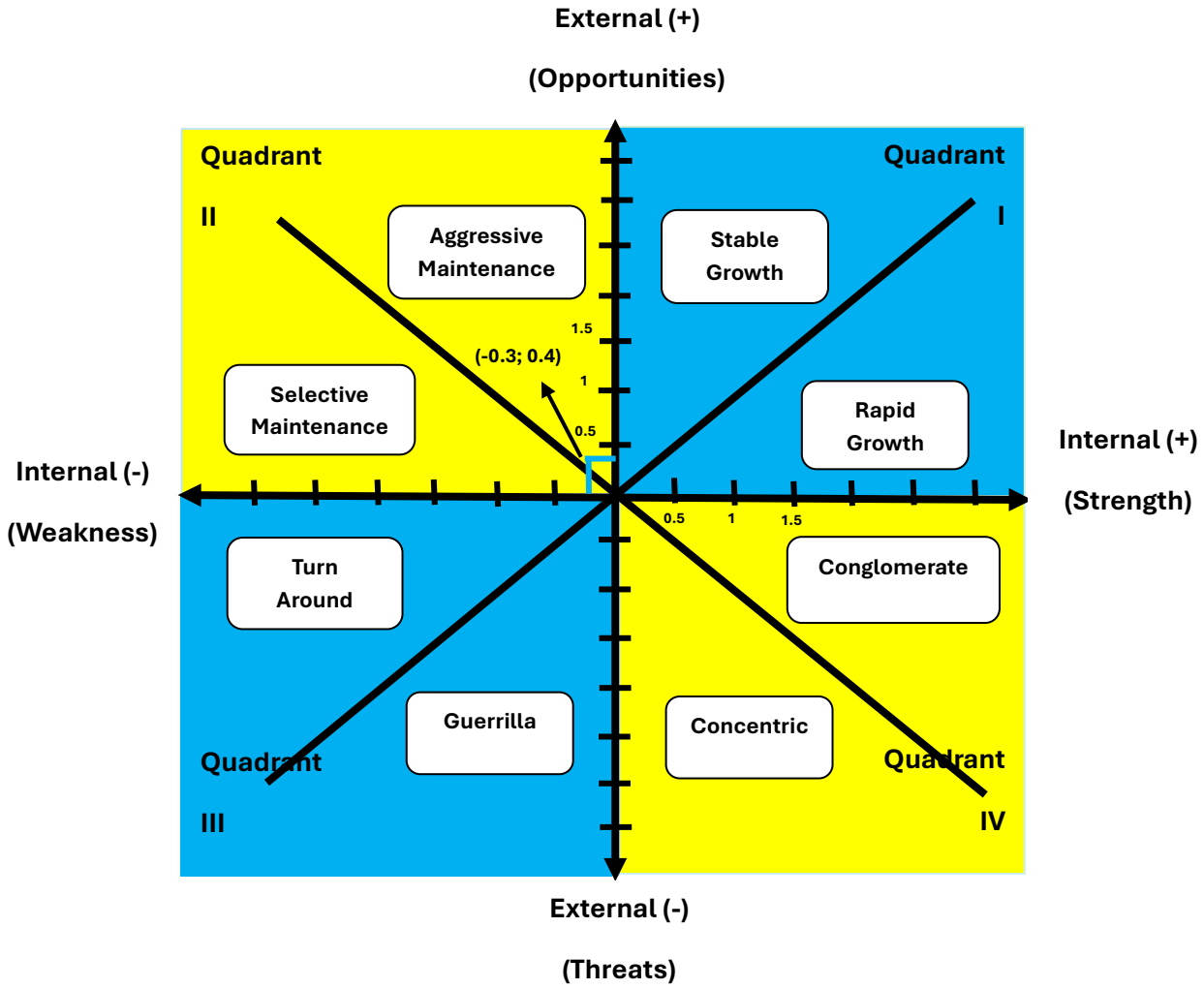

Figure 40. Grand Strategy Matrix Quadrant of IWDS in Indonesia

Based on the expert analysis, SWOT analysis and the Grand Strategy Matrix quadrant of IWDS in Indonesia, the following strategy with an aggressive maintenance approach can be immediately implemented to reduce IWDS activities

1 Reviewing recent policies and strategic plans regarding waste management in Indonesia, especially preventive measures regarding illegal waste dumping sites
2 Determining a clear-cut responsibility for waste management between the central government and regional governments

3 Determining a bottom-up approach by involving the community participation of the community in waste management, monitoring, campaign, and education through awareness-raising on IWDS activities in Indonesia
4 Conducting immediate feasibility studies to assess the effectiveness of current waste management conditions in Indonesia and to upgrade and expand existing waste infrastructure, including waste collection, transportation, and disposal facilities
5 Providing technical support for data collection and management, coaching, and mentoring of available emission calculation tools, knowledge sharing, and baseline understanding
6 Creating a legal framework regarding the possibility of IWDS becoming a recycling location that can increase the recycling rate and job creation
7 Creating regulations and legal frameworks to utilize waste from IWDS for alternative energy generation

5.4. Conclusion

The study found that the reduction of IWDS in Indonesia needs some aggressive maintenance strategies that need the strength factors to take advantage of the opportunities. Therefore, several action recommendations are developed and prioritized as follows: (1) Policy Review; (2) Governance Clarity; (3) Community Engagement; (4) Infrastructure Assessment; (5) Technical Support; (6) Recycling Framework; (7) Energy Utilization. Several strategies can also be considered to reduce IWDS activities, such as promoting waste separation at sources, formalizing informal recycling, providing better incentives and access to the market for waste management initiatives and recycling activities and more precise job descriptions for each level of stakeholder inside the government body.

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Chapter 6 Conclusions and Further Studies

6.1. Conclusion

There are several important findings that can be generated from the previous chapters.

1. Inadequate waste management in many developing countries is the cause of illegal waste disposal sites (IWDS) activities. The long-term accumulation of IWDS not only threatens local economies and ecosystems but also poses significant health risks. Studies have shown that people living around IWDS are more likely to develop cancer. Meanwhile, the data shown estimated that 30-40% of waste in Indonesia is unmanaged, which may be subjected to improper waste disposals such as direct dumping into the environment, open burning or others

2. In Indonesia, the allocation of local government budget funds reveals a significant challenge for prioritizing waste management amidst competing financial demands. On average, regency and city governments in Indonesia spend only 0.7% of their Local Government Budgets Fund (APBD) budget on waste management: city governments allocate around 2% of APBD, while regency governments allocate only 0.4%.

3. In Deli Serdang, most of IWDS are located in Plantation/estate land use, totaling 75 IWDS with an area of 141,527.84 sq.m. Plantation/estate areas consistently recorded the highest number of IWDS incidents each year in Deli Serdang. This trend can be attributed to the secluded nature of these areas, making plantations ideal locations for illegal waste dumping. The covert nature of IWDS activities aligns with their tendency to occur in hidden or less accessible areas, which complicates detection by authorities.

4. IWDS locations in Deli Serdang are increasing from 98 in 2021 to 112 in 2022 and 120 in 2023. Concurrently, the total area IWDS in Deli Serdang also rose from 115,138.1971 sq.m in 2021 to 164,194.87 sq.m in 2023. The proliferation of IWDS in Deli Serdang from 2021 to 2023 underscores a pressing environmental challenge. Each year, the number of identified IWDS has steadily increased, reflecting not only the persistence of illegal dumping but also the evolving landscape of waste management issues in the region.

5. Some initiatives have already been implemented to reduce the IWDS activities, which can be best practices for reducing the IWDS activities intensity. Reduction of IWDS in Indonesia is in the quadrant II with aggressive maintenance, meaning that the issue of IWDS needs to be actively addressed with intensive maintenance and preventive strategies to control its negative impacts. This aggressive approach involves enhanced monitoring, strict enforcement of regulations, and intensive efforts in community education and participation to promote responsible waste management practices.

6.2. Future Research Direction

Future IWDS studies should consider the following points.

1. In Indonesia, there is a big difference between city and regency. The bigger proportion of urban cluster area in city is bigger than the regency while the service area is also smaller. IWDS activities shall be higher in the residential area in the city since the lack of land availability is present. Therefore, it is suggested to study this area, especially how the waste management model should be implemented in the area.
2. Future studies should explore the behavior, social and economic factors that could contribute to the reduction of IWDS activities in Deli Serdang Regency. A deeper understanding of the motivation of people to do the illegal dumping could have a significant impact on the ongoing studies.

3. Future research should also consider the optimization of waste collection route by using the proposed collection points. Therefore, to increase the possibility of reduction of IWDS activities there should be a consideration regarding the optimization of waste collection point in Deli Serdang Regency.

4. Focus group discussion (FGDs) for policy makers should be conducted to determine the possible actions for each region to reduce the IWDS activities in Indonesia

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