ENGINEER - Vol. LVI, No. 01, pp. [83-91], 2023

DOI: http://doi.org/10.4038/engineer.v56i1.7563

Potential Environmental Impacts of the Use and Disposal of Personal Protective Equipment during the COVID-19 Pandemic in Sri Lanka

C.E. Kankanamge, G.N. Samarasekara, T. Nilojan and R.D.U.I. Rajapakshe

Abstract: Personal protective equipment (PPE) is a critical step in preventing the spread of COVID 19. It is a relatively new phenomenon in many countries, including Sri Lanka. However, used PPE is classified as hazardous waste due to the possibility of pathogen contamination, and the majority of them are made of PET, making them non-biodegradable waste. This study estimated the daily disposal of PPE waste and gathered data on the disposal techniques used by people, ultimately estimating the environmental impact of this newly added waste stream. Data collection was solely based on a questionnaire circulated online. Almost 12 million face masks, 0.2 million gloves, and 0.3 million face shields are used in a single day in Sri Lanka. In addition, as empty sanitizer bottles, 0.7 million PET (polyethylene terephthalate) bottles are discarded. The estimated annual climate change impact of PPE use across the country was nearly 100 kT CO_2 eq. Open burning is the most common method of disposal for face masks and gloves used by households; nearly half of all used face masks and gloves are burned. Transferring waste to municipal solid waste collections also results in waste ending up in open dumps with other waste. As a result of the toxins released into the air during open burning and the release of microplastics during photovoltaic degradation, PPE disposal practices in Sri Lanka have a massive environmental and public health impact. Nevertheless, PPE can be used to generate energy through incineration or pyrolysis, reducing environmental impacts while providing economic benefits if proper plans and policies are in place.

Keywords: PPE, Open burning, Self disposal, Domestic

1. Introduction

Control of spread of COVID-19, the deadly infectious disease, was one of the major challenges human kind faced during last two years and it still continues at different scales in different regions of the world. People living all over the world had an immense concern on the disease spread and personal protective equipment (PPE) use was encouraged by authorities to prevent individuals from spreading the disease. Face masks are the main PPE in use to control the spread of COVID-19 from person to person, but face shields and gloves were also used globally [1,2]. According to the observations made in Sri Lankan society, senior citizens and children use face shields the most. Although not widespread, supermarket workers, food and bakery sector workers, etc., who handle money and food, wear plastic gloves. Hand sanitizing is also recommended to help control the spread of the disease thus leaving empty PET (polyethylene terephthalate) bottles. Every day, all of these activities generate a significant amount of plastic waste globally. Because many PPE items are made of some form of plastic, the pandemic situation resulted in a relenting the control of plastics use [3]. PPE use adds to Sri Lanka's already-existing problems with managing polyethylene and plastic waste. However, because most of them are single-use plastics, more serious and long-term issues may arise as a result of the generation of PPE-associated waste in the long run [4,5]. Almost all of the above are usable for a short period and made of polythene and plastic, hence leaving heaps of non-degradable waste [1,6].

There are two main concerns on management of waste associated with PPE use. First, this waste may contribute to the spread of the disease if safe disposal practices were not

Eng.(Dr.) C.E. Kankanamge, *C. Eng., MIE(SL), B.Sc. Eng. (Hons) (Moratuwa), PhD (Saitama, Japan), Senior Lecturer, Department of Civil and Environmental Engineering, University of Ruhuna, Sri Lanka.*
Email:ellawala@cee.ruh.ac.lk
http://orcid.org/0000-0002-7237-5368
Eng.(Dr.) G.N. Samarasekara*, C. Eng., B.Sc. Eng. (Hons) (Moratuwa), PhD (Saitama, Japan), Senior Lecturer, Department of Civil Engineering, University of Sri Jayawardhenapura, Sri Lanka.*
http://orcid.org/0000-0001-6572-8324
Eng.T. Nilojan, *AMIE(SL), B.Sc. Eng. (Ruhuna), Department of Civil and Environmental Engineering, University of Ruhuna, Sri Lanka.*
http://orcid.org/0000-0002-8273-2744
Miss.R.D.U.I. Rajapakshe, *Undergraduate, Department of Civil and Environmental Engineering, University of Ruhuna.*
http://orcid.org/0000-0003-3093-6574

adopted because viruses can remain alive on the PPE materials for several days [7,8]. The second concern is that the majority of this waste is single-use plastics, resulting in the release of micro-plastics into the environment as they degrade if left in the environment. This is a more prolonged impact [6]. Many studies report improper waste disposal practises by the general public, such as roadside dumping, abandoning face masks on the ground, dumping them into the marine environment, and so on [1,5,6]. In global rich countries, household PPE related waste disposal may not be an issue, because of well-established municipal solid waste management practices and availability of sanitary landfilling or incineration of municipal solid waste [8]. However, regarding developing countries, which have poor solid waste management systems, household waste management is a significant issue even under normal circumstances [9]. Hence, developing countries are in a more vulnerable situation in the pandemic because solid waste collection is not well established and waste disposal techniques are not always environmentally safe and sound [8,9]. Therefore, under pandemic conditions, the fate of PPE related waste generated in household level has a significant impact on the country's environment and public health.

Hence, this study aims to estimate waste generation associated with PPE usage thorough collected data and investigate disposal methods employed by households in Sri Lanka. Then the study attempts to evaluate the potential environmental impact of PPE use and to propose possible mitigation measures.

2. Methodology

The study is based on a questionnaire survey. The questionnaire was distributed via email and social networks using the referral-sampling method. People living in all nine provinces of Sri Lanka participated in the survey and the participation was entirely voluntary. Care was taken to reach all income groups because income determines the affordability of PPE. The study was focused on collecting data on the number of face masks, face shields, gloves, and sanitizer bottles utilized by a family during a month and the disposal method used for each item, separately. The monthly use of fabric cloth masks, surgical masks, and N95 masks by a household unit was separately recorded. In addition, province of residence, family income, number of family members and number of family members leaving home on a daily basis, as well as socio-demographic characteristics of the respondent (gender and age) are also included. The questionnaire was conducted during April - September 2021. The sample size required for this survey was determined according to Kotrlik and Higgins [10]. Accordingly, when population size is more than 100000, approximate sample size required is 400 (with a 95% confidence level and 5% marginal error). Incomplete responses were disregarded before the analysis and study was conducted with 851 valid responses.

Table 1 - Socio-Demographic Characteristics of the Sample (n=851)

Characteristic	Ratio (%)
Respondent's age	
18-24 years	52.64
25-34 years	41.83
35-44 years	2.23
45-54 years	2.82
Above 55 years	0.47
Respondent's gender	
Female	51.23
Male	48.77
Family size	
3 members or less	15.86
4 members	36.19
5 members	34.55
6 or more members	13.28
Income of the family	
Below 25000 LKR	13.32
Between 25000-50000 LKR	28.42
Between 50000-100000 LKR	35.91
Above 100000 LKR	22.35
Province of residence	
Western province -W	20.80
Central province - C	9.05
Southern province - S	9.75
Northern province - N	9.28
Eastern province - E	8.46
North Western province - NW	7.99
North Central province - NC	5.99
Uva province - UVA	20.33
Sabaragamuwa province - SA	8.34

2.1 Estimation of Daily Use of PPE

In this study, we collected the number of family members and monthly PPE use of the corresponding family. Thereafter, we used the following equations to estimate the daily face masks, face shields, gloves and hand sanitizer bottles use in Sri Lanka.

Total daily use of PPE = Monthly PPE use in a household*Population /(Number of household members*30) (assuming a month has 30 days) (1).

2.2 Carbon Footprint and Energy Recovery Calculations

Sri Lanka produces almost all of the masks needed by the country [11]. Hence, energy use for the production of face masks was estimated considering production of one face mask utilizes 0.01 kWh of energy [12]. Carbon footprint of PPE use was estimated considering the life cycle assessment made by Rizan et al., Klemes et al. and Mejjad et al. [12-14] adopted as appropriate for this case study: 0.05 $kgCO_2$ eq. per KN95 mask [11], 0.017 $kgCO_2$ eq. per surgical mask (Klemes et al. [12] modified by Rizan et al. [13] excluding transport). For other PPE, values estimated by Majjad et al. [14] were used (0.231 $kgCO_2$ eq. for a face shield, 0.026 $kgCO_2$ eq. per pair of gloves and 1.54 $kgCO_2$ eq. for a empty sanitizer bottle).

Potential energy recovery via incineration of face masks was calculated based on the estimation of Klemes et al. [12]. Klemes et al. [12] estimated that potential energy recovery from incineration of a face mask is 0.04 MJ/unit. Potential energy recovery via incineration of other PPE was not calculated since they are not disposed regularly.

2.3 Statistical Analysis

Multiple correspondence analyses were used to evaluate the provincial variation of used PPE disposal. All the analysis was carried out using R statistical software.

3. Results and Discussion

Socio-demographic information of the sample is shown in Table 1 (n=851). Because the survey was conducted online, the majority of respondents were young people. The younger generation is more likely than the older generation to use social media and engage in other online activities. However, each respondent provided information about their own family's behavior regarding the use and disposal of PPE. There were respondents from every province in the country.

3.1 Estimation of daily use of PPE in Sri Lanka

Daily per capita face mask use in Sri Lanka is 1.35 ± 1.05, when the number of family members who leave the home on a regular basis is considered. This population seems equivalent to economically active population because schools and higher education institutes were closed during the period we conducted the study. Calculations result in an estimate of nearly 12 million face masks per day is used in Sri Lanka (Table 2). However, this includes fabric/cloth masks, hence single-use face masks per day being used in Sri Lanka is 10 million. A leading face mask manufacturer was contacted by the authors to obtain the manufacturers' estimate of market demand and he stated that expected demand of surgical and N95 masks together in Sri Lanka varies between 10-12 million per day. Besides, Selvaranjan et al. [1] estimate that the Sri Lankan population uses 14 - 70 million face masks per week, and our estimates reach the maximum of their estimate, reaching 70 million per week. According to the estimates made by other researchers, face masks usage in Sri Lanka varies from 6 -17 millions per day [4,17].

Table 2 - Population Statistics and Estimated use of Face Masks, Gloves, Face Shields, and Hand Sanitizer Bottles (Nationally and Provincially)

Total population in Sri Lanka (2020) (Millions) [a]	21.92
Economically active population (%) [b]	38.60
Estimated daily use of each PPE item (in millions)	
Face masks	11.76
Gloves	0.22
Face shields	0.29
Empty sanitizer bottles	0.73

Sources: a - [16]. b – [17].

Although face masks usage is mandatory, use of other PPE is not. Hence, face shields are not used by 38% of families, and gloves are not used by 66% of families (Figure 1). Therefore, the usage of gloves as a safety measure is very low. However, use of face shields and hand sanitizers is much higher. Monthly per capita use of gloves and face shields can be estimated as 0.34 ± 0.69 and 0.43 ± 0.63, respectively. Hence, 0.2-0.3 million gloves and face shields are used in Sri Lanka within a day (Table 2). Moreover, 0.7 million empty sanitized bottles are added to the waste. Despite the fact that many studies only estimate the use of face masks, Haque et al. [19] estimate that Bangladesh discards 1.6 million empty hand sanitizer bottles, 6.3 million surgical gloves, and 40.5 million single use polythene gloves per day.

3.2 Disposal Practices of used PPE in Household Level

The main focus of this study was to evaluate the disposal methods of used PPE in household level. Open burning is the most common disposal method of used face masks, followed by handing over to municipal solid waste collection (Figure 1). The only exception is the Eastern Province, where 55% of families handover used face masks to municipal solid waste collection and only 30% burn them. Only a small percentage of households bury their waste in pits. MCA plots reveal that open burning at home is practised in almost all of the provinces, except Northern and Eastern provinces. Burying in pits is mostly associated with the Northern Province, which has the lowest population density (Figure 2). Yet, out of the families who use gloves, face shields and sanitizer bottles, 51% of families burn used gloves, 18% of families burn used face shields and 13% of families burn hand sanitizer bottles, island wide. Very small percentages of people declare that they throw away PPE related waste without care (3%), while it is raised to 8% when it comes to empty sanitizer bottles (Figure 1). However, considering the number of items used daily in Sri Lanka, the impact of just throwing away is also not small. For instance, nearly 30000 face masks are thrown away per day, island wide.

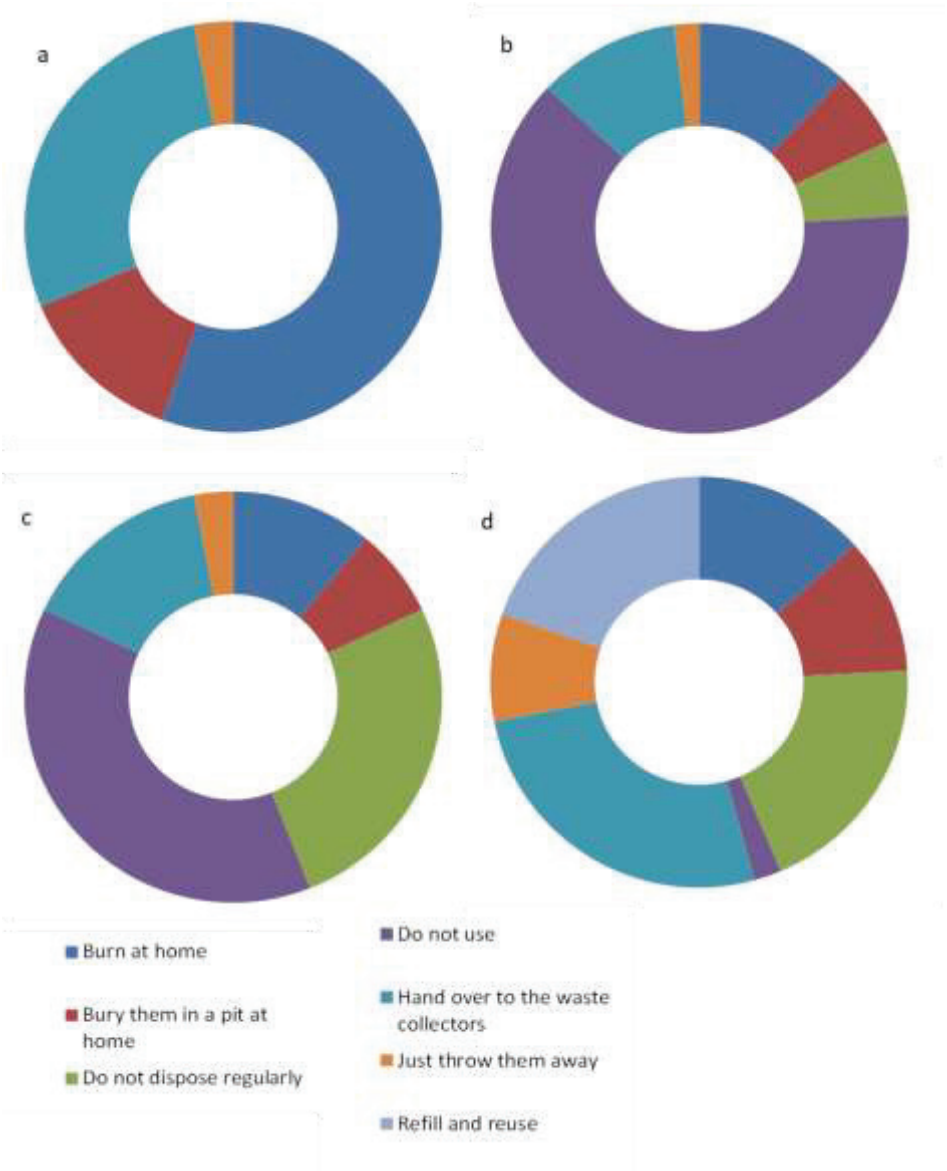
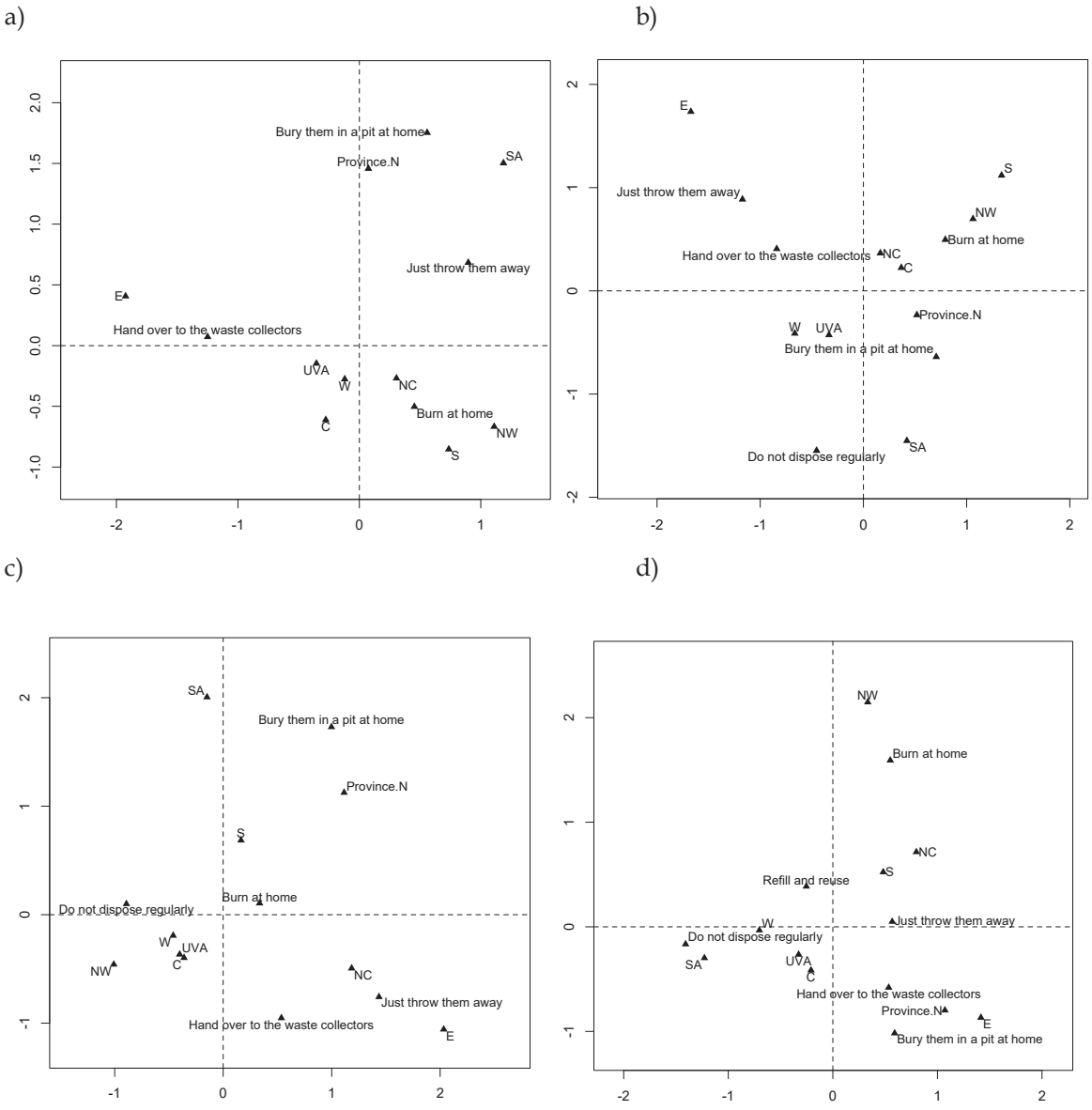


Figure 1 - PPE use and Disposal Methods, a) Face Masks, b) Gloves, c) Face Shields, d) Sanitizer Bottles (Values Shown in the Graphs are Percentage of the Population)

In fact, Sri Lanka already has so many problems in managing municipal solid waste. Different provinces in Sri Lanka have different municipal solid waste collection rates, leading different percentages of people who are left out to manage solid waste on their own. The western province has the highest municipal solid waste collection rate in Sri Lanka at 51%, and the second highest is the Eastern Province at 44%. Thereafter, the Northern Province has 31%, followed by all the other provinces varying from 16-23%, with the North-Central Province having the lowest, at 15% [18]. Higher rate of handing over used face masks to municipal solid waste in Eastern Province may be related to many respondents are from urban areas of the province, considering the fact that the questionnaire survey was conducted online as well as due to the fact that Eastern Province has the second highest waste collection rate in the country.



Note: Western Province –W, Central Province – C, Southern Province –S, Northern Province -N, Eastern Province – E, North Western Province -NW, North Central Province – NC, Uva Province – UVA, Sabaragamuwa Province -SA

Figure 2 - First Two Axes of Multiple Correspondence Analysis Plot - Provincial Variation of PPE Disposal Methods in Households: a) Face Masks b) Gloves, c) Face Shields, d) Empty Sanitizer Bottles

Within a particular province, solid waste collection rates vary dependent on the type of local authority controlling the area. Accordingly, municipal solid waste collection services are provided to 50-90% of the population living in municipal council and urban council areas, while 20-75% of people receive solid waste collection facilities when they are living in divisional council areas (Unpublished data). This situation may lead people to burn their used PPE at home. Moreover, among the people who burn used face masks, 41% declare that they separate the used PPE from other household polythene waste. Prolonged waiting periods for solid waste collection lead them to burn PPE waste and their easily burnable nature support the process. Out of the people who handover their PPE waste to municipal solid waste stream, 17% state that they separate it from other waste. Therefore, at least part of the population is already used to separate PPE waste from other household waste, which is a support in separate collection plans if implemented.

Municipal solid waste collected by many local authorities in Sri Lanka is dumped in open dumps; there are only very few exceptions where sanitary landfills are used. The Greater Colombo and Colombo Metropolitan areas in western province generate the largest amount of waste and dispose the waste into Aruwakkalu sanitary landfill and Kerawalapitiya incineration plant. Therefore, in most of the occasions, disposal of used PPE, especially face masks with other municipal solid waste, may pose a threat to public health in different ways. Handling solid waste by collection crews may expose them to the virus, openly dumped waste may be accessed by waste pickers for recyclable materials, stray animals may gain access to waste dumps, and contact with contaminated PPE will increase the risk, as suggested by Nzediegwu and Chang [8].

3.3 Potential Environmental Impact of PPE Use and Disposal Methods Used by Households

PPE use is a newly emerged trend in Sri Lanka unlike in some other countries. Therefore, potential environmental impact is also an added one to the existing problems in waste management in Sri Lanka. Potential environmental impact of PPE use was estimated considering the carbon footprint, energy use in the face mask production process and possible energy recovery by incineration of PPE. Sri Lanka generates 65 MT per day face mask waste and 88.5 MT of plastic waste daily (Table 3) and nearly 50% is subjected to open burning. Estimated annual climate change impact was nearly 100 kT CO_2 eq. due to only the PPE use within the whole country. In addition, face mask production utilize 35000 kWh of energy annually. However, Sri Lanka does not use the opportunity of converting the waste face masks to energy back via incineration or pyrolysis, which provides the opportunity to recover that energy.

Table 3 - Estimate of Generation of Waste in Sri Lanka due to PPE use, Carbon Footprint, Energy use and Energy Recovery Possibility

Item	Material	Weight of a unit (g)	Waste generated (Metric ton/day)	Waste open burnt (Metric ton/day)
Surgical Face masks	Polypropylene	2.85[b]	26.95	14.82
KN 95 Face masks	Polypropylene	18.14[a]	38.09	20.95
Face shield	LDPE	33.6[b]	9.97	1.69
Single Use gloves	Nitrile Rubber	2.5[c]	0.53	0.27
Sanitizer bottles	PET	18.5[c]	12.95	1.68

Item	PPE Waste generated (Metric ton/year)	Carbon footprint ($kgCO_2$ eq. per year)	Energy consumption for production (MWh annually)	Possible energy recovery by incineration (MWh annually)
Face masks	23741	84924000	35280	39514
Face shield	3638	6286896		
Single Use gloves	192	1965600		
Sanitizer bottles	4728	7179480		

Note: Weights were as given by Slevaranjan et al. [1] (a), Al-Omren et al. [22], Haque et al. [19](c).

Most of the PPE is produced using polypropylene (PP) or polyethylene (PE). Open burning of polypropylene and polyethylene generates polynuclear aromatic hydrocarbons (PAHs), which are known carcinogenic compounds [12,20]. In addition, open burning of PP and PE may release heavy metals into the environment [12]. Further, open disposal of PPE made of PP and PE will release microplastics to the environment upon their degradation [3,21]. Therefore, emerging challenges in managing waste associated with PPE need to be addressed during the pandemic as well as after the pandemic. Thus, improvements to waste handling policies as well as clear guidelines on separation, collection, and disposal of PPE-associated waste should be added to the pandemic control guidelines.

3.4 Limitations of the Study

Because the study was conducted online, some social groups, particularly the rural and elderly, may have difficulty accessing it. The age distribution shows that more respondents are under the age of 35, but the limitations were overcome to some extent by obtaining data on PPE use of housing units rather than individuals. Furthermore, sample distribution was not proportional to province population density, but PPE usage guidelines during the COVID 19 pandemic were consistent across the country. Nonetheless, this deviation may have an impact on our findings regarding the PPE waste disposal.

Aside from the removal of incomplete data, there was no removal of unreliable data. However, in terms of face mask usage, our data falls within the range of other studies' estimates of PPE use in Sri Lanka [1,4,17]. As a result, data is less likely to be unreliable than in other PPE types where there is no literature to compare.

3.5 PPE Waste Management: Challenges and Recommendations

Even before the pandemic, managing plastic waste was a difficult task on a global scale. It is one of the waste streams with the lowest recycling rates, with nearly 16%. 25% of waste plastic burned, 40% landfilled, and the remainder released into the environment [23]. Furthermore, most PPE was made of non-woven textiles, and recycling technologies for them were very limited due to their composition, despite the need for disinfection before recycling. As a result, many parts of the world regard the management of PPE waste generated during the COVID 19 condition as an additional challenge [8, 23]. PPE and other infectious waste must be incinerated according to WHO regulation [24]. However, this recommendation has put more strain on the incineration facilities. Therefore, the burden was less in developed nations with sustainable waste management practises, but sometimes increased waste volume led to capacity issues. For instance, incineration, which also involves energy recovery from municipal solid waste, is the most popular final disposal method for municipal solid waste in northern Europe. PPE waste was also incinerated or disposed of in sanitary landfills in other developed countries [25]. The challenge was much greater in developing nations, where there was already inefficient and unsustainable waste management. However, some countries have implemented some measures to address the issue of PPE-related waste. Several Asian countries [4] have practised introducing colour coded bins (red or yellow) for disposal of PPE (especially face masks) and issuing guidelines to store them in double-layer bags or sealed bags during the waste collection process. Non-quarantined households in Chennai, India, have been advised to store used face masks for 72 hours before disposal, and after collection, they were treated as domestic hazardous waste and incinerated [4].

The major drawbacks identified in the disposal of PPE associated waste in household level in Sri Lanka are discarding PPE related waste with household waste, not using sealed bags, not ensuring a 72-hour storage period before handing over to collection facilities, and improper disposal of this waste with collected municipal solid waste with no precautions taken. There is a guideline issued by the Central Environmental Authority of Sri Lanka [26] to handle healthcare waste generated in households under self-quarantine, but no guidance is provided to the non-quarantined households on how to dispose of PPE-related waste. In our survey, 66.5% of families declared they separate their PPE-related waste from other municipal solid waste; however, separate collection does not occur. Unidentified and symptomless infected people exist in society, and contaminated PPE used by them ends up in municipal solid waste as a result of this practice.

In proposing mitigation measures, the most important aspect that needed the attention is

regulating the collection of face mask waste. Pyrolysis is identified as a suitable method for extracting energy from used face masks [27]. Small-scale pyrolysis units may be implemented if private sector is provided with relevant guidance and technology.

4. Conclusion

PPE use in social interactions is a new trend emerged in Sri Lanka to control spread of COVID 19. Nearly 10 million single-use face masks are used daily in Sri Lanka. In addition, substantial use of face shields and hand sanitizers occur, while use of gloves is the lowest as a PPE. Sri Lanka generates nearly 89 metric tonnes of additional PP, PE and PET waste due to the PPE use on top of the other plastic waste that were already there before the pandemic. At household level, 55% burn their used face masks and 51% burn their gloves. Since the most common waste disposal method is open burning of the used PPE, additional public health issues are generated due to the release of toxins into the air. Moreover, most of the PPE waste handed over to the municipal solid waste stream is also left exposed to the environment, hence threatening ecosystems due to the release of microplastics when they are subjected to photovoltaic digestion. In addition, used PPE can be easily converted into energy via incineration or pyrolysis through small-scale plants, hence eliminating public health risks as well as threats to ecosystems.

References

1. Selvaranjan, K., Navaratnam S., Rajeev P., & Ravintherakumaran N., "Environmental Challenges Induced by Extensive Use of Face Masks during COVID-19: A Review and Potential Solutions", *Environmental Challenges*, Vol. 3, 2021, 100039.

2. Zand, A. D. & Heir, A. V., "Emanating Challenges in Urban and Healthcare Waste Management in Isfahan, Iran after the Outbreak of COVID-19", *Environmental Technology,* Vol. 42, No. 2 2021, pp. 329-336.

3. Akhbarizadeh R., Dobaradaran S., Nabipour I., Tangestani M., Abedi D., Javanfekr F., Jeddi F. & Zendehboodi A, "Abandoned Covid-19 Personal Protective Equipment along the Bushehr Shores, the Persian Gulf: An Emerging Source of Secondary Microplastics in Coastlines" *Marine Pollution Bulletin* Vol.168, 2021, 112386.

4. Sangkham S., "Face Mask and Medical Waste Disposal during the Novel COVID-19 Pandemic in Asia", *Case Studies in Chemical and Environmental Engineering*, Vol. 2, 2020, 100052.

5. Torres F.G. & De-la-Torre G.E., "Facemask Waste Generation and Management during the COVID-19 Pandemic: An Overview and the Peruvian Case", *Science of the Total Environment*, Vol. 786, 2021, 147628.

6. Abbasi, S. A., Khalil, A. B. & Arslan, M., "Extensive Use of Face Masks during COVID-19 Pandemic: Micro-Plastic Pollution and Potential Health Concerns in the Arabian Peninsula" *Saudi Journal of Biological Sciences* Vol. 27, 2020, pp. 3181–3186.

7. Kampf, G., Todt D., Pfaender S. & Steinmann E., "Persistence of Coronaviruses on Inanimate Surfaces and their Inactivation with Biocidal Agents", Journal of Hospital Infection, Vol 104, Np. 3, 2021, pp.246–251.

8. Nzediegwu, C. and Chang S. X., "Improper Solid Waste Management Increases Potential for COVID-19 Spread in Developing Countries", *Resources Conservation and Recycling*, Vol. 161, 2020, 104947.

9. Benson, N. U., Fred-Ahmadu, O. H., Bassey, D. E. & Atayero, A. A. "COVID-19 Pandemic and Emerging Plastic-Based Personal Protective Equipment Waste Pollution and Management in Africa", *Journal of Environmental Chemical Engineering,* Vol 9, No. 3, 2021, 105222.

10. Kotrlik, J. & Higgins C., "Organizational Research: Determining Appropriate Sample Size in Survey Research", *Information Technology Learning. Performance Journal*, Vol. 19 No.1, 2001, pp. 43-49.

11. http://www.adaderana.lk/news/69265/sri-lanka-to-manufacture-surgical-masks-import-halted, Visited, 2022/05/12.

12. Klemeš, J. J., Fan, Y. V. & Jiang, P, "The Energy and Environmental Footprints of COVID-19 Fighting Measures - PPE, disinfection, Supply Chains", *Energy*, Vol. 211, 2020, 118701.

13. Rizan, C., Reed, M. & Bhutta, M. F., "Environmental Impact of Personal Protective Equipment Distributed for Use by Health and Social Care Services in England in the First Six Months of the COVID-19 Pandemic", *Journal of Royal Society of Medicine,* Vol. 114, No. 5, 2021, pp250-263.

14. Mejjad, N., Cherif, E. K., Rodero, A., Krawczyk, D. A., El Kharraz, J., Moumen, A., Laqbaqbi, M. & Fekri, A., "Disposal Behavior of used Masks during the COVID-19 Pandemic in the Moroccan Community: Potential

Environmental Impact", *International Journal of Environmental Research and Public Health,* Vol 18, No.8, 2021, 4382.

15. Worldometer, 2021. Population: Asia. https://www.worldometers.info/population/countries-in-asia-by-population/. Visited, 2022/10/26.

16. Department of Census and Statistics, *Sri Lanka Census of Population and Housing Sri Lanka - 2012.* http://www.statistics.gov.lk/pophousat/cph2011/pages/activities/Reports/SriLanka.pdf., Visited, 2022/10/26.

17. Hantoko, D., Li, X., Pariatamby, A., Yoshikawa, K., Horttanainen, M. & Yan, M., "Challenges and Practices on Waste Management and Disposal during COVID-19 Pandemic", *Journal of Environmental Management*, Vol. 286, 2021, 112140.

18. JICA, "Data Collection Survey on Solid Waste Management in Democratic Socialist Republic of Sri Lanka.", https://openjicareport.jica.go.jp/pdf/12250213.pdf, Visited, 2022/10/26.

19. Haque, M. S., Sharif, S., Masnoon, A. & Rashid E., "SARS-CoV-2 Pandemic-Induced PPE and Single-Use Plastic Waste Generation Scenario", *Waste Management Research*, 2021, 734242X20980828.

20. Sarkodie, S. A. & Owusu, P. A., "Impact of COVID-19 Pandemic on Waste Management", *Environment, Development and Sustainability*, Vol. 23, 2021, pp.7951–7960.

21. Fadare, O. O. & Okoffo, E. D., "Covid-19 Facemasks: A Potential Source of Microplastic Fibers in the Environment", *Science of the Total Environment*, Vol.737, 2021, 140279.

22. Al-Omran, K., Khan, E., Ali, N. & Bilal, M. "Estimation of COVID-19 Generated Medical Waste in the Kingdom of Bahrain", *Science of the Total Environment* Vol. 801, 2021, 149642.

23. Vanapalli, K. R., Sharma, H. B., Ranjan, V. P., Samala, B., Bhattacharya, J., Dubey, B. K. & Goel, S. "Challenges and Strategies for Effective Plastic Waste Management during and Post COVID-19 Pandemic", *Science of the Total Environment* Vol. 750, 2021, 141514.

24. World Health Organization. "Safe management of wastes from health-care activities: a summary" http://apps.who.int/bookorders.%0Ahttp://apps.who.int/iris/bitstream/10665/259491/1/WHO-FWC-WSH-17.05-eng.pdf?ua=, Visited, 2020/08/06.

25. Silva, A. L. P., Prata, J. C., Walker, T. R., Duarte, A. C., Ouyang, W., Barcelò, D., & Rocha-Santos, T. "Increased Plastic Pollution due to COVID-19 Pandemic: Challenges and Recommendations", *Chemical Engineering Journal,* Vol. 405, 2021, 126683.

26. Central Environmental Authority (CEA) - Sri Lanka. http://www.cea.lk/web/images/news/2020/MSW_Guide_Covid 19_11th_April_____final.pdf., Visited 2022/10/26.

27. Aragaw, T. A. & Mekonnen, B. A. "Current Plastics Pollution Threats due to COVID-19 and its Possible Mitigation Techniques: A Waste-to-Energy Conversion via Pyrolysis", *Environmental Systems Research*, Vol.10, No. 8, 2021.