Article
Comparative Analysis of Face Mask Usage and Environmental Impact in Asian Cities during and after the COVID-19 Pandemic

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Abstract: The COVID-19 pandemic has led to a surge in face mask demand, resulting in increased face mask waste and environmental impacts. This study investigates mask usage patterns and the environmental impacts of single-use and cloth masks across three phases: pre-COVID-19, COVID-19, and the new normal. A comprehensive survey conducted in five cities across four Asian countries reveals a surge in mask usage during COVID-19 (6.81 pieces/week), followed by a decline in the new normal (3.73 pieces/week), though usage remained higher than pre-COVID-19 levels (1.46 pieces/week). For single-use masks, age significantly impacts usage in all cities, while gender and education level affect usage in Shanghai, Harbin, and Depok. Household income influences mask use in Shanghai and Harbin. For cloth masks, education level significantly correlates with usage in most cities. The study highlights the significant environmental impact of mask use, particularly in densely populated urban areas. Switching to cloth masks for one year could reduce carbon footprints by 44.27–81.9 million kgCO₂eq, decrease solid waste by 34.81–52.41 million kg, and reduce microplastic emissions by 6.50 to 15.56 trillion particles in the first 24 h after disposal. However, this transition may increase water usage by 1.73–1.86 billion m³H₂Oeq. The study also offers policy recommendations on mask usage and disposal.

Keywords: mask usage; socio-demographic factors; environmental impact; COVID-19; Asian cities

1. Introduction
Face masks are a crucial component of comprehensive infectious disease prevention and control measures, and thus play a key role in mitigating the spread of COVID-19 [1]. Consequently, due to the COVID-19 pandemic, there has been a significant increase in the demand for masks [2]. With the extensive utilization of masks, there is an emerging concern about the potential environmental repercussions of this necessity. The widespread use of disposable masks has led to an increase in waste, with a significant number of discarded masks ultimately finding their way into the environment [3]. The astonishing global monthly usage of masks has reached 129 billion masks, equivalent to 3 million masks used every minute [4]. The manufacturing materials of most masks include plastic polymers, contributing to the polluting of aquatic systems [5]. As a result, over its lifecycle, a single weathered mask can release over 1.5 million microplastics into aquatic environments [6]. This is particularly concerning as microplastics have the potential to swiftly enter the food chain and undergo bioaccumulation processes within organisms [7,8]. The potential hazards of microplastics to human health are manifested in toxic chemical components, pathways for contaminants, and physical harm [9], and composting household waste will introduce microplastics into the agro-ecosystem, enter the human body through the food chain, and affect human health [10,11]. Furthermore, it has been clearly shown that the mass production, use, and disposal of masks has negative impacts on natural resources, energy, and climate change. For example, the production of masks consumes approximately...
10–30 Wh of energy and releases 59 gCO$_2$eq greenhouse gasses into the environment [12]. Therefore, while pursuing health and safety, it is essential to recognize the significance of adopting sustainable approaches to mask usage and management in order to minimize adverse environmental impacts and safeguard the interests of future generations.

This study administered interview-type questionnaires across five cities spanning four countries in East and Southeast Asia to understand mask-wearing practices before the onset of COVID-19, during the peak of the pandemic, and in the emergence of the new normal. It placed particular emphasis on the patterns of using disposable surgical masks and reusable fabric masks during these distinct time frames. Furthermore, it performed a detailed analysis of the impact of individual characteristics, such as gender, age, education level, household income, and geographical location on mask-wearing practices. The study also included an assessment of the environmental impact of mask usage, evaluating the carbon emissions resulting from mask use, the quantity of solid waste generated, and the extent of microplastic pollution caused by mask disposal. The objectives of this research encompass a comprehensive understanding of the interplay between mask usage and the environment and strive to propose policy recommendations that achieve a balance between health needs and environmental preservation.

2. Literature Review

Extensive research has been conducted on the environmental impact of masks, primarily focusing on in-depth explorations of the following three major aspects during the COVID-19 pandemic: (1) mask usage [13,14], and disposal methods for used masks [15,16]; (2) environmental impact analysis, including mask lifecycle assessment [17,18], and the pollution of the marine environment by masks [6,19]; and (3) adverse health effects in humans [9–11] and animals [20–22]. Despite several studies on mask use during COVID-19, there remains a lack of research focusing on pre-pandemic mask usage rates, trends in the new normal, sociodemographic factors, and sustainable strategies related to mask utilization, especially in the Asian context.

2.1. Mask Usage and Disposal

Studies on mask use have been conducted mainly during the pandemic period. A natural experiment regarding mask-wearing during the COVID-19 period in the United States revealed that the number of mask wearers increased by 12%, and there was also a 7% growth in the number of people purchasing masks [13]. A survey on mask usage in China revealed that 61% of the respondents reused masks, and 50% of them reported witnessing others casually discarding used masks [14].

There are several studies on the management of used masks. A study in Bangkok assessed urban mask waste, surveying 605 participants on their mask handling. Survey results showed that 70.58% of respondents disposed of masks in regular garbage bins. Within a 13.30 km radius, 170 casually discarded single-use masks were discovered [15]. Another study conducted an in-depth analysis of the Romanian public’s knowledge, awareness, and behavior regarding disposable masks. The results showed that people’s understanding of mask material types, especially through visible labels and similar means, could positively influence better mask disposal practices. Furthermore, individuals who perceive disposable masks to have an adverse impact on waste management are more likely to handle these masks properly [16].

2.2. The Environmental Impact of Masks

Recent research has demonstrated that improperly managed disposable masks may represent an unrecognized and underestimated source of environmental microplastics, particularly in marine environments. The release of microplastic particles from disposable masks has been found to occur at a rate of approximately 360 particles per mask in still water. It has been observed that masks with higher vibration frequencies result in a greater release of microplastics. The introduction of organic solvents, including detergents and
alcohol, to water further intensifies the release of microplastics from masks [19]. A study on the effects of disposable masks in coastal environments demonstrated that physical abrasion from sand causes masks to release microplastic particles at an increased rate. The degradation of weathered masks can result in the discharge of over 1.5 million microplastic particles, with this figure potentially exceeding 16 million in the presence of sand. This emphasizes the significance of mask-induced microplastic pollution in marine settings [6].

2.3. Adverse Health Effects in Humans and Animals

The utilization of face masks has resulted in the contamination of ecosystems with microplastics, which has consequently led to human exposure through potential pathways such as ingestion, inhalation, and dermal contact [9]. Microplastic particles generated from discarded face masks also have the potential to enter the food chain, thereby posing risks to both aquatic and terrestrial organisms [9–11]. In aquatic ecosystems, microplastics are ingested by aquatic animals, which can result in adverse effects on their growth and development, as well as the transfer of nutrients to higher organisms in the food chain [20]. The presence of microplastics has been demonstrated to exert a considerable influence on the biology of amphibians and reptiles [21]. In soil environments, microplastics are a common pollutant, particularly aged PE (polyethylene) microplastics, which can damage the intestinal structure and function of soil organisms like earthworms, leading to oxidative damage within their bodies [22]. Furthermore, discarded masks may be ingested by terrestrial animals, which could result in mortality, the contamination of food chains, and ecological imbalances [23].

Overall, the widespread use of masks has resulted in various environmental issues and challenges. However, it is worth noting that previous research has predominantly focused on mask usage during the peak of the pandemic, leaving a gap in understanding with regard to the post-pandemic era when mask usage may differ. As the pandemic gradually stabilized and society returned to a semblance of normalcy, people’s attitudes, awareness, and behaviors towards mask usage may have undergone changes. However, the evolving trends and the underlying factors that shape these shifts remain unexplored territories. Therefore, this study selected five areas in East and Southeast Asia as its research subjects and conducted a comprehensive investigation into the usage patterns of masks. Specific focus is put on comparing the mask usage patterns across different areas during various stages of the COVID-19 pandemic—before, during, and after the pandemic. This comparative analysis aims to provide a comprehensive understanding of the changing patterns and influences on mask usage which can contribute to enhancing environmental awareness among the public. Furthermore, it offers valuable guidance and recommendations for sustainable development in the post-pandemic era.

3. Materials and Methods

3.1. Survey on the Usage of Resident Masks

3.1.1. Survey Site and Sample Size

The survey, conducted from September 2022 to February 2023, covered five cities across four countries (Figure 1): Shanghai (SH) and Harbin (HRB) in China, Hanoi (HAN) in Vietnam, Phnom Penh (PNH) in Cambodia, and Depok (DP) in Indonesia, during the early stages of the “new normal”. Adults aged 18 and above were surveyed using a stratified random sampling method. This study applied the calculation formula developed by Yamane [24] to determine sample sizes. With a confidence level of 95% and a margin of error of 5%, the minimum sample size was calculated to be 385. Similarly, at a confidence level of 95% and a margin of error of 6%, the minimum sample size was 267, and at a confidence level of 95% with a margin of error of 7%, the minimum sample size was 196. Difficulty in implementation varied according to the size of the city. After accounting for missing data, the study was conducted with a total of 461 responses in SH, 390 responses in HRB, 250 responses in HAN, 260 responses in PNH, and 252 responses in DP, totaling 1613. For the selection of survey locations, to verify the differences between urban and
rural areas, each city was initially divided into two primary zones (urban and rural). Employing a stratified random sampling method, survey locations were chosen to ensure coverage of 30–50% of the entire area in each zone. Sampling numbers were then distributed across the selected survey locations. Pre-trained investigators conducted personal interviews with residents through face-to-face interviews, phone interviews, and online interviews based on each country’s specific circumstances (e.g., internet penetration and pandemic-related restrictions), rather than requesting that respondents complete the survey on their own. This survey style resulted in highly accurate responses and a high response completion rate.

The World Bank [25] categorizes the global economy into four income groups—low-income, lower-middle-income, upper-middle-income, and high-income groups. In the five selected areas of this study, categorized by per capita GDP, SH falls into the high-income category, while PNH, HRB, and HAN belong to the upper-middle-income category. DP is classified as a low-income area (Table S1). The selected areas for this study encompass a wide range of income levels, enriching our understanding of differences in mask usage across different socio-economic classes.

In addition to income level, the selection of cities was influenced by our partnership with the Economic Research Institute for ASEAN and East Asia (ERIA) and the Regional Knowledge Centre for Marine Plastic Debris (RKC-MPD). These cities were chosen because they offer the potential for conducting in-depth research due to established collaborations and access to necessary data, making them suitable candidates for this study.

3.1.2. Contents of Questionnaire

The questionnaire consists of two parts. The first part covers the basic characteristics of the respondents, including gender, age, location, education level, and monthly household income, among others. The second part focuses on mask usage, including the quantities of single-use face masks and reusable face masks (i.e., cloth face masks) used during the periods before COVID-19, during COVID-19, and in the new normal.

The demographic information collected in the first part of the questionnaire is important for many reasons. Specifically, gender and age are often considered significant factors influencing mask usage, as they may be associated with health awareness and risk.
perception [26,27]. Location information helps us understand variations in mask usage across different geographical locations, which may correlate to different levels of infrastructure and social standing [28], while educational level may be linked to the understanding of the pandemic and the correct use of masks [27,29]. Additionally, household income may impact the ability to purchase and use masks [27,29]. The selection and handling of variables are shown in detail in Table S2.

The second part of the questionnaire primarily focuses on the specific usage of masks. It includes inquiries about the quantity of single-use face masks and cloth face masks used by respondents during three distinct periods: before COVID-19, during COVID-19, and in the new normal phase. These periods represent different stages of the pandemic’s development, enabling us to gain insights into the evolution of mask usage situations. In summary, a comprehensive analysis of respondent characteristics and mask usage patterns will contribute to a more holistic understanding of the factors influencing mask use and their impact on the environment.

3.2. Statistical Analysis

This study employed quantitative methods, including two-factor analysis of variance (ANOVA), independent sample t-tests, and Poisson regression analysis. Two-factor ANOVA determines the significant impact of different periods and areas on mask usage by analyzing the levels of two factors [30,31]. The independent samples t-test identifies significant differences between the means of two independent samples, helping assess urban–rural disparities in mask usage across these five areas [32,33]. Poisson regression analysis, suited for studying event frequency or counts, assesses the significance of influencing factors regarding mask usage quantity [34–36].

3.3. Mask Environmental Impact Indicators

3.3.1. Type of Masks

The following two types of mask were considered in this study.

1. Single-use face masks

Single-use face masks (Figure 2a) are composed of various types of polymers, including polyester, polypropylene, polyethylene, polycarbonate, and polyacrylonitrile, among others, which are also utilized as raw materials for producing different types of plastic products [5]. The COVID-19 pandemic made single-use face masks a ubiquitous choice for protection in medical and public environments. They offer convenience, effective protection, and versatility. Nevertheless, they have drawbacks, notably the significant resource consumption during production and the adverse environmental impact associated with the disposal of large quantities of used masks.

2. Reusable face masks

![Figure 2. (a) Single-use surgical face mask and (b) reusable face mask (cloth face mask).](image)

Reusable face masks (Figure 2b) are usually made of fabrics such as cotton, linen, or synthetic fibers. Due to their reusable nature, these masks require regular cleaning to ensure their cleanliness and effectiveness. However, it is important to note that while reusable face...
masks can be worn multiple times, their filtration efficiency and protective capabilities may not be as high as single-use face masks [37].

3.3.2. Environmental Impact Analysis of Masks

The environmental impact of masks is a multifaceted and complex issue. First, the production and disposal processes of masks involve significant energy consumption and emissions, particularly in terms of greenhouse gases, which can have potential implications for climate change [18,38–40]. Second, the production and usage of masks require substantial freshwater resources, contributing to an increase in water footprint, especially in regions prone to drought [41,42]. Third, the widespread use of masks generates substantial amounts of solid waste, necessitating proper disposal and management to mitigate adverse environmental effects [17,43]. Fourth and finally, there is growing concern about microplastic particles in masks, as these particles have the potential to enter water bodies and ecosystems, posing risks to the ecological environment [44,45].

This study presents a review of the environmental impact of single-use face masks and reusable face masks with a focus on the above four aspects, based on an analysis of the existing literature. Environmental impact intensity indicators for each type of mask were collected from the relevant literature, integrated, and summarized in Table 1. Lee et al. [17], Ajaj et al. [38], and Luo et al. [46] estimated the lifecycle carbon footprint of different mask types using a one-month reference period. As a result, the carbon footprint for single-use masks was set at 0.018–0.043 kgCO$_2$eq per piece. Cloth masks had carbon footprints of 0.23–0.571 kgCO$_2$eq per piece [17,38,41,46]. Additionally, Schmutz et al. [41] estimated the lifecycle water footprint of single-use masks and cloth masks as 0.07 m$^3$H$_2$Oeq and 0.35 m$^3$H$_2$Oeq, respectively, using a one-week reference period. The measured weights for each type of mask were 2.88 g (single-use) and 11.78 g (cloth) respectively. Yu assessed the water footprint of single-use masks and cloth masks, revealing that the water footprint for 3000 single-use masks was 121.73 m$^3$H$_2$Oeq, while for 500 cloth masks, it was 1092.51 m$^3$H$_2$Oeq [42]. Lee et al. reported that one single-use mask generates 4 g of municipal solid waste (MSW), and Ajaj et al. estimated that a single cloth mask generates 12.64 g of MSW [17,38]. Liang et al. conducted measurements and found that one single-use mask can release approximately 1136 ± 87 to 2343 ± 168 microplastic particles within a 24 h period [47]. Overall, single-use face masks generate more CO$_2$, solid waste, and microplastic particles compared to cloth masks, which have a larger water footprint.

Table 1. Environmental impact intensity indicators for masks (one piece).

<table>
<thead>
<tr>
<th>Category</th>
<th>Single-Use Face Mask</th>
<th>Cloth Face Mask</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon footprint</td>
<td>0.018–0.023 kgCO$_2$eq</td>
<td>0.23–0.571 kgCO$_2$eq</td>
<td>Lee et al. [17]; Ajaj et al. [38]; Schmutz et al. [41]; Luo et al. [46]</td>
</tr>
<tr>
<td>Water footprint</td>
<td>0.005–0.041 m$^3$H$_2$Oeq</td>
<td>1.755–2.185 m$^3$H$_2$Oeq</td>
<td>Schmutz et al. [41]; Yu [42]</td>
</tr>
<tr>
<td>Solid waste</td>
<td>2.88–4 g</td>
<td>11.75–12.64 g</td>
<td>Lee et al. [17]; Ajaj et al. [38]; Schmutz et al. [41]; Cai et al. [43]</td>
</tr>
<tr>
<td>Microplastic</td>
<td>1049–2511 microplastic particles/(piece·d)</td>
<td>-</td>
<td>Liang et al. [47]</td>
</tr>
</tbody>
</table>

Furthermore, an assessment of the environmental impact of mask usage in different cities was conducted, considering population size, the proportion of mismanaged and discarded plastics, and per capita mask usage data in each city. The extent of environmental pollution caused by mask usage is closely related to population size and the status of urban waste management. We estimated the overall mask usage in each city by multiplying the per capita mask usage data by the population of each city. Additionally, to estimate the microplastic particles generated from masks, we considered the number of masks entering the environment. According to OECD data, the share of plastics mismanaged and littered in China and other non-OECD Asian countries is 26% and 43%, respectively [48], thus...
entering the environment. The population of each city and the share of plastics mismanaged and littered are shown in Table S3.

4. Results

4.1. Characteristics of Respondents

The attributes of respondents are shown in Figure S1 and Table S2. The sample demonstrates a balanced diversity across gender, age, education, income, and location. However, in Phnom Penh and Depok, female respondents slightly outnumber male respondents. The majority of respondents fall within the 18 to 40 age range, with fewer respondents aged 60 and above. Most respondents have received secondary, vocational, or technical university education. In Shanghai and Harbin, there is a higher proportion of highly educated respondents, likely reflecting the correlation between education levels and economic status. Conversely, Phnom Penh and Depok have a higher proportion of respondents with lower levels of education, reflecting economic disparities and educational challenges. Income levels were categorized from 1 to 6, with 1 representing the lowest and 6 representing the highest income category respectively. Income levels in Shanghai and Harbin cover a wide spectrum, with a higher proportion of respondents falling under income levels 3, 4, and 5. In contrast, Hanoi and Phnom Penh predominantly have respondents at income levels 1 and 2, reflecting the local economic conditions. Depok exhibits a noticeable distribution across both low- and high-income brackets, suggesting economic disparities within the region.

4.2. Mask Use and Its Trends

The use of masks as an important protective measure increased dramatically during COVID-19 and has declined slightly in the new normal, but is still higher than pre-pandemic levels. This may be due to an ongoing concern for people’s health and safety, as well as the habituation of wearing masks. Survey data suggest that this trend holds more strongly for single-use masks than for reusable masks.

The usage of single-use and reusable face masks across different time periods (before, during, and post-pandemic) is depicted in Figure 3, while usage among cities is illustrated in Figure 4. The results of two-way ANOVA are shown in Table S4 and the average number of face masks used in different areas is shown in Table S5. Across the five sample cities, single-use face masks were used at an average rate of 1.46 pieces/week before COVID-19, 6.81 pieces/week during the COVID-19 pandemic, and the expected rate of use in the post-pandemic new normal is 3.73 pieces/week, with a significance difference at the 99% confidence interval. Survey data for cloth face masks show a similar trend. Cloth face masks were used in the sample cities at an average rate of 0.42 pieces/month before COVID-19, 0.83 pieces/month during the COVID-19 pandemic, and the expected rate in the post-pandemic new normal is 0.52 pieces/month, demonstrating no statistical significance (Figure 3). This suggests that while the pandemic had a significant impact on the use of single-use face masks, reusable mask use was not impacted as strongly. This disparity may be due to increased public awareness of the better protection provided by single-use face masks against COVID-19.

However, there were significant differences between cities for both single-use and reusable face masks (Figure 4, Table S4). Regarding single-use face masks (Figure 4a), before COVID-19, Hanoi led with the highest usage prevalence, closely trailed by Shanghai. In contrast, significant segments of the populations in Phnom Penh, Harbin, and Depok scarcely resorted to wearing single-use face masks. During COVID-19, Hanoi continued to exhibit the highest adherence to mask-wearing, with Shanghai ranking next, followed by a sequential increase in Harbin, Depok, and Phnom Penh. In the new normal, Hanoi is still the city with the highest frequency of mask wearing, followed closely by Depok with an average of 1 piece of use per day, showing that the majority of people wear masks as a norm. In contrast, Shanghai, Phnom Penh, and Harbin have relatively low rates of mask use.
Figure 3. Single-use face mask (a) and reusable face mask (b) usage. The red dots represent the average values of mask usage for each period, and the black lines represent the median values of mask usage in each period.

Figure 4. Average number for mask usage in different areas. Single-use masks use is represented in graph (a), and cloth face mask use is represented in graph (b) ** indicates significance at the 99% confidence level.
Regarding reusable face masks (Figure 4b), most people in Hanoi had the habit of wearing reusable face masks even before COVID-19, with a significantly higher utilization rate than in other areas. During COVID-19, the utilization rate of reusable face masks in Depok increased significantly, while other districts were not much affected by the pandemic. It is also worth noting that the use of all mask types in Hanoi was higher than in other regions in all periods, which is closely related to the region’s relatively poor air quality [49] and the prevalent motorcycle commuting culture. Poor air quality often indicates increased environmental pollution and health risks, prompting people to use masks to protect themselves.

4.3. Use of Masks in Urban and Rural Areas

The use of masks in urban and rural areas in each city is shown in Figure 5 and Table S6, and t-test results for differences between urban and rural areas are shown in Table S7. Before COVID-19, there were no significant urban–rural differences in the usage of both types of masks across the five sample cities. During COVID-19, Shanghai did not exhibit significant urban–rural disparities in the usage of both types of masks. This is perhaps due to the highly urbanized nature of Shanghai, with an urbanization rate of 89.3% [50] and relatively balanced economic development across the metropolitan area. Both urban and surrounding areas host significant commercial and industrial zones, which are the primary factors contributing to the minimal urban–rural disparities in Shanghai.

In Phnom Penh, there is no significant difference in the use of reusable face masks between urban and rural areas, and the difference in the use of single-use face masks is only significant during the COVID-19 period. During COVID-19, the significant difference in the use of single-use face masks can be attributed to increased awareness and preventive measures taken by residents [51–53]. Rural areas exhibited a higher usage rate than urban areas, possibly indicating that people in rural areas may be more concerned about the risk of COVID-19.

Harbin, known for its distinctive urban–rural structure [54], exhibited significant urban–rural differences during COVID-19. Urban residents exhibited higher COVID-19 concerns, resulting in more proactive mask-wearing. In the new normal, mask usage decreased, particularly in urban areas. Rural areas saw only a slight 1-piece decrease in per capita weekly single-use face mask usage compared to the COVID-19 period, suggesting a stronger mask-wearing habit among rural residents. The usage rate of reusable face masks varies between urban and rural areas, but is generally low.

Hanoi had the highest mask usage of both urban and rural areas. The usage of single-use face masks did not show significant differences between urban and rural areas, while reusable face masks exhibited noticeable urban–rural disparities in all three periods. Urban residents use reusable masks more frequently, potentially due to Hanoi’s poorer air quality and motorcycle commuting, particularly in urban areas [55].

Depok had significant urban–rural differences in single-use face mask usage during both COVID-19 and the new normal. Reusable mask usage showed significant disparities only during COVID-19. During the pandemic, urban areas saw a notable increase in single-use face mask use, while rural areas favored reusable face masks. In the new normal, overall mask usage decreased, but urban areas maintained a relatively higher level of usage.
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Figure 5. Urban–rural differences in mask usage. Graph (a) shows the quantity of single-use masks used per week across the six sample cities. Graph (b) shows the number of reusable masks used per month across the six sample cities. * indicates significance at the 95% confidence level. ** indicates significance at the 99% confidence level.

4.4. Comprehensive Impact of Respondent Characteristics on Mask Usage

The Poisson regression analysis results are summarized in Table 2. In all models, chi-squared test p-values were below 0.05, signifying a highly significant statistical distinction
between observed data and the independence assumption. This suggests an association between independent variables and mask usage quantity.

### Table 2. Empirical results of the significance of factors affecting mask usage in the five sample cities.

<table>
<thead>
<tr>
<th></th>
<th>Single-Use Face Mask</th>
<th>Cloth Face Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coef.</td>
<td>P &gt;</td>
</tr>
<tr>
<td>SH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>−0.1477</td>
<td>0.003 **</td>
</tr>
<tr>
<td>Age</td>
<td>0.1071</td>
<td>0.001 **</td>
</tr>
<tr>
<td>Education level</td>
<td>0.0756</td>
<td>0.004 **</td>
</tr>
<tr>
<td>Household income</td>
<td>0.0625</td>
<td>0.002 **</td>
</tr>
<tr>
<td>PNH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>−0.0195</td>
<td>0.826</td>
</tr>
<tr>
<td>Age</td>
<td>−0.1418</td>
<td>0.000 **</td>
</tr>
<tr>
<td>Education level</td>
<td>−0.0426</td>
<td>0.131</td>
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<tr>
<td>Household income</td>
<td>−0.0220</td>
<td>0.463</td>
</tr>
<tr>
<td>HRB</td>
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<td></td>
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<tr>
<td>Gender</td>
<td>−0.2279</td>
<td>0.002 **</td>
</tr>
<tr>
<td>Age</td>
<td>−0.4951</td>
<td>0.000 **</td>
</tr>
<tr>
<td>Education level</td>
<td>0.0532</td>
<td>0.040 *</td>
</tr>
<tr>
<td>Household income</td>
<td>0.1390</td>
<td>0.000 **</td>
</tr>
<tr>
<td>HAN</td>
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<td></td>
</tr>
<tr>
<td>Gender</td>
<td>−0.0465</td>
<td>0.300</td>
</tr>
<tr>
<td>Age</td>
<td>−0.1710</td>
<td>0.000 **</td>
</tr>
<tr>
<td>Education level</td>
<td>0.0144</td>
<td>0.511</td>
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<tr>
<td>Household income</td>
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<td>0.595</td>
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<tr>
<td>DP</td>
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<tr>
<td>Gender</td>
<td>0.1959</td>
<td>0.004 **</td>
</tr>
<tr>
<td>Age</td>
<td>−0.0564</td>
<td>0.044 *</td>
</tr>
<tr>
<td>Education level</td>
<td>0.0577</td>
<td>0.033 *</td>
</tr>
<tr>
<td>Household income</td>
<td>−0.0031</td>
<td>0.843</td>
</tr>
</tbody>
</table>

* indicates significance at the 95% confidence level. ** indicates significance at the 99% confidence level.

For Shanghai, all four respondent characteristics (gender, age, education level, and household income) have a significant impact on the use of single-use face masks, while only age demonstrates influence over the use of cloth face masks. Gender significantly influences the usage of single-use face masks in a negative manner, while age, education level, and household income all exhibit positive correlations. Specifically, females, older individuals, those with higher education levels, and individuals with higher household incomes use single-use masks more frequently. Age shows a negative correlation with the use of cloth face masks, with younger individuals tending to use cloth face masks more frequently.

For Phnom Penh, age has a significant impact on the use of single-use face masks, exhibiting a negative correlation. This means that younger individuals tend to use single-use face masks more. Gender and education level are significant influencing factors for the use of cloth face masks, both showing a positive correlation. This implies that males use more cloth face masks than females, and individuals with higher levels of education are more likely to use cloth face masks.

For Harbin, all four factors significantly influence the use of single-use face masks. Gender and age exhibit a negative correlation, while education level and household income show positive correlations. In terms of single-use face masks, it is noteworthy that females, younger individuals, and those with higher education levels and household incomes tend to use them more frequently. Regarding cloth face masks, education level significantly influences their usage, and shows positive correlations. Individuals with higher education levels use more cloth face masks.

For Hanoi, the significant factor influencing the use of single-use face masks is age, and it has a negative correlation, meaning that younger individuals tend to use single-use face masks more frequently. Gender, education level, and household income all have
a significant impact on the use of cloth face masks. Gender and household income are positively correlated, indicating that males use cloth face masks more frequently, and the number of cloth face masks used increases with higher household income. Education level shows a negative correlation, suggesting that those with lower education levels tend to use cloth face masks more.

For Depok, gender, age, and education level significantly influence the use of single-use face masks. Gender and education level exhibit a positive correlation, indicating that males and individuals with higher education levels tend to use more single-use face masks. About 40% of the respondents were housewives in Depok and did not need to wear a mask when at home, which may have influenced the results. Conversely, age shows a negative correlation, implying that younger people use more single-use face masks. Moreover, age, education level, and household income have a significant impact on cloth face mask usage, all of which show a negative correlation. This means that younger individuals, those with lower education levels, and those with lower household incomes are more likely to use cloth face masks.

To summarize, the choice and use of masks exhibit significant variations among different areas. The type of mask chosen and mask-wearing habits are not fixed but rather vary depending on individuals’ needs, risk perceptions, geographical locations, and societal contexts. Therefore, when formulating mask-related policies and conducting public awareness campaigns, it is essential to take these variations into account. This approach will help better cater to the diverse needs of different population groups, ultimately increasing mask usage rates and enhancing the overall effectiveness of public health protections.

4.5. The Environmental Impact of Mask Usage

The environmental impact (the number of masks used, carbon footprint, water footprint, solid waste generated, and the production of microplastics) generated by both single-use surgical face masks and cloth face masks over a year in each city is shown in Table 3. Based on estimates, in these five study areas, a total of 16.6 billion single-use face masks and 0.64 billion cloth face masks were used in one year. This resulted in a carbon footprint of 0.45–1.08 billion kgCO$_2$eq, a water footprint of 1.20–2.08 billion m$^3$H$_2$Oeq, 55.31–74.47 million kg of solid waste, and between 6.50 and 15.56 trillion microplastic particles (the cumulative amount of microplastic particles generated within 24 h after single-use face mask disposal) in total.

<table>
<thead>
<tr>
<th>Number (Billion Pieces)</th>
<th>Single-Use Surgical Face Mask</th>
<th>Cloth Face Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Footprint (Million kgCO$_2$eq)</td>
<td>Water Footprint (Million m$^3$H$_2$Oeq)</td>
<td>Solid Waste (Million kg)</td>
</tr>
<tr>
<td>SH</td>
<td>4.57</td>
<td>82.26–196.61</td>
</tr>
<tr>
<td>PNH</td>
<td>0.33</td>
<td>5.94–14.19</td>
</tr>
<tr>
<td>HRB</td>
<td>1.00</td>
<td>18.00–43.00</td>
</tr>
<tr>
<td>Total</td>
<td>16.61</td>
<td>298.98–714.23</td>
</tr>
</tbody>
</table>

Depok has the highest level of environmental impact from single-use surgical face masks, followed by Shanghai, Hanoi, Harbin, and Phnom Penh. This is largely consistent with population data, as Depok has the highest population among the sample cities, followed by Shanghai, Harbin, Hanoi, and Phnom Penh.

The impact of cloth face masks is also significant, with Depok again leading in terms of environmental impact, followed by Hanoi, which has the highest usage of cloth masks. Shanghai, Harbin, and Phnom Penh show lower levels of impact compared to Depok and Hanoi.

It is noteworthy that while Harbin has a larger population than Hanoi, the environmental pollution caused by mask usage is more severe in Hanoi. This indicates that the
frequency and habits of mask usage significantly influence the overall pollution caused by masks and, in some cases, may be more decisive than population size.

5. Discussion and Recommendations

5.1. Discussion

5.1.1. The Use of Masks

Many studies consistently indicate a significant increase in mask usage during the COVID-19 pandemic [56–58]. However, research on mask usage from before the pandemic and in the context of the “new normal” remains limited. This study covers changes in mask usage across various East and Southeast Asian cities, spanning the period before COVID-19, during COVID-19, and the early phase of the “new normal”, effectively filling a knowledge gap in the research landscape. Our findings reveal that, compared to the peak of COVID-19, there has been a decrease in mask usage in various areas during the “new normal”. Nevertheless, mask usage in all the cities we studied remains higher than the levels seen before COVID-19. This suggests that the experience of the COVID-19 pandemic may have enduring effects on human behavior regarding mask use.

5.1.2. The Influence of Respondent Characteristics on Mask Use

In studies examining the influence of respondent characteristics on mask usage, certain key trends have emerged. Some research has indicated that mask usage is higher in urban areas [28], women tend to wear masks more frequently than men [28,59,60], and older individuals are more likely to adhere to mandatory mask-wearing policies [24,60,61]. Furthermore, some studies suggest that individuals with a higher education level tend to have stronger awareness of preventive measures and wear more masks [62,63]. However, there are also studies that indicate no significant correlation between education level and mask usage [61,64]. Household income also plays a role in mask usage [65]. The impact of participant characteristics on mask usage is a multifaceted and complex phenomenon influenced by many factors, including cultural norms, public health policies, economic conditions, and the specific context of COVID-19.

In this study, we observed that mask usage in five sample cities across East and Southeast Asia is influenced by multiple factors. For single-use face masks, age is the most prevalent influencing factor, significantly impacting all five sample cities. Gender and education level follow as the next most significant factors, with significant impacts shown in three cities. Household income and location only have a significant impact on two cities each. However, the pattern is slightly different when considering cloth face masks. Education level is the single most widespread influencing factor, significantly affecting four sample cities. Next is gender, age, and household income, significantly influencing two cities each. Location does not exert a widespread influence in the sample cities.

5.1.3. The Environmental Impact of Masks

The widespread use of masks, particularly single-use masks, has had significant environmental impacts, including increased carbon emissions, higher water consumption, increased solid waste production, and microplastic pollution [3,17,41,42,66,67]. The findings of this study underscore the substantial environmental burden posed by mask usage, especially in densely populated urban areas. The data suggest a need for the promotion of sustainable alternatives to mitigate the environmental impact of masks.

The functional unit (FU) for masks is typically defined as the quantity of masks used over the course of one month (30 days). For single-use face masks, 1 FU is equivalent to 30 pieces [17,38], while for cloth face masks, 1 FU is equivalent to 2 pieces [38]. In other words, using two cloth face masks is equivalent in frequency to using 30 single-use face masks. Replacing single-use face masks with cloth face masks in the five studied areas would result in a reduction of 44.27–81.9 million kgCO$_2$eq, 34.81–52.41 million kg of solid waste, and a decrease in microplastic particles ranging from 6.50 trillion to 15.56 trillion per year. However, it would increase water usage by 1.73–1.86 billion m$^3$H$_2$Oeq per year.
Thus, this study demonstrates that opting for cloth face masks can reduce carbon footprint, solid waste, and microplastics, but it may increase the water footprint. This underscores the complexity of environmental conservation measures and emphasizes the need for a comprehensive balance of various factors when formulating sustainable environmental policies. Adopting sustainable mask-wearing practices can help reduce unnecessary resource consumption and environmental burdens. Additionally, when calculating the emission of microplastic particles from masks in this study, only mismanaged masks were considered, and the calculation was for microplastic particles released into the environment within the first 24 h after disposal, rather than for the complete decomposition of masks. In reality, the number of microplastic particles emitted from single-use masks may exceed the calculated values in this study.

5.2. Policy Recommendations

Balancing health protection and environmental impact requires strategic and thoughtful measures. This study has revealed a number of ways in which population characteristics interact with mask-use habits, suggesting a number of potential steps that could be taken to develop better habits at the individual, industry, and government levels. The following recommendations could be proposed to enhance the sustainability of supply chains for single-use and reusable masks:

(1) Establishing an environmentally friendly mask supply chain.

To establish an environmentally friendly mask supply chain, a series of sustainable practices need to be implemented at the upstream, midstream, and downstream levels of the supply chain:

a. In the upstream supply chain, promote the use of biodegradable mask materials, develop high-performance cloth face masks to reduce the risk of microplastic pollution.
b. Simultaneously, reduce the weight of masks, minimize material waste, and implement eco-friendly manufacturing methods such as the use of renewable energy sources to decrease carbon emissions.
c. In the midstream supply chain, use recyclable materials for mask packaging, reduce packaging usage to lower solid waste generation, and alleviate plastic pollution pressure.
d. In the downstream supply chain, establish recycling programs to recycle used masks to reduce waste and microplastic generation.
e. Additionally, formulate washing standards suitable for cloth face masks to decrease water resource wastage.

Implementing these comprehensive measures will enhance the sustainability of the supply chain, mitigating the adverse environmental impact of mask production and use.

(2) Promoting sustainable use and the proper disposal of masks.

Due to the heightened awareness of protection brought about by the COVID-19 pandemic, there is increased sensitivity towards mask usage, indicating that masks may be more commonly worn not only during future pandemics but also during cold and flu seasons. Additionally, with the normalization and even fashionization of mask-wearing, many individuals may continue to wear masks even in the new normal. Proactive information dissemination can play a crucial role in striking a balance between health needs and environmental protection, facilitating a more sustainable adaptation to current challenges. For example, research suggests a correlation between the duration of use of disposable masks and the quantity consumed [68]. Therefore, establishing clear guidelines for effective mask usage duration could potentially reduce consumption. Furthermore, it is imperative to ensure that proper disposal methods align with local waste management practices, emphasizing classification, recycling, and reuse. This approach not only reduces environmental impact but also promotes a circular economy, contributing to long-term sustainability.

(3) Implementing awareness campaigns for proper mask selection and usage among specific demographic groups.
Conducting targeted awareness campaigns aimed at specific demographic groups would be effective in reducing the use of disposable surgical masks. For example, in Shanghai and Harbin, focusing on women, highly educated individuals, and those with higher incomes would be more effective. Additionally, in Shanghai, priority should be given to the elderly, while efforts in Harbin should be directed towards young people and rural residents. In Phnom Penh and Hanoi, targeting young people in promotional activities may be more effective, while in Depok, campaigns should be carried out targeting men, young individuals, those with higher education, and urban populations. See the following:

a. Closely examining the reasons why people are using masks (i.e., urban air pollution, managing air-borne disease) and sharing this information with the business community can help industry to develop masks that meet the specific needs of users, while reducing the use of plastics and other chemicals.

b. Enhancing awareness about the best uses for different types of mask can also help guide consumption away from more intensely polluting masks toward lighter, less environmentally damaging masks that meet the needs of individuals.

c. Awareness campaigns targeting proper disposal practices for masks can help to reduce the number of masks going to landfill or ending up in local ecosystems and waterways.

6. Conclusions

In conclusion, this study, based on questionnaire surveys conducted in five representative cities (Shanghai, Harbin, Hanoi, Phnom Penh, and Depok) across East and Southeast Asia (with a total of 1613 respondents), analyzed the usage patterns of single-use and cloth face masks during different periods of the COVID-19 pandemic, including before, during, and post-pandemic phases. Additionally, the study examined individual characteristics influencing mask usage patterns and estimated the environmental impact of mask usage.

Our findings reveal that the outbreak of COVID-19 led to a significant increase in the usage of single-use face masks across all five sample cities, with a five-fold increase observed during the pandemic. Although there was a decline in usage during the transition to the ‘new normal’ phase, mask usage remained three times higher than pre-pandemic levels. Furthermore, mask usage patterns were influenced not only by demographic factors such as age, gender, and education level but also by regional characteristics including air quality and commuting habits.

The observed trends underscore the complex interplay between public health priorities and environmental considerations. As such, careful strategies are needed to strike a balance between protecting health and minimizing environmental impact. Recommendations stemming from our study include the promotion of sustainable mask-wearing practices, such as the adoption of reusable options, raising awareness of proper mask use and disposal, and the implementation of proper disposal methods.

This survey was conducted during the early stages of transitioning into the “new normal”. While it provides valuable insights, it is essential to acknowledge its limitations in fully reflecting the true state of the new normal period. The habituation of mask-wearing is influenced by various factors, including the pandemic’s progression, other infectious diseases, climate change, and lifestyle habits. Further tracking of mask usage patterns and understanding the multifaceted factors shaping these trends are crucial. By integrating insights from both public health and environmental perspectives, policymakers and stakeholders can develop effective strategies to address current and future challenges related to mask usage, thereby safeguarding human health and the environment.
**Supplementary Materials:** The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16156683/s1, Figure S1: characteristics of respondents, Table S1: GDP and per capita GDP, Table S2: selection and handling of variables, Table S3: results of t-test for differences between urban and rural (surrounding) areas, Table S4: results of two-way ANOVA, Table S5: average number of mask usage in different areas, Table S6: mask usage in urban and rural areas, Table S7: results of t-test for differences between urban and rural (surrounding) areas. References [69–76] are cited in the Supplementary Materials.

**Author Contributions:** Conceptualization, C.L. (Chen Liu); methodology, C.L. (Chang Liu) and C.L. (Chen Liu); formal analysis, C.L. (Chang Liu); investigation, C.L. (Chang Liu) and C.L. (Chen Liu); resources, C.L. (Chen Liu); data curation, C.L. (Chang Liu) and C.L. (Chen Liu); writing—original draft preparation, C.L. (Chang Liu); writing—review and editing, C.L. (Chen Liu) and D.A.; supervision, C.L. (Chen Liu); project administration, Y.H. All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** This study was exempt from ethical review as the surveys were anonymous and did not collect personally identifiable information. The surveys focused on general behaviors and perceptions related to face mask usage and did not include sensitive or high-risk questions. We followed ethical guidelines to ensure participants’ privacy and confidentiality.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

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