waste

Article

Exploring Municipal Solid Waste Dynamics in Rural Cambodia: Insights from Three Underrepresented Cities

Kohei Hibino [1,*], Chochoe Devaporihartakula [2], Phalla Sam [3], Rithy Uch [3], Bophaphal Sean [3], John Chek [3], Sophalin Sen [3], Premakumara Jagath Dickella Gamaralalage [4] and Yasuhiko Hotta [5]

[1] Kitakyushu Urban Centre, Institute for Global Environmental Strategies, 1-1-1, Hirano, Yahatahigashi-ku, Kitakyushu, Fukuoka 805-0062, Japan
[2] Regional Centre in Bangkok, Institute for Global Environmental Strategies, 287 Liberty Square Building, Unit 2103, 21st Floor, Silom Road, Silom, Bangrak, Bangkok 10500, Thailand; chochoe@iges.or.jp
[3] Environmental Education and Recycling Organization, #444, Str. 57BT, Sangkat Boeng Tumpun II, Khan Mean Chey, Phnom Penh P.O. Box 955, Cambodia
[4] IGES Centre Collaborating with UNEP on Environmental Technologies (IGES-CCET), Sustainble Consumption and Production Area, Institute for Global Environmental Strategies, 2108-11, Kamiyamaguchi, Hayama, Kitakyushu 240-0115, Japan; premakumara@iges.or.jp
[5] Sustainble Consumption and Production Area, Institute for Global Environmental Strategies, 2108-11, Kamiyamaguchi, Hayama, Kitakyushu 240-0115, Japan; hotta@iges.or.jp
* Correspondence: hibino@iges.or.jp

Abstract: (1) The enactment of Sub-Decree No. 113/2015 on Solid Waste Management marked a significant policy shift towards the decentralisation of waste management in Cambodia and some progress has been observed in Phnom Penh and some other large cities and tourist destinations. However, information in rural areas is lacking. Rapid and simple waste assessment methodologies are needed in rural areas where waste data is scarce and different waste management measures are required compared to urban areas. This study aimed to fill the information gap on the status and fate of municipal solid waste management in rural areas by focusing on three underrepresented cities in different geographical areas through empirical studies. (2) Rapid waste assessments, including waste composition analysis, truck scaling, waste recovery surveys, waste flow analysis, and waste hotspot surveys, were conducted. (3) The per capita waste generation averaged 0.44 kg/day, which is lower than the national average, but did not show significant differences between income levels. The waste composition was similar to that of urban areas, with plastics making up more than 20% of the waste. There were major contrasts in the waste collection rates, with one city having a high rate (85.9%) while the other two cities were as low as 22.6% and 24.2%, respectively. This suggests that rural cities in Cambodia are at different stages of transition in establishing their waste management systems after the decentralisation of waste management to municipalities. The main cause of the low waste collection rate was that private waste collectors were finding it difficult to collect service fees. In the absence of waste collection services, a total of 370 waste hotspots were identified outside of the waste collection areas, where littering and open burning of waste were common. (4) Addressing these challenges requires urgent development of sustainable financing mechanisms, enhanced institutional capacities, and implementation of targeted awareness-raising programmes. These measures are essential for providing basic waste collection and disposal services, as well as for curbing littering and open burning of waste in rural cities in Cambodia.

Keywords: Cambodia; rural; waste; recycling; decentralisation; plastic

check for updates

Citation: Hibino, K.; Devaporihartakula, C.; Sam, P.; Uch, R.; Sean, B.; Chek, J.; Sen, S.; Dickella Gamaralalage, P.J.; Hotta, Y. Exploring Municipal Solid Waste Dynamics in Rural Cambodia: Insights from Three Underrepresented Cities. *Waste* **2024**, *2*, 279–292. https://doi.org/10.3390/waste2030016

Academic Editors: Apostolos Giannis and Chao He

Received: 31 May 2024
Revised: 22 July 2024
Accepted: 24 July 2024
Published: 31 July 2024

1. Introduction

Cambodia has seen a steady increase in population and economic growth, accompanied by urbanisation and changes in people's lifestyle and consumption patterns, which have caused an increase in ecological footprints [1]. The per capita Domestic Material Consumption (DMC) of Cambodia was 7.5 tonnes in 2019 which was lower than the ASEAN average [2]. However, at that time, the country was going through transition to an industrial socio-metabolic regime [3], and this highlighted the urgent need for sustainable waste management strategies that can adapt to current conditions and deal with future increases in waste production. It has been estimated that on average, 54% of the generated waste was collected in 2021 and subsequently landfilled. The majority of disposal sites in Cambodia are unsanitary open dumpsites lacking essential environmental protections such as soil cover, leachate treatment, and gas control systems [4]. Other intermediate methods of waste treatment include recycling, incineration and composting but these are limited, and a significant proportion of generated waste is disposed of through uncontrolled dumping [4], which not only exacerbates environmental degradation but also poses significant health risks to the local population.

The enactment of Sub-Decree No. 113/2015 on Solid Waste Management marked a significant policy shift towards the decentralisation of waste management, transferring the responsibility of managing municipal solid waste (MSW) from national to provincial and municipal/district levels. It allowed the municipal government to entrust waste management services to private operators [5,6]. While this has enabled some progress, particularly in larger cities and tourist destinations such as Phnom Penh, Battambang and Siem Reap, rural areas have seen limited benefits due to poor institutional management, lack of capacity and limited resources [7]. Previous studies have pointed out the existence of gaps between urban and rural cities on waste management services, where some rural cities do not even have access to basic waste collection and disposal [4,8]. These disparities emphasise the need for targeted interventions by both governments and non-governmental organisations (NGOs) to address the unique challenges faced by rural areas.

Despite such a fragile waste management system, people's lifestyles have been modernised rapidly throughout the country, a change that is evident in the rapid increase in plastic consumption and disposal [9]. As a consequence, discarded plastic waste is leaked into the water environment through various water channels. Cambodia is home to Tonle Sap Lake and Tonle Sap River, which make up the largest freshwater lake-river system in Southeast Asia. The vast catchment area and the lake-river system connect to the Mekong River and eventually flow into the South China Sea. The projected amount of mismanaged plastic waste that could enter this basin between 2021 and 2030 was estimated to be 282,300 $\pm$ 8700 tonnes [10].

The capital city of Phnom Penh is home to about 15% of the population and about 39% of all Cambodia's waste is generated in this city [4,11]. Given the economic and political importance of Phnom Penh, many waste management projects and studies have taken place [5,12,13] resulting in a high waste collection rate of about 95% in urban areas and 80% in peri-urban areas [14]. Other large cities and tourist destinations, such as Siem Reap [15], Sihanoukville [16], Battambang [17], and Kep [18], etc. are also subject to well-documented donor funding and waste management projects. Despite the large population coverage and economic contributions of these major cities, their geographical coverage is limited, and there are many rural cities distributed throughout the country in various geographical areas. These rural cities are less exposed, receive less support and funding, and lack waste data. The dynamics of waste generation and its challenges are not well understood. This kind of basic information is important in designing appropriate policies and strategies for waste management peculiar to rural cities which have limited funding and resources and thus require different approaches from urban and/or more exposed cities. To this end, rapid and simple yet scientifically consistent waste assessment methodologies are needed to widen the coverage of data collection in rural areas.

Thus, this study aimed to fill the information gaps on the status and fate of MSW management in rural cities in Cambodia by focusing on three underrepresented rural cities in different geographical areas through empirical studies. Appropriate rapid waste assessment methodologies were identified and implemented, including waste composition analysis, truck scaling, waste recovery surveys, waste flow analysis, and waste hotspot surveys. Based on the findings and analysis, common challenges and features in these rural cities were identified and ways to improve MSW management and reduction of environmental impacts were discussed.

2. Materials and Methods

Selection of the three target cities was based on the following criteria: (a) limited exposures in terms of donor-funded waste management projects and lacking MSW data, (b) geographic representation, and (c) willingness and commitment to assist in implementing the survey. The geographical representation included the catchment areas of Tonle Sap Lake, the Mekong River, and a coastal area in Cambodia. The three selected cities were:

- Bokor City (BK), Kampot Province: Newly developed city in 2021, this city is divided into three communes and has a population of 23,866 (Source: Bokor City). It is located along the coast and was chosen to represent the coastal area;
- Steung Saen Municipality (SS), Kampong Thom Province: The city is divided into eight communes and has a population of 59,890 (Source: Steung Saen Municipality). It is located upstream of the Tonle Sap Lake and was chosen to represent the catchment of Tonle Sap Lake;
- Ou Reang Ov District (ORO), Tboung Khmum Province: The district is subdivided into seven communes and has a population of 101,485 (Source: Ou Reang Ov District). It is located in the lowlands of the Mekong River delta and was chosen to represent the catchment of the Mekong River.

Household waste was sampled to estimate the per capita waste generation and identify the waste composition from randomly selected 15 households, five households in each of three different income levels (i.e., high-income, middle-income, and low-income), in each target city. Income levels were determined based on the subjective rating from the outlook of the housing, properties such as owned vehicles, and occupations, verified by the village chief (in BK and ORO) and Sangkat/commune chief (in SS). The number of family members in each household was obtained during prior interviews. Sampling was conducted over five consecutive days, including weekdays and weekends (ORO was sampled for three consecutive days). Upon prior briefing and obtaining consent, household owners were asked to collect all waste generated in one full day in a provided plastic bag on the day before each sampling. The weight of the waste collected from each household was measured using a scale on-site to ensure accuracy in data collection.

Accurate data on the proportion of income levels in each city could not be obtained from the local governments, leading to potential biases in waste generation estimates. Consequently, the overall per capita waste generation for each city was calculated using the following Equation (1) under the assumption that the proportion of high-income, middle-income and low-income households was equal. The total amount of waste generation in each city was estimated by multiplying the per capita waste generation and the population of the city. Industrial and commercial waste generation was not accounted for, likely resulting in an underestimation of total waste.

$$PCWG_c = \frac{PCWG_{hi} + PCWG_{mi} + PCWG_{li}}{3} \tag{1}$$

where,

$PCWG_c$ = per capita waste generation of the entire city
$PCWG_{hi}$ = per capita waste generation of high-income households
$PCWG_{mi}$ = per capita waste generation of middle-income households
$PCWG_{li}$ = per capita waste generation of low-income households

Commercial waste was sampled for waste composition analysis from 10 randomly selected small-scale businesses (restaurants, grocery stores, hotels) in the town over five consecutive days (ORO was sampled for two consecutive days), targeting the same business operators to maintain consistency. The same sampling method as the household waste was used. Landfill waste was sampled for waste composition analysis before the waste was dumped into the landfills to avoid valuable waste being picked up by the scavengers. This was intended to provide insights into the final composition of waste entering the landfill, offering a complete picture of waste management in the study areas. Waste from randomly selected waste collection trucks serving each city was sampled over consecutive days (three days for ORO and five days for SS). BK did not have a formally designated landfill (only a temporary dumpsite), so landfill data were not collected. Approximately 100 kg of waste was randomly sampled from each truck during the collection period.

Waste composition analysis aimed to characterise the sampled waste from households, commercial sectors, and landfills (the sampled waste of households and commercial sectors in SS was mixed and measured together). The coning and quartering method was applied to extract homogenised waste samples for detailed analysis from the large mass waste [19]. This method was selected due to its efficacy in reducing sample size while maintaining a representative mix of waste types, though it did not correct for moisture content in dry materials, such as papers, plastics, textiles, etc., potentially leading to overestimations of certain waste components when they got wet during the homogenising process. The final waste heap (1/4 of the initial amount) was then separated into six categories (Paper, Plastic, Glass, Metal, Other, and Organic) according to the Waste Flow Diagram (WFD) methodology [20] and weighed separately.

To address the lack of a proper weighbridge to measure the weight of waste input at landfills (including temporary dump sites) of three cities, a portable truck scale was employed to measure the weight of all trucks (including other types of vehicles such as motorised tricycles) that entered the landfills to dispose of waste in one full day (on weekdays). The accuracy of this data was limited compared to using an onboard weighing scale (full scale) or an axle scale (double scale). Trucks carrying waste from neighbouring cities were excluded from the measurement, and confirmation was made with the designated waste collection companies that no trucks collected waste from more than two cities in a single collection. The available portable truck scale was only one, so the following Equation (2) was applied to estimate the net weight of waste. An appropriate site for measurement (asphalt or concrete stable substrate) was selected where the four tyres (three tyres in the case of motorised tricycles) could be kept at the same level when the tyre is placed on the scale.

$$NW = (W_{bf} \times 2 + W_{br} \times 2) - (W_{af} \times 2 + W_{ar} \times 2) \quad (2)$$

where,

NW = Net weight of waste amount unloaded in the landfill per truck, kg
W_{bf} = Weight of front wheel before unloading waste, kg
W_{br} = Weight of rear wheel before unloading waste, kg
W_{af} = Weight of front wheel after unloading waste, kg
W_{ar} = Weight of rear wheel after unloading waste, kg

In all three cities, there were no formal waste recovery systems, such as composting centres, material recovery facilities (MRF), or refuse-derived fuel (RDF) production plants, making the informal sector the only waste recovery mechanism available. This study categorised the informal sector into three types: (a) waste pickers, individuals who pick recyclable waste from household waste bins, temporary waste storage and landfills; (b) waste buyers, individuals or groups using a push-cart to visit household and commercial sectors to buy recyclable materials; and (c) junk shops, shop owners who buy and stock recyclable waste from waste pickers and buyers and sell them to recycling industries or junk dealers for exporting to other countries for recycling [4].

Extensive in-person interviews were conducted by visiting the available junk shops, waste buyers, and waste pickers in each city to the extent possible. However, given their informal nature, it was challenging to interview all of them nor was it possible to ascertain the exact population of the informal sector in the target cities accurately. Some individuals refused to respond to the interviews or could not be reached. Interviews were conducted verbally (as some of the interviewees cannot read/write) based on the predefined set of questions on waste recovery. Prior to the interviews, informed consent was obtained. Personal information was not collected from the interviewees and they were anonymised. Initially, it was considered that the recovery amount reported by junk shops would indicate the overall recovery amount in the city. However, interviewing all the junk shops proved difficult, and it also revealed substantial daily fluctuations in the waste acceptance amount, suggesting difficulty in estimating the waste recovery amount from the junk shop data alone. On the other hand, a majority (79%) of the interviewed waste buyers and waste pickers were working full-time (seven days per week), and their perception of daily recovery amount was considered more accurate than that of the junk shops. Therefore, the estimated waste recovery amount in the city was calculated from primary data obtained through interviews with the waste pickers and buyers by multiplying the average amount of waste recovery per individual by the perceived population of the informal sectors in each city. The waste buying price of major recyclable waste types was also surveyed, and the potential monetary value generated by the informal sector was estimated.

A Waste Flow Diagram (WFD) tool [20] was initially employed to map the material flow and potential fate of waste based on the obtained dataset in the target cities. WFD is a rapid assessment methodology for mapping the flows of macro waste in an MSW management system, including quantifying the sources and fate of any plastic pollution. Aside from using the primary data taken in this study, subjective data based on rank ratings were verified by city government officials responsible for waste management in each city. However, the authors found that many of the subjective rating data did not have firm evidence and/or were lacking and difficult to obtain as suggested in the WFD user manual [20]. Therefore, the data reliability was considered to be low, and the authors decided not to use WFD but to make a simpler waste flow diagram using SankeyMATIC [21], which could be generated only by using an objective dataset.

Mobile Application for Macro Plastic Survey is a mobile phone application tool developed using ArcGIS Survey123 [22] for identifying local plastic hotspots by visual inspection and mapping them on the online GIS platform [23,24]. Before conducting the survey, three cities were added to the platform to allow data entry. The survey areas were identified outside the waste collection area where waste littering was expected. The boundaries of the waste collection were clarified by interviewing the waste collection companies. The survey was undertaken using motorcycles by driving along all the roads within the survey area. Whenever a waste hotspot was spotted, visual estimation of the occupied volume of waste, the type of waste, and location type was recorded, and GIS coordinates and photos were taken and uploaded to the platform. The occupied volume of waste is an indicative figure where waste was scattered (length × width × height) and does not represent the actual volume of waste. The period of the Macro Plastic Survey differed depending on the size of the targeted area and availability of waste hotspots, and was not standardised among the three cities. The survey took seven days for BK, four days for ORO, and three days for SS. Each location type was not clearly defined in the guidelines, so they are defined as follows:

- Artificial barrier: An accumulation of waste where the majority is in the water body, blocking or restricting the movement of water. An intertidal zone where the waste is submerged during high tide was also included even when the waste was not submerged in the water at the time of the survey.
- Littering spot: A relatively new accumulation of waste where people dispose of waste out of habit, on a scale that is smaller than an uncontrolled dump site (i.e., limited to a few households).
- Uncontrolled dump site: An informal open dumping site where people have been disposing of waste out of habit for years and where there is a large accumulation of waste (i.e., more than 1 m in height).

A rank-based non-parametric Kruskal–Wallis test was used to determine if there were statistically significant differences between the groups (p-values < 0.05). The null hypothesis was that the mean ranks of the groups were the same. The open-source software Jamovi [25] was used for the analysis, providing robust statistical validation of the findings.

3. Results

3.1. Waste Generation and Composition

The per capita waste generation in the three cities averaged 0.44 kg/day. There were no significant differences in the per capita waste generation between the three income levels (N = 46; χ^2 = 0.154; df = 2; p = 0.926) which ranged between 0.41 to 0.48 kg/day on average. On the other hand, the per capita waste generation showed a significant difference between the three cities (N = 46; χ^2 = 29.4; df = 2; p < 0.001) where SS showed the highest value at 0.52 kg/day and BK the lowest at 0.31 kg/day on average (Table 1).

Table 1. Result of per capita waste generation at different income levels and the estimated amount of waste generation in the three cities. The population data was obtained from each city.

City	Population	Per Capita Waste Generation (kg/person/day)				Estimated Amount of Waste Generation (tonne/day)
		High Income	Middle Income	Low Income	Average	
Bokor	23,866	0.47	0.22	0.23	0.31	7.40
Steung Saen	59,890	0.47	0.59	0.49	0.52	31.14
Ou Reang Ov	101,485	0.49	0.43	0.52	0.48	48.71
Average		0.48	0.41	0.41	0.44	

The results of waste composition analysis in households, the commercial sector, and landfills showed that organic waste was dominant throughout all cities and all sectors, ranging between 45.4% and 67.4% (average 56.1%) of the total amount of waste. Plastic waste was the second-most dominant composition, ranging between 18.3% and 24.4% (average 20.8%). It was expected that landfill waste would have less recyclable waste contents, such as plastic, glass, and metal, as these types of waste could have been taken by the informal sector before being collected by the waste trucks. However, it was not reflected in the result of the waste composition (Table 2).

Table 2. Result of waste composition analysis in the three cities in households, commercial sector, and landfills (unit: %).

City	Sector	Organic	Paper	Plastic	Glass	Metal	Other
Bokor	Household	63.35	2.66	24.36	1.36	0.53	7.74
	Commercial	59.86	11.99	18.99	2.18	0.81	6.17
	Landfill	-	-	-	-	-	-
Steung Saen	Household Commercial	45.77	18.00	18.26	6.14	1.78	10.04
	Landfill	59.83	10.05	19.80	1.04	0.80	8.48
Ou Reang Ov	Household	67.40	4.78	17.48	0.66	1.47	8.21
	Commercial	51.29	13.62	22.76	3.51	1.25	7.56
	Landfill	45.35	10.31	23.91	1.97	1.46	17.00
Average		56.12	10.20	20.79	2.41	1.16	9.31

3.2. Waste Collection and Final Disposal

The results of truck scaling enabled the amount of waste disposed in the three cities to be quantified for the first time (Table 3). The amount of waste disposed of in landfill in SS was the largest, while that of BK (temporary dump site) was very small. The waste collection rate estimated from the amount of waste generation (Table 1) and the amount of waste disposed in the landfill showed that SS was exceptionally high (85.9%) while BK (22.6%) and ORO (24.2%) were significantly lower. In comparison with the average for the province [4], SS was higher and BK and ORO were lower.

Table 3. Amount of waste dumped in landfills (including temporary dump sites) in one full day in the three cities using a truck scale and the estimated waste collection rates.

City	Number of Waste-Carrying Vehicles	Number of Trips Made for Disposal in One Day	Average Amount One Vehicle Carried (tonnes)	Amount of Waste Disposed to the Landfill (tonne/day)	Waste Collection Rate	
					City Average (%)	Province Average (%) [4]
Bokor	4	7	0.24	1.67	22.6	79 (Kampot)
Steung Saen	4	11	2.43	26.75	85.9	34 (Kampong Thom)
Ou Reang Ov	2	6	1.97	11.80	24.2	51 (Tboung Khmum)

All the existing landfills and temporary dump sites available in these three cities were unsanitary open dumpsites without soil coverage, landfill liners, leachate treatment facilities, or gas control systems. Open burning of waste was observed across all the landfills and temporary dump sites. At the time when the survey was conducted in July 2022, BK did not have a formally designated state-owned landfill and only a temporary disposal site (private landfill) was available in Sangkat Preaek Tnoat. There was also no formal waste collection service in BK until June 2022, so the survey was conducted just after a partial waste collection service began and this could be the reason for the low waste collection rate (22.6%). The only waste collection available before that was by some private initiatives. The central market of BK was collecting waste from its tenant shops for a service fee. Similarly, the chief of Sangkat Preaek Tnoat was collecting waste from households for a service fee using the motorised cart he owned. SS had three landfills including the old landfill (closed), the current landfill, and the Asian Development Bank (ADB)-financed landfill which was under construction at the time of the survey. ORO was the first district that started formal waste collection among all districts in Cambodia (according to the Ministry of Environment). ORO District exchanged a contract with a private operator in April 2021 to start waste collection and disposal in the state-owned landfill targeting four out of the seven communes in the district. Before the waste collection service was initiated, only market waste was collected by a private contractor. When the private operators in ORO were interviewed, they noted the challenges of collecting waste fees from the household and commercial sectors to finance the operation.

3.3. Waste Recovery

The number of interviews carried out with the informal sector in each city were as follows: waste pickers (BK: 2, SS: 3, ORO: 9), waste buyers (BK: 3, SS: 13, ORO: 13) and junk shops (BK: 1, SS: 6, ORO: 5). The results showed that the estimated amount of waste recovery by informal sectors differed considerably between the three cities. BK revealed the highest recovery amount and rate (3532 kg/day; 47.7%), followed by SS (3081 kg/day; 9.9%), and ORO was the lowest both in the recovery amount and rate (1565 kg/day; 3.2%). Among the waste types, plastics (32.0%) exhibited the highest recovery rate followed by paper (23.3%) (Table 4). On the other hand, plastics (611 Riel/kg) and paper (434 Riel/kg) had a lower selling price by an order of magnitude than copper (7244 Riel/kg) and aluminium (5236 Riel/kg) (Table 5).

Waste buyers in all three cities exhibited both higher waste recovery amount and sales revenue compared to waste pickers (Figure 1). As defined in the Section 2, waste buyers use push-carts and go around households and commercial sectors to purchase waste items. This type of waste collection method was shown to be much more effective in terms of accessing recyclable waste compared to waste pickers who usually collect waste off the streets or from landfills. In particular, aluminium recovered by waste buyers gained outstanding sales revenue (Riel 137,165/day) which indicated that it is a driver in the informal sector in the three cities.

Table 4. The average amount of waste recovery and estimated total recovery amount by waste buyers and waste pickers in the three target cities.

City	Informal Sector			Average Amount of Waste Recovery (kg/day) of Interviewed Individuals									Subtotal (kg/day) [a × b]	Total (kg/day)
	Type	Number Interviewed	Number Estimated [a]	Pa	Pl	Gl	Al	Ir	Co	Ba	Ot	Total [b]		
Bokor	Buyer	3	19.0	60.0	58.0	0.0	36.7	21.0	0.0	5.0	0.0	180.7	3432.7	3532
	Picker	2	3.0	5.0	10.0	0.0	3.0	15.0	0.0	0.0	0.0	33.0	99.1	
Steung Saen	Buyer	3	7.0	28.7	33.3	0.0	26.0	23.3	3.3	12.3	11.3	138.3	2942.2	3081
	Picker	13	14.5	9.7	21.0	0.2	1.5	1.8	0.0	0.0	6.8	41.0	138.5	
Ou Reang Ov	Buyer	13	33.9	10.5	28.8	0.0	15.9	27.3	0.1	2.3	1.8	86.8	968.3	1565
	Picker	9	4.1 *	1.8	7.3	0.0	2.4	2.5	0.6	0.9	0.0	15.4	596.6	
	Percentage (%)			23.3	32.0	0.0	17.3	18.4	0.8	4.1	4.0	100		

Waste type acronyms: Pa: Paper, Pl: Plastic, Gl: Glass, Al: Aluminium, Ir: Iron, Co: Copper, Ba: Battery, Ot: Other. * The number of estimated waste pickers was smaller than the number of interviewed waste pickers, so the number of interviewed (9) was used to estimate the subtotal of waste amount.

Table 5. The average selling price of major recyclable waste items by waste buyers and waste pickers to junk shops in the three target cities (unit: Riel/kg).

City (Number of Respondents)	Paper	Plastic	Glass	Aluminium	Iron	Copper	Battery	Other
Bokor (5)	475	550	-	5140	1000	1700	3000	-
Steung Saen (16)	277	447	250	4981	818	16,200	3167	331
Ou Reang Ov (22)	550	835	-	5586	1188	3833	3260	650
Average	434	611	250	5236	1002	7244	3142	491

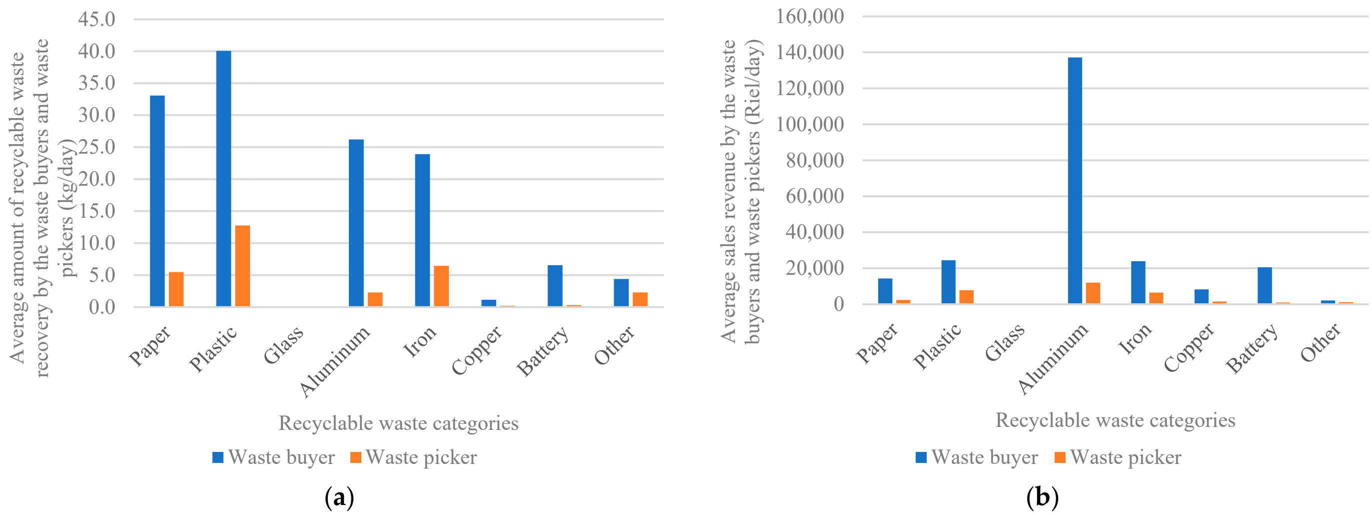
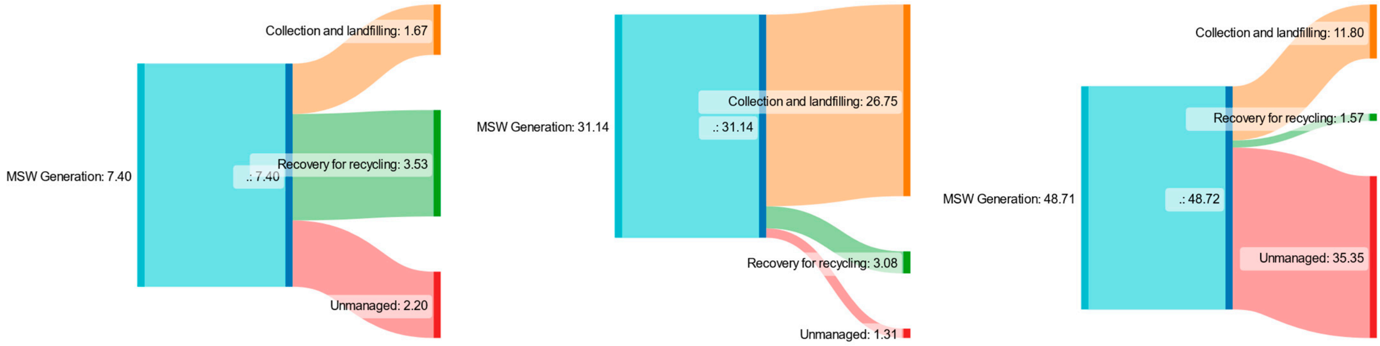


Figure 1. The average amount of daily waste recovery (**a**) and sales revenue (**b**) by the informal sectors (waste buyers and waste pickers) in the three target cities.

3.4. Waste Flow

The overall waste material flow in the three target cities is shown in the the Sankey diagram in Figure 2. It clearly shows the different characteristics of waste management and the fate of the waste in the three cities. BK was balanced between waste collection, waste recovery and unmanaged waste, with recovery waste taking up the largest portion. In contrast, SS was dominated by waste collection and landfilling, and ORO was dominated by unmanaged waste.



(**a**) (**b**) (**c**)

Figure 2. An overall waste material flow in Bokor (**a**), Steung Saen (**b**) and Ou Reang Ov (**c**) is illustrated by the Sankey diagram using Sankey004DATIC [21]. The numbers are shown in tonnes/day.

3.5. Waste Hotspots

The results of the Macro Plastic Survey enabled an understanding of the spatial distribution of unmanaged waste in the cities, as well as the type of location and indicative figure for the occupied volume of waste in the waste hotspots. In total, 370 waste hotspots were identified, recorded and then made available on the online GIS platform [23]. In terms of the type of location of the waste hotspots, littering spots were most dominant (82%) followed by artificial barriers (18%) while it was found that there were no uncontrolled dump sites (0%). BK had the largest number of hotspots identified as artificial barriers (25%) among the three cities, which could be explained by its location in a coastal area. The average occupied volume of waste hotspots was the largest in SS. Most of the waste hotspots (76.5%) were small and fell within the volume size range of 0–10 m^3 (Table 6) and none of them had a large pile of waste accumulation that was more than 1 m in height (as defined in the uncontrolled dump site category). Essentially, most waste in the identified hotspots was domestic solid waste containing plastics, food waste, paper, etc., so it was difficult to clearly distinguish the type of waste, and therefore the data was not taken.

Table 6. Type of location, number and occupied volume of waste in identified waste hotspots in the three cities. The occupied volume of waste is an indicative figure where waste was scattered (length × width × height) and does not represent the actual volume of waste.

City	Number of Days Used for the Survey	Type of Location			Sub-Total	Average Occupied Volume of Waste (m^3)	Number (%) of Hotspots with a Volume of 0–10 m^3
		Littering Spot	Artificial Barrier	Uncontrolled Dump Site			
Bokor	7 days	141	47	0	188	9.2	155 (82%)
Steung Saen	3 days	108	11	0	119	16.4	75 (63%)
Ou Reang Ov	4 days	54	9	0	63	8.3	53 (84%)
Total		303	67	0	370	11.4	283 (76.5%)

4. Discussion

According to the ASEAN Statistical Yearbook, Cambodia experienced the highest population growth rate in the region, reaching 1.6% in 2021 [26]. Concurrently, the country's per capita GDP more than doubled from USD 746 in 2008 to USD 1512 in 2018. Accompanying this economic and population growth was an increase in per capita waste generation, rising from 0.73 kg/day in 2008 to 0.78 kg/day in 2018 [4]. However, the average per capita waste generation in the three cities targeted in this study was significantly lower at 0.44 kg/day, indicating a disparity between urban and rural waste generation rates, which aligns with previous findings that urban areas typically have higher waste generation rates than rural areas in developing countries [27]. Interestingly, the general concept that waste generation increases in line with income growth up to a certain level [28] did not hold true in this study. The results showed no significant differences in per capita waste generation across three different income levels. This anomaly may be attributed to the small sample size of this study but also suggested that factors other than income (economic), including social and geographical factors, might be influencing the waste generation [28].

The waste composition analysis in three cities revealed that organic waste (56.12%) and plastic waste (20.79%) are the predominant types of the MSW. This is consistent with trends in the capital city, Phnom Penh, where there has been a significant shift from predominantly food waste which declined from 87% in 1999 to 50% in 2015, while plastic waste showed a drastic increase from only 6% in 1999 to 21% in 2015 [4,29]. This indicates a transformation in the waste composition in Cambodia, with a notable rise in plastic and other non-biodegradable materials, especially single-use plastics and packaging waste which reflected the change in consumption patterns in both urban and rural areas.

The overall waste material flow in the three cities (Figure 2) showed a clear contrast between them. In particular, the differences in the waste collection rate revealed a significant gap. SS had a high collection rate of 85.9%, while the other two cities, BK (22.6%) and ORO (24.2%) lagged significantly behind. These variations emphasise the challenges and inefficiencies in waste management infrastructure across different regions, further compounded by the absence of consistent policy enforcement and financial support. BK did not even have a formal state-owned landfill at the time of the survey, and had only recently started waste collection using a private contractor. At the time of the survey, the contractor only collected waste from the central market and a few households and businesses around the market. ORO began its waste collection service using a private contractor about a year before the survey (April 2021) but struggled with low service coverage due to difficulties in collecting the service fees. In order to fill the shortfall in service fees, the private contractor for ORO began to cover two other districts in addition to ORO. In contrast, the waste collection service in SS was also privatised but had begun operating much earlier in 2008 and covered all eight communes, reaching a mature stage with a high collection rate. SS also hired another private contractor to do clean-ups and sweeping activities along the roads and rivers with a budget supported by the central government. These situations suggest that rural cities in Cambodia are at a quite different stages of operationalising their MSW management systems following the enactment of the Sub-Decree No. 113/2015 on decentralisation of waste management to municipal/district levels.

Financing remains a major bottleneck in scaling waste management services, especially in rural areas. Challenges when collecting service fees are exacerbated by a lack of enforcement and institutional support, which has led to ineffective fee collection strategies in many low-income countries [30,31]. In Cambodia, a lack of institutional arrangement and enforcement to secure service fees for waste collection has also been identified by previous studies [4,5]. There have been some attempts made to integrate waste collection fees into the other utility bills, such as electricity bills, to ensure effective fee collection. However, this approach was unsuccessful due to protests from residents regarding the poor service performance of the private contractors [7,32]. Consequently, cities are struggling to find effective fee collection methods. In all three cities, local authorities hire private contractors to provide waste collection services and it is the responsibility of the private contractors to collect the service fees from residents and businesses. When interviewing the private contractors, it emerged that the village authorities in SS accompanied the private contractor when they began collecting fees, allowing smoother monthly fee collections. This evidence was also described in the previous study [32]. However, private contractors in BK and ORO did not mention this kind of direct support by the local authorities. While collection of service fees necessarily entails trial and error, it also requires stronger commitments by local authorities, and in fact, one reason for the high waste collection rate in SS could be attributed to this support by the village authorities at the beginning of the contract.

Several interviews in ORO revealed that many residents are unwilling to pay waste collection fees because it is not customary nor is it strictly enforced. With limited fee recovery and inadequate municipal support, it is challenging for designated private operators to expand or even continue the waste collection services. This situation provides evidence for the lower waste collection rate in rural cities compared to urban and tourist areas which have larger and more stable revenue bases. Thus, establishing an appropriate and sustainable financing mechanism for these rural cities is a priority to enable basic waste collection and disposal services. This should be done before introducing more sophisticated development approaches such as proper sanitary landfills, promotion of source separation, and material recovery and recycling facilities.

The informal sector was the main mechanism for waste recovery in the country, and the only mechanism available in all three target cities. The results showed that waste buyers are the major contributors to waste recovery and sales in the three cities exceeding the contribution of waste pickers. The top four categories of recovered waste were plastic, paper, aluminium and iron, consistent with the waste recovered by junk shops in Cambodia from 2010 to 2021 [4]. The survey found that the sales revenue of aluminium by waste buyers was significantly higher compared to other materials and recovery by waste pickers, suggesting that aluminium is the main driver of informal recycling in rural cities. This insight could inform targeted recycling programmes that prioritise high-value materials to enhance economic incentives for waste collectors. This study also highlighted the difficulties and limitations of accurately estimating the quantity of waste recovery by the informal sector. The exceptionally high waste recovery rate in BK (47.7%) could not be fully explained, potentially due to overestimation or underestimation of total waste generation. However, it suggested the high potential of waste recovery by the informal sector.

The results of the Macro Plastic Survey showed that littering is a commonly observed practice outside the waste collection area in all three cities. The waste collection rate in SS was estimated to be 85.9% which was notably higher than that of the other two cities and the national average. However, littering was still prevalent outside the waste collection area in SS despite its high collection rate. Most littering spots were identified along public roads and near housing or residential areas. As most waste hotspots (76.5%) were small in volume (0–10 m^3) and there were no large-scale uncontrolled dumpsites, it was considered that these littering spots serve as a place for nearby communities to dispose of daily waste. In addition, open burning of waste was commonly observed at most of these hotspots as pointed out in a previous study [33]. Although this rapid assessment did not include data on measuring open burning of waste, a previous study done in Steung Saen Municipality [34] identified that 21.17% of the generated waste was burned at either the source (10.9%, or 3876 kg/day) or at the disposal facility (10.25%, or 3640 kg/day). Open burning of waste is the major source of PCDD/Fs and dioxin-like PCBs from low-temperature and incomplete combustion of waste [35]. These toxic materials contaminate water, soil, and sediment and are eventually taken up by organisms that people consume through bioaccumulation, such as freshwater fish [36] in the case of SS and ORO, and coastal benthic biota and mussels in the case of BK [37]. The same study [34] estimated that the total amount of black carbon (BC) emissions from waste burning in SS was 8535 g/day and the total climate impact from BC emissions was 13,123 kg CO2-eq. In total, it was estimated that the climate impact that would occur from BC emissions from open burning of waste in SS amounted to 4790 tonnes CO2-eq/year. According to both these results and the observations from this study, communities that routinely conduct open burning of waste do not seem to be aware of the potential climate and health hazard. Thus, there needs to be more awareness raising and stricter enforcement to stop littering and open burning of waste, in addition to providing basic waste collection services.

One of the intentions of this study was to identify and test appropriate rapid waste assessment methodologies to facilitate data collection even with limited budget and resources in rural cities in Cambodia. Consequently, the surveys took more than a week per city and were conducted by three skilled full-time staff from the local waste management consultant film in addition to two supervisors involved in an advisory role. All the agencies responsible for waste management in the three cities were understaffed and lacking in the skills necessary to undertake this kind of waste assessment by themselves. The study demonstrated that the series of rapid assessment methods enabled sufficient basic waste data to be obtained for strategy development including generation, composition, recovery, and waste hotspots. However, there is still room for further consideration on the appropriateness of the methodologies, considering trade-offs between data quality, duration and resource input.

5. Conclusions

This study illuminates the significant disparities in waste management practices between urban and rural areas within Cambodia, with a focus on three underrepresented rural cities. Through comprehensive waste assessments including waste composition analysis, truck scaling, waste recovery surveys, waste flow analysis, and waste hotspot surveys, the study revealed some peculiar features of MSW management in rural cities. The per capita waste generation in the three cities (average 0.44 kg/day) was much lower than the national average, which is dominated by a few large urban areas, including Phnom Penh. However, the waste composition, particularly plastics, was similar to that of the urban cities, suggesting that there are no major differences in the consumption pattern between urban and rural cities. A significant contrast was observed in waste collection rates with SS showing a high rate (85.9%) while BK and ORO had much lower rates of 22.6% and 24.2%, respectively. This suggested that rural cities in Cambodia are at different stages of transition in establishing their waste management systems following the decentralisation of waste management responsibilities to municipalities. The critical challenge identified through this study is the effective collection of waste management fees, which is a common issue in rural settings where institutional support and enforcement are lacking. The absence of adequate waste collection services has led to the proliferation of 370 waste hotspots, particularly in areas outside regular collection routes, where open burning and littering are prevalent. To address these challenges, it is imperative to develop sustainable financing mechanisms and institutional capacities. There is also a pressing need for robust awareness-raising programmes to educate communities about the importance of proper waste disposal and the environmental and health hazards associated with improper waste practices including littering and open burning of waste in rural cities in Cambodia. Future efforts should focus on integrating these rural waste management systems into broader national and regional policies to ensure a cohesive approach that aligns with international environmental standards. Existing national waste management policies, which are more focused on solving urban waste problems, need to give equal weight to rural waste management issues. For example, a cost-sharing model for waste management charges between urban and rural or national and rural areas could be considered, in addition to charging local communities to ensure the provision of essential services in rural areas. Moreover, building institutional capacities and fostering innovations in appropriate waste management technologies and practices could significantly enhance the efficiency and sustainability of these rural waste management systems.

Author Contributions: Conceptualization, K.H. and P.J.D.G.; Methodology, K.H. and C.D.; Validation, K.H.; Formal Analysis, K.H.; Investigation, B.S., J.C., S.S., K.H. and C.D.; Resources, P.S. and R.U.; Data Curation, K.H. and B.S.; Writing—Original Draft Preparation, K.H.; Writing—Review & Editing, K.H., C.D., P.S., R.U., B.S., P.J.D.G. and Y.H.; Supervision, Y.H., P.J.D.G., P.S. and R.U.; Project Administration, Y.H. and P.J.D.G.; Funding Acquisition, Y.H. and P.J.D.G. All authors have read and agreed to the published version of the manuscript.

Funding: This study was part of the "Strengthening Capacity for Marine Debris Reduction in ASEAN Region through formulation of National Action Plans for ASEAN Member States and Integrated Land-to-Sea Policy Approach (Phase 2)" funded by the Japan-ASEAN Integration Fund (JAIF). The project was implemented from January 2022 to December 2023.

Institutional Review Board Statement: Institutional Review Board approval was not acquired as IGES didn't have one at the time of the survey. However, the authors followed the basic ethical procedures, including informed consent, anonymity, and data protection when interviewing informal sectors.

Informed Consent Statement: Informed consent was obtained from the informal sector interviewees verbally because some of them cannot read/write.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to thank Ministry of Environment of Cambodia, Bokor City, Steung Saen Municipality, and Ou Reang Ov District for providing guidance and support to implement the surveys.

Conflicts of Interest: Authors Phalla Sam, Rithy Uch, Bophaphal Sean, John Chek, Sophalin Sen are employed by the company Environmental Education and Re-cycling Organization. The remaining authors declare that the research was conducted in the ab-sence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Kaur, R.; Kaur, T.P. Modelling Urbanization, Economic Growth, and Ecological Footprint Using Environment Kuznets' Curve in Selected Asian Countries. *Int. J. Soc. Ecol. Sustain. Dev.* **2023**, *14*, 1–19. [CrossRef]
2. Schandl, H.; Soonsawad, N.; Martinez, M. *State of Resource Efficiency in Cambodia, Lao PDR, Philippines, and Viet Nam in 2019*; CSIRO: Canberra, Australia, 2022.
3. Martinico-Perez, M.F.; Chiu, A.S.; Laganao, K.J.; Mallari, C.B.; Molina, J.L.; Wang, X. Material Flow and Material Footprint in Cambodia, Laos, and Myanmar. *Clean. Responsible Consum.* **2023**, *11*, 100153. [CrossRef]
4. Pheakdey, D.V.; Quan, N.V.; Khanh, T.D.; Xuan, T.D. Challenges and Priorities of Municipal Solid Waste Management in Cambodia. *Int. J. Environ. Res. Public Health* **2022**, *19*, 8458. [CrossRef] [PubMed]
5. Spoann, V.; Fujiwara, T.; Seng, B.; Lay, C.; Yim, M. Assessment of Public–Private Partnership in Municipal Solid Waste Management in Phnom Penh, Cambodia. *Sustainability* **2019**, *11*, 1228. [CrossRef]
6. Vong, M. *Progress and Challenges of Deconcentration in Cambodia: The Case of Urban Solid Waste Management*; CDRI Working Paper Series; Cambodia Development Resource Institute: Phnom Penh, Cambodia, 2016; ISBN 9789924500100.
7. Yagasa, R.; Uch, R.; Sam, P. Solid Waste Management in Cambodia. In *Advances in Environmental Engineering and Green Technologies*; Pariatamby, A., Shahul Hamid, F., Bhatti, M.S., Eds.; IGI Global: Hershey Penn, PA, USA, 2020; pp. 56–85, ISBN 978-1-79980-198-6.
8. Sethy, S.; Sothun, C.; Wildblood, R. Municipal Solid Waste Management in Cambodia. In *Municipal Solid Waste Management in Asia and the Pacific Islands*; Pariatamby, A., Tanaka, M., Eds.; Environmental Science and Engineering; Springer: Singapore, 2014; pp. 77–94, ISBN 978-981-4451-72-7.
9. Seng, B.; Kaneko, H.; Hirayama, K.; Katayama-Hirayama, K. Municipal Solid Waste Management in Phnom Penh, Capital City of Cambodia. *Waste Manag. Res.* **2011**, *29*, 491–500. [CrossRef] [PubMed]
10. Finnegan, A.M.D.; Gouramanis, C. Projected Plastic Waste Loss Scenarios between 2000 and 2030 into the Largest Freshwater-Lake System in Southeast Asia. *Sci. Rep.* **2021**, *11*, 3897. [CrossRef] [PubMed]
11. Mam, S.; Raji, M. Improving the Capacity of Public Private Partnership (PPP) in Municipal Solid Waste Management, Phnom Penh. *Int. J. Sci. Eng. Res.* **2021**, *12*, 619–672.
12. Pheakdey, D.V.; Quan, N.V.; Xuan, T.D. Economic and Environmental Benefits of Energy Recovery from Municipal Solid Waste in Phnom Penh Municipality, Cambodia. *Energies* **2023**, *16*, 3234. [CrossRef]
13. Chinda, T.; Thay, S. Long-Term Food Waste Management in Phnom Penh Utilizing a System Dynamics Modeling Approach. *Environ. Eng. Res.* **2020**, *27*, 200603. [CrossRef]
14. Mongtoeun, Y.; Sousan, L.; Reasey, H.S.; Pasicolan, T.J.; Pasicolan, P.N. Current Situation of Municipal Solid Waste Management in the Urban and Peri-Urban of Phnom Penh, Cambodia. *Ann. Civ. Environ. Eng.* **2023**, *7*, 67–72. [CrossRef]
15. Parizeau, K.; Maclaren, V.; Chanthy, L. Waste Characterization as an Element of Waste Management Planning: Lessons Learned from a Study in Siem Reap, Cambodia. *Resour. Conserv. Recycl.* **2006**, *49*, 110–128. [CrossRef]
16. Jackie Ong, L.T.; Smith, R.A. Perception and Reality of Managing Sustainable Coastal Tourism in Emerging Destinations: The Case of Sihanoukville, Cambodia. *J. Sustain. Tour.* **2014**, *22*, 256–278. [CrossRef]
17. COMPED. Battambang Solid Waste Management: Baseline Survey. 2011, *27*. Available online: https://hdl.handle.net/20.500.12870/4734 (accessed on 23 July 2024).
18. Godlove, C.; Pak, K. *Solid Waste Management in Kep Province*; The Asia Foundation: San Francisco, CA, USA, 2020.
19. Gerlach, R.W.; Dobb, D.E.; Raab, G.A.; Nocerino, J.M. Gy Sampling Theory in Environmental Studies. 1. Assessing Soil Splitting Protocols. *J. Chemom.* **2002**, *16*, 321–328. [CrossRef]

20. GIZ; University of Leeds; Eawag-Sandec, Wasteaware. *User Manual: Waste Flow Diagram (WFD): A Rapid Assessment Tool for Mapping Waste Flows and Quantifying Plastic Leakage*; Version 1.0; GIZ: Bonn, Germany; Available online: https://archive.researchdata.leeds.ac.uk/id/eprint/751 (accessed on 23 July 2024).
21. Bogart, S. SankeyMATIC. Available online: https://sankeymatic.com/ (accessed on 11 November 2023).
22. ESRI. ArcGIS Survey123. Available online: https://www.esri.com/en-us/arcgis/products/arcgis-survey123/ (accessed on 24 April 2024).
23. Geoinformatics Center. Mobile Application for Macro Plastic Survey. Available online: https://arcg.is/1yDHym0 (accessed on 24 April 2024).
24. Geoinformatics Center. *User Guide for the Macro Plastic Survey*; Asian Institute of Technology: Pathum Thani, Thailand, 2022; p. 12.
25. Şahin, M.; Aybek, E. Jamovi: An Easy to Use Statistical Software for the Social Scientists. *Int. J. Assess. Tools Educ.* **2020**, *6*, 670–692. [CrossRef]
26. ASEAN. *ASEAN Statistical Yearbook 2022*; ASEAN Secretariat: Jakarta, Indonesia, 2022.
27. Kawai, K.; Tasaki, T. Revisiting Estimates of Municipal Solid Waste Generation per Capita and Their Reliability. *J. Mater. Cycles Waste Manag.* **2016**, *18*, 1–13. [CrossRef]
28. Chen, C.C. Spatial Inequality in Municipal Solid Waste Disposal across Regions in Developing Countries. *Int. J. Environ. Sci. Technol.* **2010**, *7*, 447–456. [CrossRef]
29. Seng, B.; Fujiwara, T.; Seng, B. Suitability Assessment for Handling Methods of Municipal Solid Waste. *Glob. J. Environ. Sci. Manag.* **2018**, *4*, 113–126. [CrossRef]
30. Alzamora, B.R.; Barros, R.T.D.V. Review of Municipal Waste Management Charging Methods in Different Countries. *Waste Manag.* **2020**, *115*, 47–55. [CrossRef] [PubMed]
31. Kaza, S.; Yao, L.C.; Bhada-Tata, P.; Van Woerden, F. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*; World Bank: Washington, DC, USA, 2018; ISBN 978-1-4648-1329-0.
32. Muny, M. *Survey Report on Waste Management Practices At Municipality/District Level*; The National League of Local Councils: Phnom Penh, Cambodia, 2016.
33. Creaser, E.; Smith, J.; Thomson, A. Perspectives of Solid Waste Management in Rural Cambodia. *J. Humanit. Eng.* **2019**, *6*, 18–25. [CrossRef]
34. Menikpura, N.; Kumar Singh, R.; Dickella Gamaralalage, P.J. *Assessment of Climate Impact of Black Carbon Emissions from Open Burning of Solid Waste in Asian Cities*; United Nations Environment Programme: Nairobi, Kenya, 2022; p. 47.
35. Zhang, M.; Buekens, A.; Li, X. Dioxins from Biomass Combustion: An Overview. *Waste Biomass Valor* **2017**, *8*, 1–20. [CrossRef]
36. Mikolajczyk, S.; Warenik-Bany, M.; Maszewski, S.; Pajurek, M. Dioxins and PCBs–Environment Impact on Freshwater Fish Contamination and Risk to Consumers. *Environ. Pollut.* **2020**, *263*, 114611. [CrossRef]
37. Micheletti, C.; Critto, A.; Marcomini, A. Assessment of Ecological Risk from Bioaccumulation of PCDD/Fs and Dioxin-like PCBs in a Coastal Lagoon. *Environ. Int.* **2007**, *33*, 45–55. [CrossRef] [PubMed]