





Evaluación del impacto ambiental de los residuos de los equipos de protección industrial: una revisión sistemática del arte postpandemia

Environmental impact assessment of industrial protective equipment waste: a systematic review of the post-pandemic art

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Resumen

Introducción: En el mundo durante la pandemia provocada por el COVID 19, se generaron alrededor de 8,4 y 9,2 millones de toneladas de residuos plásticos que incluyen en su mayoría los equipos de protección industrial (EPP), que fueron utilizados por toda la población mundial principalmente para frenar el nivel de contagio del Coronavirus. Sin embargo, muchos de estos residuos terminaron como desechos en ríos, océanos o incinerados, lo cual ha contribuido a un impacto ambiental negativo, mismo que es la fuente de cambios climáticos, aumento del efecto invernadero, contaminación principalmente marítima y la muerte de cientos de especies. **Objetivo:** Realizar una revisión sistemática de las evaluaciones del impacto ambiental de los generados por los residuos de los equipos de protección industrial postpandemia. **Resultados:** Las distintas investigaciones muestran claramente la inadecuada gestión de residuos sólidos que existe a nivel general, en términos de huella de carbono y huella energética de los residuos de equipos de protección el impacto al ambiente es inminentemente negativo, además se pudo demostrar a liberación de micro plásticos (MP) y microfibras (MF) de los EPP desechados se convierte en una amenaza emergente para la sostenibilidad ambiental. **Discusión:** Las investigaciones desarrolladas alrededor del problema generado por los residuos sólidos de los equipos de protección personal son el soporte para mostrar el pésimo manejo de residuos que se tiene en todo el mundo, especialmente en países poco desarrollados, pero aún más importante la necesidad de implementar programas de concientizar social y por otro lado generar políticas ambientales que mitiguen contaminación postpandemia. **Conclusión:** Se concluyó que las investigaciones desarrolladas establecieron impactos considerable negativos al medio ambiente, entre los que se encuentra generación de residuos sólidos por los EPP que siguen generando contaminación en afluentes hídricos y en la atmósfera.

Abstract

Introduction: In the world during the pandemic caused by COVID 19, about 8.4 and 9.2 million tons of plastic waste were generated, which included mostly industrial protective equipment (PPE), which were used by the entire world population to curb the level of

protection,
personnel.

Coronavirus contagion. However, much of this waste ended up as debris in rivers, oceans or incinerated, which has contributed to a negative environmental impact, which is the source of climate change, increased greenhouse effect, marine pollution, and the death of hundreds of species. Objective: To conduct a systematic review of the environmental impact assessments of post-pandemic industrial protective equipment waste. Results: The different investigations clearly show the inadequate management of solid waste that exists at a general level, in terms of carbon footprint and energy footprint of the waste from protective equipment the impact on the environment is imminently negative, in addition it could be demonstrated that the release of micro plastics (MP) and microfibers (MF) from discarded PPE becomes an emerging threat to environmental sustainability. Discussion: The research developed around the problem generated by solid waste from personal protective equipment (PPE) is the support to show the bad waste management around the world, especially in underdeveloped countries, but even more important is the need to implement social awareness programs and on the other hand to generate environmental policies to mitigate post-pandemic contamination. Conclusion: It was concluded that the research conducted established considerable negative impacts on the environment, among which is the generation of solid waste from PPE that continues to generate pollution in waterways and in the atmosphere.

Introduction

There is currently a global environmental crisis due to improper management of solid waste originating in the personal protective equipment (PPE) used during the Coronavirus pandemic, which is why it is necessary to implement "Effective solid waste processing systems that protect biodiversity and ecosystems, in order to guarantee future environmental sanitation caused by the excessive and improvised use of industrial PPE" (Franchini & Mauad, 2022). In this sense, it should be noted that the use of personal protective equipment that was previously used exclusively in the industry and its use as a protective measure against contagion increased the demand for it during the pandemic. This increase is currently generating serious environmental problems according to different studies carried out.

COVID-19 generated a pandemic that had a global impact, causing millions of people to become infected and many of them to die, but the change also occurred in organizations, which had to adapt to the new reality. Industrial activities were noticeably affected, mainly by social isolation, quarantine and confinement. In this context, "the economy suffered a drastic fall, as well as a decrease in income and quality of life of people, who had to protect themselves from the virus using even industrial-use PPE" (Severo et al., 2023). In this context, the amount of waste increased disproportionately, generating a negative impact on the environment.

The pandemic caused by COVID-19 put a lot of pressure on the existing waste management system, due to "Excessive consumption of personal protective equipment, increased industrial production for the production of supplies such as face shields that were used exclusively in industry and were urgently used to prevent contagion" (Rhee, 2020). Therefore, the improper disposal of PPE shows in the different investigations the negative impact on the environment, an impact that is present worldwide and its consequences are more noticeable in coastal areas, where studies have been developed to mitigate these impacts and to establish environmental sanitation measures.

PPE is produced from a variety of different polymers and materials: polyacrylonitrile, polypropylene and/or polyurethane face masks, latex, vinyl, synthetic polymers and disposable nitrile and leather gloves, and other synthetic fibers, which when released cause contaminant leaks, which is why "Inadequate disposal of PPE can cause stress to infrastructure and waste management systems" (Czigany & Ronkay, 2020). For the aforementioned reasons, PPE waste generated in the pandemic must be treated through specialized and strictly regulated waste management systems, which often involve the sterilization and incineration of said waste, seeking a lesser impact on the environment.

Personal protective equipment is classified into many types, including face shields, which were until before the pandemic exclusively used in the industrial sector. This caused the demand for PPE to increase considerably worldwide, "It is estimated that around 65 billion face shields were used every month worldwide. In the end, it adds a huge burden to traditional solid waste management systems" (Prata et al., 2020). This burden is an environmental problem worldwide and continues to cause concern to the governments in power.

According to the United Nations (UN), the high production of waste with a contaminating biological risk produced by the virus that causes COVID-19 contributes significantly to the contamination of the environment and its elements, increasing the risk of the proliferation of diseases and saturating solid waste treatment systems. For this reason, educating and raising awareness among the general population about the proper management of waste from the use of PPE represents a challenge for each country, mainly at a cultural level.

During the pandemic, both public and private companies from all areas implemented biosecurity measures that allow them to fulfill their roles, "The main ones being the use of single-use industrial protection equipment (gloves, conventional masks, N95 masks, protective glasses, visors), which is why the amount of waste increased dramatically worldwide" (Sánchez-Gutiérrez, 2021). These measures undoubtedly saturated solid waste processing systems worldwide, causing environmental impacts to this day.

According to the UN, during the pandemic they have generated shipments of a total of 87,000 tons of protective equipment to several countries (UN News, 2022). According to them, 60% of medical units in underdeveloped countries are not equipped to manage this level of waste that represents a risk to health, which in underdeveloped countries such as Ecuador highlighted the lack of waste treatment that we currently have and also warned about the damage that not modernizing these systems causes to the environment (Basadre, 2021). Based on the above, it was possible to establish that the environmental impact will persist in the coming years, and that it could even worsen if the necessary measures are not taken for adequate environmental remediation.

Article 55 of the COOTAD in force in Ecuador states that "Municipal Decentralized Autonomous Governments are directly responsible for the management of their waste" Program 'PNGIDS' Ecuador (Ministry of Environment, Water and Ecological Transition, 2024). However, the treatment of this waste with the methodology of collection and final disposal in the open air represents an obsolete and unsustainable method, which is practically only carried out in underdeveloped countries and which undoubtedly increases the negative environmental impact.

The objective of this research work is therefore to carry out a systematic review of the research on environmental assessments related to PPE, to establish the impact that the increase in this type of waste has had on the health of the environment, as well as to raise social and political awareness among the population about the importance of protecting the environment, especially in the proper disposal of solid waste generated by PPE, and finally to implement adequate and modern systems for the collection and treatment of biologically contaminating waste.

Therefore, it was established that "COVID-19 should be considered a holistic risk to the environment and public health, as well as to global economic and social institutions and plastic waste management" (Silva et al., 2020). In this sense, the impact on the environment is evident to this day, where we have garbage dumps saturated with industrial-type PPE and that release fibers that are polluting the air of different cities.

Methodology

Type of scientific research

This research is of a documentary nature, since it is based on the bibliographic compilation of information and research developed around the increase in solid waste caused by industrial protection equipment used during the pandemic experienced in previous years by COVID-19, with the aim of analyzing, comparing and establishing the environmental impact generated worldwide.

Scientific method

The research method used is the Synthetic Method, since it is based on the knowledge of the various panoramas that COVID-19 has left, mainly in the consequences it left as a negative impact on the environment, in order to achieve a general knowledge of the current reality, starting from different investigations to carry out a complete analysis, developing a methodical and brief explosion of the lack of solid waste management systems throughout the planet.

Research design

The design used is qualitative participatory research, since its purpose is to make known the impact that waste from industrial protection equipment used during the pandemic of the years 2020-2023 has generated on the environment and, above all, to raise awareness of the importance of proper waste management for the care of ecosystems and therefore of life itself, an analysis that has a theoretical foundation from the different investigations outlined in this study.

Results

The global population during the pandemic generated an enormous demand for personal protective equipment made of plastic. This material is widely used for its excellent strength-to-weight ratio, in addition to its durability and low production cost, to the point that items such as industrial face shields were used as protective devices against COVID 19. Unfortunately, the uncontrolled use of plastic protectors has become one of the problems affecting the environment after the pandemic occurred.

In Ecuador, as an environmental protection measure, protocols were designed for the collection, management and treatment of waste from industrial protection equipment and some other waste classified as biologically hazardous waste, but unfortunately in several cities that do not have adequate solids management, the problem persists to this day, causing negative impacts on the environment.

Collection of waste from industrial protective equipment in Ecuador

Waste from protective equipment during the pandemic was categorized within waste with biological risk and according to the protocol for disposing of protective equipment issued

by the Secretariat of Risk Management (2024), the following steps must be followed for proper waste management:

- Waste is stored in red plastic bags in red bins (preferably with a lid and pedal to open) that should be placed as close as possible to the place where the waste is generated.
- When the bag is $\frac{3}{4}$ full, remove it from the bin by tying a knot at the top.
- Each disposal bag must be weighed and labeled with the type of waste and the total weight, taking into account that it must not exceed 10 kilograms.
- Collection is carried out at times established by the different Decentralized Autonomous Governments (GAD's) for subsequent disposal (Protocols and manuals).

The above is not complied with in most cities, due to the lack of solid waste management plans, which makes proper treatment of personal protective equipment impossible.

Comprehensive waste management at municipal level

In Ecuador, there are companies that are responsible for collecting highly polluting or biologically hazardous solid waste, such as the Metropolitan Company for Comprehensive Solid Waste Management (EMGIRS-EP).

This company is responsible for eliminating waste under the regulations of “Management of Infectious Waste for the Health Services Network in Ecuador” issued by the Ministry of Public Health. EMGIRS-EP is responsible for managing, processing, collecting, transporting, treating and disposing of all waste considered hazardous.

Waste disposal process implemented by EMGIRS-EP

- Waste collection using biological irrigation in red plastic bags that will be transported to collection centers.
- Waste mobility to the Biological Risk Waste Treatment Plant, under strict legal, environmental and biosecurity regulations.
- Placement in the treatment system containers for sterilization by means of heat transfer using saturated steam.
- Sterilization by destruction and inactivation of microorganisms under conditions of direct exposure.
- Finally, the material is transported to a truck with a hydraulic push system for unloading and final disposal in the landfill.

Even though this type of waste treatment seeks to have the least possible impact on the environment, it requires proper management from the place where it originates in order to treat it, and this is one of the largest sources of environmental pollution that has been

determined in this study. However, many of these personal protective equipment items, when used at home, end up contaminating the environment, since the general population, to date, does not know how to dispose of these types of items used in industrial activities.

Environmental impact produced by industrial protection equipment

According to the Proceedings of the National Academy of Sciences of the United States of America, up to 2021, approximately 9.2 million tons of plastic waste (including PPE) associated with the pandemic were generated in an analysis of 193 countries.(Peng et al., 2021, pp. 7-9). These wastes undoubtedly generated impacts on aquatic systems as shown in Table 1:

Maritime pollution

Table 1

Mass of poorly managed plastics associated with the pandemic that end up in the environment

Continentes	Casos de pacientes confirmados (%)	MMPW (%)	El caudal fluvial (%)		
			Total	Microplástico	macroplástico
África	3.8	7.9	5.9	5.6	6.1
Asia	31.2	46.3	72.5	75.6	69.6
Europa	25,7	23.8	11.2	10.0	12.5
América del norte	21.9	5.6	1.9	1.5	2.3
Sudamerica	17.3	16.4	6.9	6.0	7.6
Oceanía	0.1	<0,1	1.6	1.3	1.9

Fountain:Peng et al. (2021)

According to a study carried out during 2021, Asia was the continent with the highest production of poorly managed plastics that were associated with the increase in waste production during the pandemic, estimated to be approximately between 8.4 and 9.2 million tons, and it is stipulated that between 25,900 and 29,500 tons have reached the oceans around the world (Ronja, 2022).

Nanjing University designed a model that mentions that waste carried by rivers reaches the oceans, beaches and seabeds within a period of 3 years. In addition, it shows the main

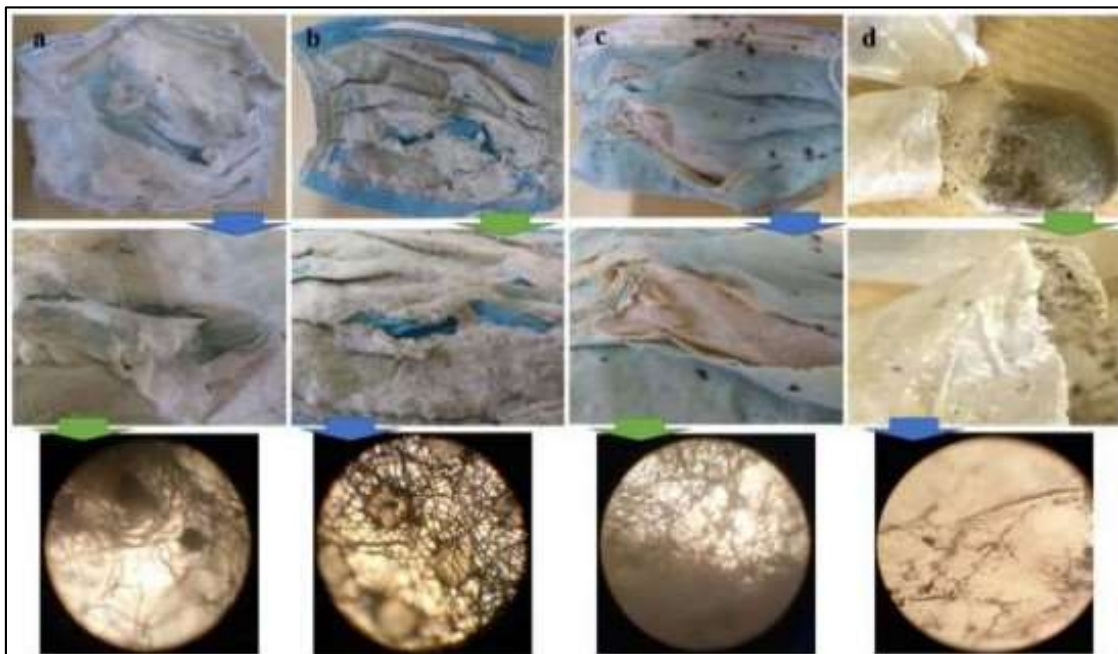
processes of waste once it reaches the sea, these being: stranding, drift, sedimentation, biofouling, abrasion and fragmentation (Wu et al., 2021, pp. 14-26).

According to PNAS, a long-lasting impact on global oceans is estimated due to the release of waste associated with the pandemic, suggesting that 28.8% of this waste will end up on the seabed or 70.5% on beaches, potentially harming benthic ecosystems (Peng et al., 2021, pp. 18-19).

On the other hand, an analysis carried out at César Vallejo University establishes that masks are the most predominant protective equipment, followed by gloves and other types of PPE such as caps and masks in smaller quantities. Among the masks, single-use masks, KN95 masks, and cloth or unidentified masks were found (Rodríguez & Vera, 2022, pp. 42-58).

Figure 1

Analysis of damaged masks and gloves obtained from coastal ports



Fountain:Rakib et al. (2021, pp. 14-15)

These plastic items that have not been adequately treated for disposal can slowly degrade under environmental conditions, however, in aquatic environments the decomposition is faster, generating microplastics that negatively affect marine life, since, when decomposing, they release fibers that are usually consumed by marine animals, causing their death (Rakib et al., 2021, pp. 14-15).

An article published in 2021 by a group of researchers showed the deaths of marine species due to the consumption of fibers released by PPE in the ocean.

Figure 2

Results of the necropsy performed on a marine species



Fountain: Neto et al. (2021, pp. 28-30)

The article mentions that global ocean pollution is causing climate change that is forcing several species to migrate, seriously affecting the food chain, causing animals to lose food and being forced to change their diet to what is found in the sea. In this way, they consume fibers from millions of tons of waste that have entered the oceans during the pandemic, causing the death of hundreds of thousands of species around the world (Neto et al., 2021, pp. 28-30).

Air pollution

Poor waste management, coupled with a massive increase in mostly plastic waste generated by the COVID-19 pandemic, led to much of this waste being incinerated as a measure taken in response to the rapid spread of the virus.

According to Celis et al. (2021), During the pandemic, around 15 thousand tons of plastic waste were incinerated, including PPE. (pp. 6-8) Furthermore, it was estimated that 99.2%

of the plastic waste from industrial protective equipment incinerated is composed of polypropylene. This practice generates a serious footprint on the environment, since it favors the production of greenhouse gases.

The greenhouse effect causes the planet's heat radiation to be absorbed by atmospheric gases and sent back in all directions, causing an increase in the Earth's temperature. that generates serious climate changes such as: loss of glaciers, rising sea levels, coral bleaching, floods, heat waves, droughts, among others (Hernández, 2020, pp. 2-5).

Political response and its implications

Faced with the problem of waste produced during the pandemic, governments belonging to the European Union took action in which a budget is directed to address the level of illegal dumping attributed to the COVID-19 crisis. This contributes greatly to environmental protection as it allows public and private companies to improve waste treatment and therefore reduce the amount of waste that ends up in the oceans.

On the other hand, in underdeveloped countries the health crisis has considerably worsened economic stability, and they have seen it as a priority to provide citizens with protective equipment to reduce the level of contagion, however, they have largely neglected the proper management of the waste they have created. This has a high impact on the health of the environment and reflects the need for support in terms of infrastructure design and technology that improve the waste disposal system.

Discussion

While the COVID-19 pandemic has caused a serious health crisis that has cost millions of lives around the world, it is important to also focus on the repercussions that the pandemic has left on an environmental level, since in the long term it can mean not only the loss of millions of lives but also the complete deterioration of our planet and the extinction of the human race, as well as some animal and plant species.

The implementation of environmentally friendly systems focused primarily on the proper treatment of solid waste, not only the waste generated during the pandemic but in general, should be a primary task for all governments in the world. This is one of the general discussions found in the bibliographic review carried out in the present study, and this is because when talking about environmental protection, a commitment to caring for the environment in which it interacts is always sought.

In general terms, the research consulted and analyzed establishes that “awareness of social and environmental responsibility” is essential to reduce the impact on the environment generated during and after the COVID-19 pandemic, and the different authors agree that

only in this way will it be possible to increase resilience to other pandemics that the world will imminently suffer.

Finally, the accumulation of plastic waste from PPE in urban areas, particularly from sewage systems, can increase the risk of flooding (Adam et al., 2020), constituting breeding grounds for the generation of diseases of zoonotic origin. Another fundamental case analyzed in the present research is the detachment of PPE fibers, which are transported by the wind to aquatic ecosystems, this has caused an accelerated degradation of the same, even in several investigations it has been proven that, in the most remote areas of the Earth, for example lakes on isolated islands in Antarctica and even in deep waters (Ajith et al., 2020), there is evidence of waste from PPE. Making it evident that in our country these environmental problems are also present.

Conclusions

- It was concluded that humanity has an indisputable dependence on plastic as a raw material, this has become evident during the COVID-19 pandemic, which gives rise to the need for stricter environmental policies, which aim to guarantee the sustainable use of plastics in the production of PPE in the future and, at the same time, extract the greatest benefits both at an economic level as well as at a safety and hygiene level.

It was determined that during the COVID-19 pandemic, the use of PPE increased uncontrollably, so the different investigations agreed on the need to rethink and redesign the plastics used in the production of easy protectors, since they were originally used only in the industrial sector, to the point of looking for ecological solutions where cost is still a pending issue.

- It was concluded that, in general, the studies analyzed propose the need to implement an improvement in recycling flows, especially for solid waste, with the aim of guaranteeing an adequate end of life for the PPE used during the pandemic, in addition to producing reusable alternatives for this type of items.
- The environmental impacts generated by waste from industrial protective equipment after the pandemic were established through a systematic review of different investigations, where the need for greater public awareness and the generation of sustainable solutions in the management of solid waste at local, national and global levels is evident.

Conflict of interest

The authors declare that there is no conflict of interest in relation to the submitted article.

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