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Infectious Waste Management as the Effects of Covid-19 Pandemic in Indonesia

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Abstract: There is no doubt that covid-19 is harmful for health and environment because of greatly infectious waste Generation which potentially acted as secondary virus medium transmission. This current research presents an investigation on medical waste from covid-19 intensive care hospitals and disposable face mask waste generation in Indonesia. The results showed that the generation of medical waste is estimated 16.74-25.12 times lower than disposable face mask waste of 80.37 tons/day and 1,345.99-2,018.98 Tons/Day, Respectively. It proves that masks have become an important part for human life sustainability. Meanwhile, the rate of medical waste generation is 1.58 Kg/bed/day. Therefore, Indonesia has been generating 1,699.46-2,372.45 tons/day of Infectious waste during the covid-19 outbreak. Some guidelines have been implemented by the government to manage infectious waste in Indonesia, but it has not been optimally performed. Therefore, all aspects of infectious waste management need to be improved, including the role and responsibility of the government to avoid further phenomena due to the abundance of infectious waste.

Keywords: Covid-19, disposable face mask waste, Indonesia, infectious waste, medical waste generation

1. INTRODUCTION

The coronavirus diseases (Covid-19) pandemic phenomenon has many impacts on socio-economy, mental health, and environment aspects since December 2019 then estimated to be more severe than any previous outbreaks such as H1N1 and Ebola [1, 2, 3, 4]. One of the impacts is the rapid growth of infectious medical waste generation such as used personal protective equipment (PPE), laboratory specimens, pharmaceutical materials and device, and domestic waste from isolation room of healthcare facilities [4, 5, 6, 7].

Shi and Zheng [8]; Sharma et al. [9] reported that in Hubei Province, China, the generation of medical waste during Covid-19 pandemic has increased from 40 tons/day to 240 tons/day. Furthermore, in all areas of China the amount of medical waste reached to 486.90 tons/day [7]. An increasing amount of medical waste is also reported by Somani et al. [10] in Ahmedabed, India, by 0.55-0.60 tons/day to 3.00 ton/day. It means that the increasing number of medical waste generation is about 6.00 times higher than before. ADB [11] also stated that several cities in various countries showed a high generation of medical waste in 2020, such as in Manila, Kuala Lumpur, Bangkok, Ha Noi of 280; 154; 210; and 160 tons/day, respectively. Similar to those cities, at the end of 2020, Jakarta is estimated to produce 212 tons medical waste/day [7, 12]. In addition, infectious waste is also generated by household activities, such as used disposable face mask, sanitizers and disinfectant packaging [3], which might be accumulated in large quantities during Covid-19 pandemic.

Infectious waste generation has become the concern of the current research because a proper handling is needed to minimize the risks of Covid-19 transmission, human exposure, and environmental pollution [8, 13, 14]. As described by Rume and Islam [5]; Sarkodie and Owusu [15]; Mihai [16] that the main problem for

determining the proper handling during the Covid-19 outbreak is the limitation of scientific data in all regions, especially for developing countries that lack of waste management facilities including Indonesia. Scientific data is also needed for mapping environmental conditions in order to plan preventive actions to reduce and manage the risks in the future.

To the best of our knowledge infectious waste generation in Indonesia, which is one of the countries with the highest infection have reached to 780,232 cases by the end of December 2020 [17], has not been widely studied. To fill this gap, this current study aims to investigate medical waste generation on Covid-19 intensive care hospitals in Indonesia and face mask waste generated throughout Indonesia. In addition, some established policies, guidelines, and an approach to appropriate solutions for infectious waste handling in Indonesia are also explored and discussed in this paper.

2. MATERIAL AND METHODS

Medical waste data were collected from several Covid-19 intensive care hospitals to estimate its generation in Indonesia, in accordance to the sample population calculation by Kotz [18]. The medical waste generation rate could be calculated based on the following formula:

$$RMWG = \frac{TMW}{Ncp} \quad (1)$$

Where:

RMWG = Rate of medical waste generation (kg/bed/day)

TMW = Total of medical waste (tons/day)

Ncp = Number of Covid-19 patients (bed)

RMWG would be utilized as a basis for estimating the medical waste amount in Indonesia, according to Sangkham [7] formula:

$$AMW = \frac{Ncp\ x\ RMWG}{1000} \quad (2)$$

Where:

AMW = Amount of medical waste (tons/day)

Nch = Number of Covid-19 patients (bed)

RMWG = Rate of medical waste generation (kg/bed/day)

In addition, an online survey was conducted on 5-25 January 2021 to identify public knowledge on medical waste generated from household activities. Due to the limitations of primary data, this research was complemented by collecting and analyzing various data from reliable scientific literatures [5, 15].

3. RESULT AND DISCUSSION

A. Medical Waste Generation on Covid-19 Intensive Care Hospitals in Indonesia

The population in Indonesia at 2020 was 269,197,500 people, where 0.27% of population has been confirmed as Covid-19 patients [19]. The amount of medical waste in one of intensive care hospitals in Indonesia during 2020 ranged from 873.38 kg to 4,231.60 kg (see Table 1). The highest was found in December, where the number of Covid-19 patients increased massively in all regions in Indonesia. Table 1 shows an increase in the average amount of medical waste before and during the Covid-19 outbreak, reaching 1.3 times higher (1,288.04 kg/month). An increase was also found in an intensive care hospital in Jakarta of 1.47 times higher than before.

Table 1. Medical Waste Generation in Covid-19 Intensive Care Hospital in Indonesia

Items	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20
The amount of medical waste (kg)	873.38	919.25	916.16	1,017.42	1,002.46	1,022.32	1,038.92	1,017.42	1,072.20	1,099.27	1,493.09	4,231.60
The average of medical waste for Covid-19 intensive care (kg)	-	-	-	-	-	-	-	-	-	2,274.65		
The Number of Covid-19 patients (bed)	-	-	-	-	-	-	-	-	-	103		
The average of medical waste generation (kg/bed/day)*	-	-	-	-	-	-	-	-	-	1.58		

*Covid-19 intensive care in the hospital was carried out for 14 days

Medical waste generation from patient care increased by 1.58 kg/bed/day (Table 1), which was 1.43 times higher than the stated by Directorate of Hazardous and Non-Hazardous Waste Assessment [20] of 1.10 kg/bed/day. Similar finding was found in Jordan, where the generation on medical waste during Covid-19 pandemic increased by 1.47 times, from 2.69 kg/bed/day [21] up to 3.95 kg/bed/day [6]. There are a 4.17-fold increase on medical waste generation was reported in Wuhan City, the centre of Covid-19 spread, from 0.60 kg/bed/day to 2.50 kg/bed/day [14]. A higher medical waste increasing of 5.00-8.00 times was found in India, from 0.50 kg/bed/day to 2.50-4.00 kg/bed/day [4]. These conditions confirm that the rate of medical waste generation in Covid-19 intensive care hospital during pandemic has significantly increased. It was influenced by the complexity of Covid-19 treatment procedure, which is determined by symptoms diagnosis and hospitalization duration [22, 23], thus requiring more health workers and medical equipment and materials. Abu-Qdais et al. [6] described that 90% of these medical equipment and materials are disposable.

In addition, based on information from the authorities in West Java, it was found that the average requirement of Covid-19 detection kits and PPE for health workers, in terms of hazmat suits, medical masks, and gloves in the 86 Covid-19 intensive care hospitals are 950.44 kg/month. As it is known that PPE and Covid-19 detection tools which have been used up will end up as infectious waste, then mixed with other medical wastes. Compared to the amount of medical waste in Table 1, the composition of PPE and Covid-19 detection kits waste were; and infectious domestic waste were estimated at 41.78% and 58.22%, respectively.

B. Medical Waste Generation on Covid-19 Intensive Care Hospitals in Indonesia

The amount of medical waste generated by Covid-19 intensive care hospitals throughout Indonesia during 2020 was estimated amounted to 4,948.60 tons (Table 2). The value was lower than prediction made by Sangkham [7] because the calculation using medical waste generation rate in Jordan of 3.95 kg/bed/day. On the other hand, the estimation of medical waste amount was carried out for 14 days of intensive care per patient in accordance to Covid-19 protocol in Indonesia.

Table 2. Estimation of medical waste from Covid-19 intensive care hospitals in Indonesia

Provinces	Covid-19 Patients (people)	Covid-19 Patient in Intensive Care Hospitals (person)	Medical Waste Generation (kg/bed/day)	The Amount of Medical Waste during Covid-19 Intensive Care (kg)	PPE and Covid-19 Detection Kits Waste (kg)
Aceh	8,746	2,698		59,682.88	24,935.51
Bali	17,593	5,427		120,054.98	50,158.97
Banten	19,048	5,876		129,983.93	54,307.29
Bengkulu	3,601	1,111		24,573.30	10,266.72
Yogyakarta	12,155	3,750		82,945.96	34,654.82
Jakarta	164,881	50,866		1,125,151.24	470,088.19
Gorontalo	3,840	1,185		26,204.24	10,948.13
Jambi	3,226	995		22,014.29	9,197.57
West Java	83,579	25,784		570,344.77	238,290.04
Central Java	81,715	25,209		557,624.79	232,975.64
East Java	84,152	25,961		574,254.93	239,923.71
West Kalimantan	3,120	963		21,290.94	8,895.36
South Kalimantan	15,300	4,720		104,407.51	43,621.46
Central Kalimantan	9,740	3,005		66,465.95	27,769.48
East Kalimantan	27,076	8,353		184,767.17	77,195.72
North Kalimantan	3,804	1,174		25,958.57	10,845.49
Bangka Belitung Islands	2,337	721		15,947.73	6,662.96
Riau Island	7,002	2,160	1,58	47,781.79	19,963.23
Lampung	6,211	1,916		42,383.99	17,708.03
Maluku	5,722	1,765		39,047.04	16,313.85
North Maluku	2,771	855		18,909.36	7,900.33
West Nusa Tenggara	5,662	1,747		38,637.60	16,142.79
East Nusa Tenggara	2,171	670		14,814.95	6,189.69
Papua	13,164	4,061		89,831.40	37,531.56
West Papua	5,979	1,845		40,800.82	17,046.58
Riau	24,967	7,702		170,375.31	71,182.80
West Sulawesi	1,941	599		13,245.42	5,533.94
South Sulawesi	31,092	9,592		212,172.43	88,645.64
Central Sulawesi	3,552	1,096		24,238.92	10,127.02
Southeast Sulawesi	7,907	2,439		53,957.53	22,543.45
North Sulawesi	9,668	2,983		65,974.63	27,564.20
West Sumatera	23,471	7,241		160,166.57	66,917.59
South Sumatera	11,826	3,648		80,700.86	33,716.82
North Sumatera	18,155	5,601		123,890.08	51,761.28
Indonesia (total)	**725,174**	**223,716**		**4,948,601.88**	**2,067,525.87**

Table 2 also shows that the amount of medical waste in each Covid-19 intensive care hospitals in Indonesia varied from 13.25 up to 1,125.15 tons, where the highest was found in DKI Jakarta, followed by East Java, West Java, and Central Java. The estimation of medical waste amount in DKI Jakarta was lower than previous research by ADB [11] that estimated the medical waste generation reached to 80.37 tons/day and 220 tons/day, respectively. The difference might be caused by scope area for current research only for Covid-19 intensive care hospitals, which also affected the number of Covid-19 patients as a basis data for calculation. Therefore, similar study in other health facility that also dealt with Covid-19 is needed to obtain comprehensive information.

Large quantities of infectious medical waste might be posed a huge risk for health because it is of the main media for secondary transmission of Covid-19. As described by UNEP [24] and Wang et al. [25] that Covid-19 can survive on the surface of medical waste such as stainless steel and plastic, cardboard, and copper surfaces up to 48-72; 24; and 4 hours, respectively. Moreover, Kampf et al. [2] found a longer Covid-19 lifespan at the plastic, glass, and metal surfaces reached to 216 hours or 9 days at room temperatures.

C. Estimation of Face Masks Waste Generation in Indonesia

The results recorded 1,045 responses which indicated that there were no citizens who did not use masks every day (Fig. 1). Fig. 1 has shown that most citizens use 2-3 and 1-2 disposable face masks/day with the respective percentages of 67.46% and 14.83%, respectively. It indicates that the people are increasingly aware in preventing Covid-19 transmission as it has been stated as a mandatory [7], where the productive systems are

around 16 hours. It is also in accordance to disposable face mask specifications, which is only used for less than 6 hours due to virus contamination outside [26].

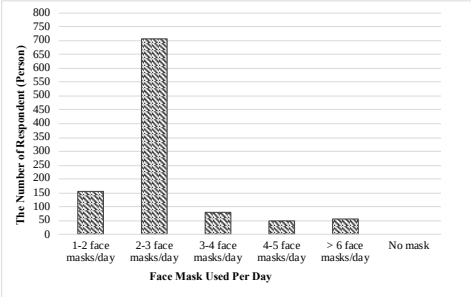


Figure 1. The amount of face mask used per day in Indonesia

Disposable face mask used in Indonesia during 2020 was estimated amounted to 538,40-807,59 million pieces/day or 1,345.99-2,018.98 tons/day (see Table 3). When combined with medical waste, the total amount of infectious waste in Indonesia per day may reach 1,699.46-2,372.45 tons. Table 3 shows that the highest generation of face mask waste in Indonesia are found at West Java, followed by East Java and Central Java of 247.83-371.74; 199.78-299.67; and 173.69-260.54 tons/day, respectively. The results confirmed that the larger population in an area, the more disposable face masks are used, and the more waste is generated. On the other point of view, a high demand of face mask has also led to the scarcity for unsafe mask recycling.

Table 4. The Estimation of Disposable Face Mask Waste Generation in Indonesia

Provinces	Population (people)*	Face mask for the use of 2 pieces per day		Face mask for the use of 3 pieces per day	
		Pieces	Tons	Pieces	Tons
Aceh	5,388,100	10,776,200	26.94	16,164,300	40.41
Bali	4,414,400	8,828,800	22.07	13,243,200	33.11
Banten	12,895,300	25,790,600	64.48	38,685,900	96.71
Bengkulu	1,994,300	3,988,600	9.97	5,982,900	14.96
Yogyakarta	3,919,200	7,838,400	19.60	11,757,600	29.39
Jakarta	10,576,400	21,152,800	52.88	31,729,200	79.32
Gorontalo	1,176,400	2,352,800	5.88	3,529,200	8.82
Jambi	3,604,200	7,208,400	18.02	10,812,600	27.03
West Java	49,565,200	99,130,400	247.83	148,695,600	371.74
Central Java	34,738,200	69,476,400	173.69	104,214,600	260.54
East Java	39,955,900	79,911,800	199.78	119,867,700	299.67
West Kalimantan	5,104,900	10,209,800	25.52	15,314,700	38.29
South Kalimantan	4,268,600	8,537,200	21.34	12,805,800	32.01
Central Kalimantan	2,686,300	5,372,600	13.43	8,058,900	20.15
East Kalimantan	3,664,700	7,329,400	18.32	10,994,100	27.49
North Kalimantan	708,400	1,416,800	3.54	2,125,200	5.31
Bang Belitung Islands	1,469,800	2,939,600	7.35	4,409,400	11.02
Riau Island	2,309,500	4,619,000	11.55	6,928,500	17.32
Lampung	8,534,800	17,069,600	42.67	25,604,400	64.01
Maluku	1,787,100	3,574,200	8.94	5,361,300	13.40
North Maluku	1,252,300	2,504,600	6.26	3,756,900	9.39
West Nusa Tenggara	5,225,900	10,451,800	26.13	15,677,700	39.19
East Nusa Tenggara	5,513,400	11,026,800	27.57	16,540,200	41.35
Papua	3,393,100	6,786,200	16.97	10,179,300	25.45
West Papua	986,000	1,972,000	4.93	2,958,000	7.40
Riau	6,951,200	13,902,400	34.76	20,853,600	52.13
West Sulawesi	1,378,100	2,756,200	6.89	4,134,300	10.34
South Sulawesi	8,888,800	17,777,600	44.44	26,666,400	66.67
Sulawesi Tengah	3,081,700	6,163,400	15.41	9,245,100	23.11
Southeast Sulawesi	2,307,500	4,615,000	11.54	6,922,500	17.31
North Sulawesi	2,512,900	5,025,800	12.56	7,538,700	18.85
West Sumatera	5,545,700	11,091,400	27.73	16,637,100	41.59
South Sumatera	8,600,800	17,201,600	43.00	25,802,400	64.51
North Sumatera	14,798,400	29,596,800	73.99	44,395,200	110.99
Indonesia (Total)	**269,197,500**	**538,395,000**	**1,345.99**	**807.592.500**	**2,018.98**

D. Management of Infectious Medical Waste during Covid-19 Outbreaks in Indonesia

There are several rules for infectious waste management in Indonesia that was modified from WHO [27] and UNEP [28] by Directorate of Environmental Health (2020) in terms of segregation, collection, storage, transportation, and disposal (Fig. 2). Waste workers safety is ensured by using PPE and proper cleaning procedures. Infectious waste from Covid-19 intensive care hospitals are collected in a yellow leak-proof plastic bag with biohazard clearly symbol for up to 12 hours or ¾ filled. The yellow bags were disinfected using 0.50% chlorine in 30 minutes and stored in hazardous short-term storage for a maximum period of 48-hours (2 days); 168-hours (7 days); or 2,160-hours (90 days) at room temperature; 3.00-8.00°C; or ≤ 0.00°C, respectively [29, 30]. Chlorine use is prioritized following Wang et al. [25] who stated that it has been able to inactivate the Covid-19 in a short-time because of its vulnerability.

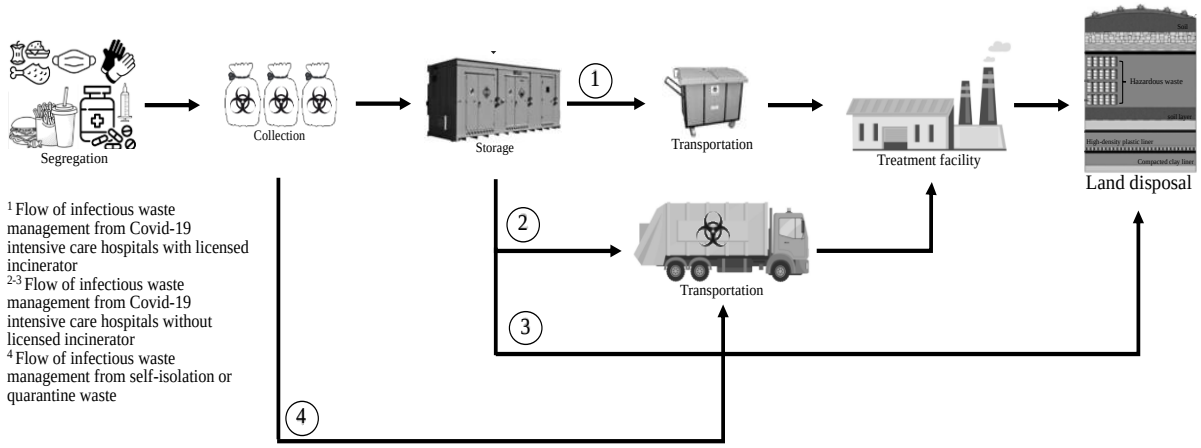


Figure 2. Infectious waste management in Indonesia during Covid-19 outbreak [29, 31, 32]

Furthermore, figure 2 shows several flows for transportation and treatment depending on facility availability. For Covid-19 intensive care with a licensed incinerator, disinfected yellow bags can be transported immediately by a trolley to the hazardous treatment facility to incinerated and sterilized using an autoclave with a shredder at 850-1200°C and 121-135°C, respectively [29]. The residue is toxic bottom ash due to the fact that it might be contained in polychlorinated dibenzodioxins and heavy metals from combustion process [24], which must be immobilized in a permanently closed container or solidified or encapsulated, then placed on a licensed landfill [24, 29]. Infectious waste management in Bangladesh, China, India, Japan, Kenya, Malaysia, Mexico, Nepal, Saint Lucia, South Africa, Sri Lanka, and Thailand has been reported by Sangkham [7] and UNEP [24] are similar to those of flows in Indonesia, which mostly use incinerator as a destruction technology [28].

If licensed landfill does not available, the residue is allowed for on-site disposal in a well-designed pit (fig. 3), following to the WHO [13]; UNEP [24]; and Directorate of Environmental Health [29] standard. On-site disposal is also permitted for infectious waste generated in areas without incinerator or autoclave facilities, but has been confirmed to be disinfected using chlorine. In addition, Covid-19 intensive care hospital without licensed incinerator should be collaborated with third party to transport and process labelled yellow bags by incineration or sterilization, then disposed it in licensed landfill.

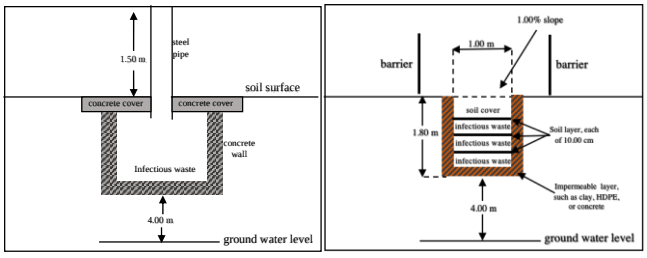


Figure 3. Construction for on-site disposal of infectious waste [29]

Similar actions have been also prepared for infectious waste from self-isolation or quarantine place. The difference are masks, gloves, tissues, etc. those contaminated with nasal or mouth droplets were collected in a

trash bag or strong black bag for less than 6 hours prior to transported to the government central storage facility for processing [29, 31, 32]. Moreso, it must be ensured that waste transportation uses closed and sealed vehicle so as not to endanger public health [33].

E. Management of Infectious Waste during Covid-19 Outbreaks from Household Activities in Indonesia

The guidelines were composed by simply rules for disposable face mask waste management, in terms of segregation, disinfection, devastation, collection, then being managed as municipal solid waste (MSW) to be transported and disposed of in landfills. Segregation in the guidelines is intended not only for disposable face mask waste, but also other infectious waste generated from household activities such as gloves, sanitizer and disinfectant packaging. Authorities in Malaysia, Thailand, Philippines, China, India, Kenya, and Sri Lanka are also enforcing segregation of household waste. It is necessary to minimize non-infectious waste from household activities during Covid-19 pandemic which has been proven by Italia that reduce 27.50% of paper, cardboard, glass, plastic packaging, and food scraps [9, 15]. As a comparison, households infectious waste management from other developing countries is also listed in Table 5.

Sufficient guidelines do not guarantee public compliance. In Indonesia, it has been found that public adherence to segregated-collected disposable face mask waste in different container of 56.46% (fig. 4a) which indicates that nearly half of population has not. Waste mixing also occurs in Nigeria [34], Guyana [3], India [9], and Morocco [35] that could be enhanced the risk of contamination.

Furthermore, additional rules for disinfection and devastation of disposable face mask waste were added into guideline to avoid scavenging that leads to unsafe recycling. These rules only found in Indonesia and India among other developing countries (see Table 5). Unfortunately, only 16.27% of people follow these rules while 44.98% did not (Fig. 4b). Plastic bag is widely used as waste container (Fig. 4c), where UNEP [29] advised for using double bagged.

Then, waste is managed like MSW where almost all population about 95.73% (fig. 4d) stated that waste container is placed in temporary shelters for residents and transported by waste workers to the sanitary landfill using sterilized vehicle [11]. In fact, most of waste workers in Indonesia are not equipped with appropriate PPE which causes work related illness as occurs in India where 40 people were confirmed Covid-19 and 15 people died [4]. Another problem is the lack of sanitary landfills and inequality of the availability throughout Indonesia [36], which is also found in Nigeria and Guyana [3]. Along to the rapidly growth of MSW, the amount of waste landfilled is also escalated which has an impact on the significantly decreased of landfill area. Zand and Zeir [37] reported that it causes landfill capacity in Isfahan, Iran, decreased 3.60 times faster.

Then, waste is managed like MSW where almost all population about 95.73% (fig. 4d) stated that waste container is placed in temporary shelters for residents and transported by waste workers to the sanitary landfill using sterilized vehicle [11]. In fact, most of waste workers in Indonesia are not equipped with appropriate PPE which causes work related illness as occurs in India where 40 people were confirmed Covid-19 and 15 people died [4].

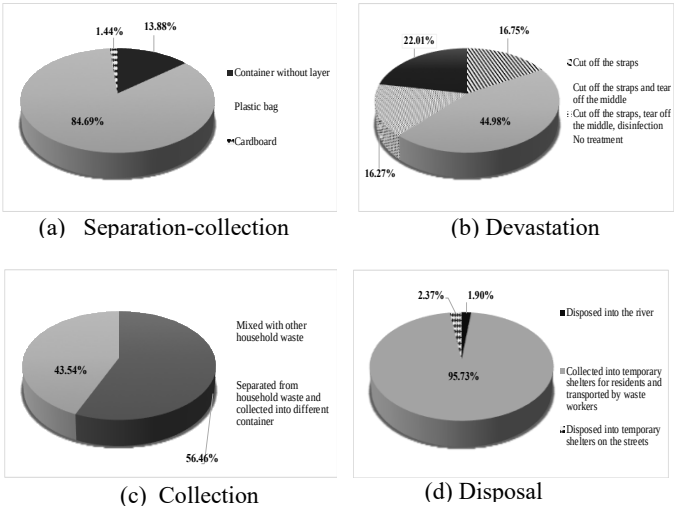
Table 5. Face mask waste management in several development countries

Developing Country	Face Mask Management											References
	Separated from household waste	Disinfected	Broke the mask	Collected in different bag with other waste	Placed at temporary waste shelter residents	Picked up by waste workers	Managed as municipal solid waste	Disposed at landfills	Transported to the treatment facilities	Incineration	Disposed at secure/licenced landfill	
Indonesia	Yes	Yes, using disinfectant/chlorine/bleach solution	Yes, by tearing and cutting off the middle and straps, respectively	Yes, in a plastic bag	Yes	Yes	Yes	Yes	N/A	N/A	N/A	[24]
Malaysia	Yes	No	No, but the mask is folded and rolled up to hide the mask contaminated side	Yes, in a plastic bag.	Yes	Yes	N/A	N/A	Yes	Yes	Yes	[29, 38]
Thailand	Yes	No	No	Yes, in a plastic bag labelled medical waste		Yes, using special vehicle with medical waste bin inside	N/A	N/A	Yes	Yes	N/A	[7, 39]
Philippines	Yes	Yes, using a mixture of bleach solution with fresh water.	No	Yes, in a plastic bag labelled biomedical waste or infectious waste for a maximum 72-hours period	Yes	Yes	Yes	Yes	N/A	N/A	N/A	[40, 41]
China	Yes	No	No	Yes, in a plastic bag	Yes	Yes, using special vehicle	N/A	N/A	Yes	Yes	N/A	[7]
Bangladesh	No	No	No	No	Yes	Yes	Yes	Yes	N/A	N/A	N/A	[33]
India	Yes	Yes, using bleach solution or NaOCl	Yes, by cutting of the straps	Yes, in a paper bag for a maximum 72-hours period	Yes, or burned/buried at the depth of 10 m from topsoil	Yes	Yes	Yes	N/A	N/A	N/A	[29, 42]
Iran	No	No	No	No	N/A	N/A	Yes	N/A	N/A	N/A	N/A	[43]
Kenya	Yes	Yes	No	Yes, in a plastic bag for a maximum 72-hours period	N/A	Yes	N/A	N/A	Yes	Yes	-	[44]
Sri Lanka	Yes	No	No	Yes, in a leak-proof yellow plastic bag labelled special waste for less than 72 hours	Yes	Yes, the bag is disinfected when loaded on to vehicle	N/A	N/A	Yes	Yes	N/A	[29]
South Africa	N/A	No	No	No	Yes	Yes	Yes	N/A	N/A	N/A	N/A	[29]
Nigeria	No	No	No	No	Yes	Yes	Yes	N/A	N/A	N/A	N/A	[3, 34]
Morocco	No	No	No	No	Yes	Yes	Yes	N/A	N/A	N/A	N/A	[35]

Another problem is the lack of sanitary landfills and inequality of the availability throughout Indonesia [36], which is also found in Nigeria and Guyana [3]. Along to the rapidly growth of MSW, the amount of waste landfilled is also escalated which has an impact on the significantly decreased of landfill area. Zand and Zeir [37] reported that it causes landfill capacity in Isfahan, Iran, decreased 3.60 times faster.

On another point of view, Table 5 shows that several countries such as Malaysia, Thailand, China, Kenya, and Sri Lanka avoided unsafe scavenging and recycling by centralization of infectious waste management to ensure the appropriate mechanisms. The centralization is collecting infectious waste in sealed container, transporting, and treating it separately using incineration which follows UNEP [29] recommendation to avoid pollution by complying various disposal standards [9].

Based on those results, it can be concluded that half of public in Indonesia has not managed infectious waste properly due to many people who do not know the guidelines which reach to 71.29%. It was poor, considering the amount of disposable face mask waste in Indonesia is 16.74-25.12 times greater than the medical waste from the Covid-19 intensive care hospital. Similar finding was also found in Romania [16]. It is due to the lack of infrastructure provided by the government and guidelines campaign to the public. Those problems commonly occurred in developing countries with difficulties in implementing sustainable waste management such as high investment costs (15; 33, 37].



(a) Separation-collection (b) Devastation

(c) Collection (d) Disposal

Figure 4. Management of disposable face mask from household activities

F. The Challenges and Recommendation for Infectious Waste Management in Indonesia

Inappropriate management practice causes many illegal dumps that subsequently leads to an increase of plastic debris which is 60-80% accumulated in the ocean [33, 45, 46]. Meanwhile, Sarkodie and Owusu [15] reported that there is a 3-fold increase in plastic waste disposal in UK and 4.20 times in Thailand. Plastic debris by disposable face mask waste disposal has been confirmed by Shammi and Tareq [33]; Lambert and Wagner [47] could affect microplastic pollution because it consists of various polymers such as polypropylene, polyurethane, polycarbonate, polyethylene, etc. It can be destructed or fragmented into smaller particle of < 5 mm. Invasive pathogens can attach to microplastic, then potentially contributing to the spread of disease (Reid et al., 2019). Therefore, plastic debris by disposable face mask waste could be disrupting ecosystems, food chain and health through biomagnification process ([33, 48, 49].

Furthermore, incinerator that is recommended as infectious medical waste destruction technology is hard to use optimally in Indonesia and other developing countries. It is due to high operating costs and limited number of incinerators. UNEP [24] reported that only 20 Covid-19 intensive care hospitals have licensed incinerator in Indonesia with processing capacity of 54.00 tons/day [24]. Compared with the previous estimate, there were 26.37 tons/day of untreated infectious medical waste. It can be submitted to the third parties who have licensed incinerator located in Java, Kalimantan, Sumatera, and Sulawesi Island for 7; 1; 1; and 1 company, respectively. Despite untreated waste was sent, rough third-party locations pose accessibility and transportation problem that might increase the risk of open burning and illegal dumping [33]. Limited incineration facility not only exist in Indonesia, but also in Bangladesh, India, Kenya, Malaysia, Mexico, Saint Lucia, South Africa, and Thailand each are 3; 225; 10; 12; 19; 20; 9; 87 operated unit [24, 33].

Incinerator also potentially caused cross-contamination by gas emission as by-products of incomplete combustion. It is inevitable that both of them contained by toxic compounds and significantly polluting the air, soil, and water if not managed soundly [15, 24]. UNEP [24] explained that gas emission containing particulate matter 2.50 and 10.00; polychlorinated dibenzodioxins, polychlorinated benzofuran, carbon monoxide, acid gasses (hydrogen chloride, sulfur dioxide, nitrogen oxides, carbon dioxide), various metals (cadmium, arsenic, chromium, copper, mercury, manganese, nickel, lead), and persistent organic pollutants in relatively high concentrations. Moreover, Johnke [50] stated that carbon dioxide concentration in incineration gas emission is at least 10 times higher than other combustion emissions. Johnke [50] also explained that 1.00 mg of incinerated MSW will release 0.70-1.20 mg of carbon dioxide contained in gas emissions that affect climate change. In case of Indonesia implementing incinerator as the main method for MSW elimination, it is estimated that all incinerators in 1 month must operate for a minimum 10 days period, following to the calculation of Prihartanto [31]. Thus, the effectiveness of incineration is not worth for serious pollution as its long-term impact threatens human health and environment.

An approach to deal with the impact of infectious waste is implement cradle to grave as suggested by life cycle assessment. It is conducted by using biodegradable materials such as cassava starch as raw material for

disposable mask and glove production. These biodegradable wastes only need sterilization to remove its infectious characteristic and on-site burying (fig. 3) as final treatments. UNEP [29] supported steam-based sterilization using autoclave or microwave as alternative technologies. Autoclave is operated at 121-135°C and 30 of steam pressure during 30 minutes [29, 43] and takes approximately 30 m^2 area [51]. Autoclave also needs to be upgraded to mobile treatment facilities for facilitated underserved areas in Indonesia [14, 33].

However, comprehensive mapping, planning, and monitoring with measurable targets are main requirements for long-term approach to implementing the alternatives above equipped with integrated monitoring system in Indonesia. Mapping the source of infectious waste from healthcare facilities and household activities are necessary to identify and observe the growth and composition of waste. Extensive campaigns about infectious waste management are also needed to improve public knowledge, awareness, and ability for waste segregation, minimization, devastation, collection, packaging and storage [5, 29, 35, 45]. It was suggested by 41.15% of respondents to ensure and optimize the collection-transport schedule and treatment adjustment [16, 29] to optimize infectious waste reduction as implemented in Italy [15].

Therefore, the role of local authorities in supervision needs to be increased by adapting the existing national guidelines to a local scale, including education and sanctions. It means that the commitment of public, local-national authorities, and third parties to engage, collaborate, and keep a priority in realizing consistent long-term actions are also needed to achieve common goals in Indonesia and other developing countries.

4. CONCLUSION

There is undeniable that the large amount of infectious waste during Covid-19 outbreaks in Indonesia, that estimated at 80.37 tons/day and 1,345.99-2,018.98 tons/day for medical and disposable face mask, respectively, was caused by the huge number of Covid-19 patients and its symptoms, and also early protective measures. Infectious waste handling in Indonesia still not optimally managed, which also occurred in other developing countries which may be due to inadequate planning, lack of public knowledge and infectious waste facilities. It needs more focus and commitment from all parties to update, improve, and implement the infectious waste management guidelines responsibly, in terms of 1) source mapping; 2) plan an build an adequate integrated infectious waste management systems; 3) improve the technology to meet the requirements of based on cradle to grave principle, such as utilization of biodegradable plastics as raw material for PPE and mobile autoclave. Especially for infectious waste household activities, frequent campaigns and workshops are also needed to make the public familiar with guidelines and succeed waste minimization for infectious waste handling. Infectious waste from household activities not only come from disposable face mask, but also disinfectant and sanitizer packaging, therefore a further research is needed to complete the data about infectious waste composition in household waste.

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