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REVIEW PAPER

MICROPLASTIC IN THE ENVIRONMENT. THE ROLE OF EDUCATION IN RAISING SOCIAL AWARENESS OF THE HANDLING OF PLASTIC WASTE*

Jarosław Chmielewski[1], Jarogniew J. Łuszczki[2], Ilona Żeber-Dzikowska[3], Małgorzata Dziechciaż[4], Małgorzata Czarny-Działak[5], Barbara Gworek[6], Mariola Wojciechowska[3]

[1] College of Rehabilitation in Warsaw, Poland
[2] Institute of Rural Health in Lublin, Poland
[3] Department of Social Work Institute of Pedagogy The Jan Kochanowski University in Kielce, Poland
[4] Health Care Institute State School of Higher Vocational and Economic Education Jarosław, Poland
[5] Institute of Health Sciences, Collegium Medicum Jan Kochanowski University in Kielce, Poland
[6] Institute of Environmental Protection National Research Institute in Warsaw, Poland

Abstract

Microplastics (MPs) are particles and fragments of plastic materials of the size < 5 mm. The most popular ones include polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS), polyurethane (PUR), and polyethylene terephthalate (PET). The article presents issues related to the pollution of the environment by MPs as a byproduct of plastic decay, and the resulting health hazards. Aim of the study: Showcasing the negative effects of environmental exposure to MPs on the human health and the necessity of taking action to raise social awareness as far as the handling of plastic waste is concerned. Method: Bibliometry was used in the study as a means of evaluating the area of research related to environmental exposure to MPs. A literature review was carried out by browsing through the PubMed database, including articles written in English, using the advanced search option, on the basis of key words

Jarosław Chmielewski, PhD, College of Rehabilitation, St. Kasprzaka 49, 01-234 Warsaw, e-mail: j.chmielewski@ios.gov.pl

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or their combinations and a set time frame. Some of the articles included in the review were found in the Google Scholar browser, also through the use of key words. Results: In the scope of the analysed database, there has been an increase in the interest in the topic of MPs, especially environmental exposure, which dominates the areas of interest of scientists. MPs may be a threat to human health, and consequently a cause of many illnesses, including chronic conditions of the respiratory system, depression, liver damage, obesity, and cancers. Conclusions: Environmental exposure to MPs may be the cause of chronic conditions of the respiratory system, as well as other organs. Both now and in the future, the subject of MPs is bound to remain an important global issue, not only because of the pollution of the environment with plastic waste, but also the impact of this pollutant on the health of animals and people.

Keywords: plastics, microplastics (MPs), environmental exposure, pollution, toxicology, biodegradation, health, education.

INTRODUCTION

The outbreak of the COVID-19 pandemic in 2020, per the World Health Organization (WHO)'s recommendations, caused a worldwide increase in the use of protective face masks as personal protection equipment (PPE) against the SARS-CoV-2 virus infection. The COVID-19 pandemic caused a simultaneous increase in the production of other PPEs against infection, including disposable gloves, boilersuits, face shields and protective glasses, wet tissues for hand disinfection, and laboratory materials (e.g., swab sticks). PPE is mostly made from a variety of different polymers and materials, and is disposable. The most common materials amongst the ones used in the production of PPE are polyacrylonitrile, polypropylene and/or polyurethane, latex, vinyl, synthetic polymers, and/or nitrile, and other synthetic fibers. Considering the increase in the global PPE demand due to the COVID-19 pandemic, one has to simultaneously be aware of the fact that it is relates to the need for proper management of its waste and disposal. Unlike protective face masks, which are commonly used around the world nowadays, PPE waste from the healthcare escort is strictly regulated and falls under the scope of the waste management system. It is estimated that hitherto in the COVID-19 pandemic, the improper management of PPE has contributed to the contamination of the environment with plastics with a monthly average of 129 billion face masks and 65 billion gloves. It has to be noted here that face masks made from many layers of different polymers are much more difficult to recycle. The significant nature of this problem for environmental protection can be proven by the fact that in the Hubei province of the People's Republic of China (PRC) only, a 340% increase was noted, from 40 tons to 240 tons of only medical waste, containing a significant amount of plastic disposed daily (Prata et al. 2020, Shen et al. 2021, Shruti et al. 2021, Vanapalli et al. 2021).

The common use of PPE recommended by WHO recommendations as a means of curtailing negative health consequences of the SARS-CoV-2 virus during the COVID-19 pandemic caused a significant growth in the production and use of products containing plastics, which ultimately end up in waste streams.

WHO estimated the monthly needs of PPE for healthcare professionals at 89 million medical masks, 76 million gloves, 1.6 million goggles. Given the hitherto capacity of managing waste containing plastics, the issue of their proper disposal without threatening the environment and health has to be approached with great concern. With such a high increase in the production and use of PPE, the existing infrastructure for waste incineration may not be able to meet the challenge of handling the additionally produced plastic waste. The disposal of waste containing plastic through incineration alone contributed an equivalent to 5.9 million metric tons of CO_2 by emission in the U.S. and globally 16 million metric tons of greenhouse gases in the year 2015. Greenhouse gas emission was predicted to increase to 49 million metric tons in 2030 and 91 million metric tons by 2050, respectively, as per previous estimates of the production of plastic and incineration. Concern is raised about the risk of releasing dangerous gases, such as dioxins and furans, into the atmosphere in the process of plastic disposal through incineration in ineffective and insufficiently maintained recycling installations or by burning landfills containing PPE. The uncontrolled burning of waste which contains plastic, including PPE, may contribute to higher emissions of greenhouse gases to the environment, causing a negative impact on global warming, which is why it is so important to push for broad education aiming to raise social awareness of the impact of plastic on the environment and health in the context of environmental and public health (Canning-Clode et al. 2020, Chmielewski et al. 2020, 2020*a*, 2020*b*, Prata et al. 2020, Ardusso et al. 2021, Prata et al. 2021, Silva et al. 2021, Vanapalli et al. 2021).

MPS AS A COMPONENT OF PLASTICS

Plastic materials are not found naturally in the environment; they are a result of human activity. Universal properties of plastics and consequently a broad scope of their possible use and relatively low production costs have made them one of the most widespread materials used in many industry branches and in daily life. Plastic materials, referred to as plastics, are materials that include many chemical substances. Their primary components are polymers, which are multi-molecular chemical compounds obtained in the industrial process of polymerization. They are synthetic organic polymers, produced through the polymerization of monomers originating from petroleum and natural gas, while also containing antioxidants, thermal stabilizers, different catalysts, and coloring agents added in the production process of polymer materials. In the plastic processing industry, there are currently over one hundred different (as far as chemistry is concerned) polymers in use, including: polyethylene (PE), including low density polyethylene (LDPE) and high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), copolymer acrylonitrile, butadiene and styrene (ABS), copolymer styrene and acrylonitrile (SAN), polyvinylchloride (PVC), polyoxymethylene (POM), polycarbonate (PC), polyamide (PA), epoxy resins (EP), silicon (SL), cellulose nitrate (CN), unsaturated polyesters (UP), polyurethane (PU), polyimides (PI), polytetrafluoroethylene (PTFE), polymethylmethacrylate (PMMA), polyether(ether ketone) (PEEK), poly(ethylene terephthalate) (PET), poly(lactic acid) (PLA), poly(butylene succinate) (PBS), poly(butylene adipate terephthalate) (PBAT), polyhydroxyalkonates (PHAs), poly(hydroxybutyrate) (PHB), polyvinyl alcohol (PVA), poly(lactic-co-glycolic acid) (PLGA), which are applicable in approximately 60 000 plastic recipes in the industry. Commonly produced and used polymers include PP (19.3%), LDPE (17.5%), HDPE (12.3%), PVC (10.2%), PU (7.7%), PET (7,4%) and PS (6,6%), which constitute over 90% of the produced plastics, becoming the most frequent polymer pollutants in the world (Gao et al. 2015, Li et al. 2016, Geyer et al. 2017, Wagner 2017, Ramkumar et al. 2021).

Unique versatility of polymer materials and very useful characteristics, as well as the low production costs have allowed them to replace an array of traditional materials, becoming more widely used in the production of many industrial products, such as the production of containers (plastic bottles, trash bags, shopping bags), the construction industry (polystyrene, PVC, window frames), the automotive industry (vehicle headlights, bumpers, dashboards), the electrical and electronics industry (wire insulation), agriculture (gardening tools, plant pots), medicine (syringes, blood bags, artificial cornea, caps for drugs, artificial heart) or sport (shoes, tennis rackets, boats) – Li et. al. (2016), Wagner (2017), Rizan et al. (2020).

Examples of different plastics commonly found in the environment are shown in Table 1 (Li et al. 2016).

Available data on the global scale indicate that there is an acceleration is the production of plastics at a level of 8% a year, from 21 million tons in the 1950s to the current production level of >405 million tons, where 51% of the global production comes from Asia alone. In 2014, plastic material production amounted to 322 million tons worldwide, 58 million tons in Europe alone, while in 2016, approximately 380 million tons were produced already, 40% of which was used for disposable plastic containers. It is estimated that in the United States alone, the healthcare sector generates over 1.7 million tons of plastic waste every year. The share of MPs is predicted to be equal to 13.2% of all the accumulated plastic in the world by the end of 2060 (Geyer et al. 2017, Horton et al. 2017, Wright et al. 2017, Rizan et al. 2020, Ramkumar et al. 2021, Sharma et al. 2021).

According to the data of the Statistics Poland (former: Polish Central Statistical Office GUS), the amount of plastic container waste produced in the 28 member states of the European Union in the years 2007-2017

Table 1

Types of plastic commonly found in the natural environment
(modified after Li et. al. 2016)

Type of plastic/acronym	Use/application
Polyester (PES)	fibers and textiles
Polyethylene terephthalate (PET)	soft drink and water bottles, salad domes, biscuit trays, salad dressing, and peanut butter containers
Polyethylene (PE)	wide range of inexpensive uses including supermarket bags, plastic bottles
Polyvinyl chloride (PVC)	plumbing pipes and fittings, cosmetic containers, electrical conduit, wall cladding, roof sheeting, garden hoses, blood bags, and tubing
Polypropylene (PP)	dip bottles and ice cream tubs, potato chip bags, microwave dishes, kettles, garden furniture, lunch boxes, blue packing tape
Polystyrene (PS)	packaging foam, food containers, plastic tableware, disposable cups, plates, cutlery, CD, cassette boxes, tanks, jugs, building materials (insulation)
Polyamides (PA) (nylons)	fibers, toothbrush bristles, fishing line, making films for food packaging, under-the-hood car engine moldings
Polycarbonate (PC)	compact discs, eyeglasses, riot shields, security windows, traffic lights, lenses, construction materials
High-density polyethylene (HDPE)	freezer bags, milk bottles, juice bottles, shampoo, chemical and detergent bottles, rigid agriculture pipe
High impact polystyrene (HIPS)	refrigerator liners, food packaging, vending cups, electronics
Acrylonitrile butadiene styrene (ABS)	electronic equipment cases (e.g., computer monitors, printers, keyboards), drainage pipe, automotive bumper bars
Polycarbonate/acrylonitrile butadiene styrene (PC/ABS)	a blend of PC and ABS that creates a stronger plastic. Used in car interior and exterior parts and mobile phone bodies

reached 1.7 million tons. In the same period, there was an increase in the amount of recycled plastic container waste, by 2.9 million ton. Meanwhile, the amount of received or selectively collected waste in the form of plastic materials per capita in Poland was 10 kg in 2019, compared to 9 kg in 2018 (GUS 2020), while in 2014, in USA alone, 103.465 billion disposable plastic shopping bags were used (Wagner 2017).

Table 2 shows estimates of the yearly use of disposable shopping bags in chosen countries (Wagner 2017).

Table 2

Estimated yearly consumption of disposable shopping bags per capita (modified after Wagner 2017)

Country	Pre-action consumption	Notes
Ireland	328	plastic bags only
Israel	300	plastic bags only
Japan	360	plastic bags only
USA	319.5	plastic bags only
Australia	303	HDPE bags only*

* HDPE – High Density Polyethylene

Improper management of plastic waste (such as bags, disposable bags, PET bottles, disposable face masks), such as disposing of is on municipal waste landfills, caused the widespread occurrence of MPs, which has become a global ecological and health problem. MPs are difficult to detect and can be transported in the air, soil, and water. The low social awareness and the costs related to waste management and recycling plastics create a significant social problem. Plastic waste management, including the burning of landfills which makes MPs spread on a wide scale, poses a significant threat to the environment and to the health of people and animals (Andrady et al. 2017, Alimi et al. 2018, Rizan et al. 2020, Chmielewski et al. 2020*b*, Walosik et al. 2021).

Most plastic materials are made from petroleum, where in the production process, different chemical particles undergo transformation, producing incredibly strong carbon bonds which do not resemble anything that occurs in nature. This unique property of plastics encourages their broad use in almost every aspect of the human life. The high resistance of many synthetic plastic materials is the reason why organisms that are able to degrade organic material cannot decompose plastics. Their persistence in the environment and the growing amount of waste containing these compounds in landfills and groundwaters mean that plastics are now a global problem (Wei, Zimmermann 2017, Chmielewski et al. 2020*c*, Kasar et al. 2020).

MPS IN THE ENVIRONMENT

MPs are plastic particles with a diameter smaller than 5 mm, which do not spontaneously occur in the natural environment. MPs are considered to be persistent organic pollutants (POPs) because of the polymers that constitute them. It is considered to be a growing global problem, not only due to ecological concerns, but also because of public health matters. MPs may be transported in the environment through wind, sea currents, surface water run-offs and precipitation. Its presence is noted virtually all around the world, even in places which are least contaminated with industrial activity, such as the Arctic and Antarctic. When MPs spread to the environment, they pose a threat to living organisms, both humans and animals. It stems from the fact that MPs can be a vector of the chemical transfer of pollution in food chains (Andrady et al. 2017, Alimi et al. 2018, Hantoro et al. 2019, Chmielewski et al. 2020*b*, Kanhai et al. 2020, Klemeš et al. 2020, Zhang et al. 2020, Baho et al. 2021, Chmielewski et al. 2021, Sharma el al. 2021).

MPs in the air

The environmental exposure to MPs present in the atmosphere depends on the prevalence of its sources. Urban dust is considered the most important source of primary MPs originating from car tyre wearoff, burnings of landfills containing waste, clothes and furniture made from materials that contain plastic, sewage sludge, soil and fertilizers used in gardening, etc. (Marnane et al. 2006, Liebezeit, Liebezeit 2015).

Studies show that MPs are present in outdoor and indoor air (Dris et al. 2016, Cai et al. 2017, Prata 2018, Prata et al. 2020, 2020*a*). Significant levels of MPs in the air have been identified in a remote, terrestrial location in the Pyrenees (Allen et al. 2019). Results show that MPs are ubiquitously deposited in the atmosphere of the metropolitan region of Hamburg (Klein, Fischer 2019). Indoor environments are susceptible to MP pollution, but its level is diverse depending on the differences in local environments. One of the main factors influencing the quantity of MPs in the indoor air is the number of textile products and the flow of the air caused by air conditioners (Zhang et al. 2020).

Data on the shape and size distribution of microplastic particles recorded in the air are contained in Table 3 (Klein, Fischer 2019).

MPs in water

The occurrence of MPs in water bodies has long been indicated in a multitude of studies (Eerkes-Medrano et al. 2015, Auta et al. 2017, Tong et al. 2020, Zhang et. al. 2020).

Table 3

Shape and size distribution of microplastic particles recorded at different sampling sites (modified after Klein, Fischer 2019)

Sampling site	Size in number of particles		
	>300 μm	300-63 μm	<63 μm
University	25	108	249
Beech/oakforest	8	120	341
Douglas firforest	23	138	539
Open field	16	118	369

Studies show that rivers transport 70-80% of plastics, leading to their extensive deposition in the world's oceans (Horton et al. 2017). MPs are detected and labelled in raw and drinking water, as well as bottled mineral water (Pivokonsky et al. 2018, Welle, Franz 2018).

The distribution of MPs in the seas and oceans of the world is illustrated in Table 4 (Auta et al. 2017).

Table 4

MP distribution in the seas and oceans of the world
(modified after Auta et al. 2017)

Marine environment	Distribution (%)	Concentration
Arctic polar waters	95	0-1.31 particles m^{-3}
Yangtze estuary and East China Sea	90	0-144 particles m^{-3}
North east Atlantic Ocean	89	2.46 particles m^{-3}
Mediterranean Sea	74	0.90±0.10 microplastics g^{-1}
Jade Bay, southern North Sea	70	1770 particles L^{-1}
Northwestern Atlantic	60	2500 particles km^{-2}
Beaches of Guanabara Bay, Southeast Brazil	56	12-1300 particles m^{-2}
Laurentian Great Lake	20	43,000 particles km^{-2} to 466,000 particles km^{-2}
Swedish Ccoast	-	150-2400 particles m^{-3} to 68,000-102,000 particles m^{-3}
Chinese Bohai Sea	-	63-201 items kg^{-1}

MPs in the soil

The contamination with MPs has mostly been studied in the context of aquatic environments. The reason was that they were much more difficult to find and quantify in soil. Soil is generally composed of a large number of particles with a great surface area and a big amount of organic material. MPs may spread to the soil environment directly (e.g., through the use of biomass, water in irrigation, atmospheric sedimentation) or indirectly, through the *in-situ* degradation of large chunks of plastic (e.g., from plastic mulch films). Recently, however, a growing interest in soil pollution with MPs among researchers has been observed (Scheurer, Bigalke 2018, Wang et al. 2019, Chai et al. 2020, Sarker et al. 2020, Baho et al. 2021).

Studies have shown that MPs in soil are dominated by pieces and fibers of polymers, e.g. polyethylene, polypropylene, polyester, artificial silk, acrylic and polyamide, which suggests that irrigation residues and plastic waste play a role in the accumulation of MPs. The size of MP particles in soil most often ranged between 1 and 3 mm, compared to between 90 µm up to 1 mm in waters (Zhou et al. 2020). These findings were confirmed in other studies, which showed that major causes of MPs pollution in agricultural soils include application of biosolids and compost, wastewater irrigation, mulching film, polymer-based fertilizers and pesticides, and atmospheric deposition. The fate and dispersion of MPs in the soil environment are mainly associated with the soil characteristics, cultivation practices, and diversity of soil biota (Kumar et al. 2020).

THE EFFECT OF MICROPLASTICS ON HEALTH

Virtually every person is exposed to MPs in the modern world. However, the health consequences of this exposure, like to any chemical substances, depend on many factors. Generally, the health consequences of MPs exposure will depend on physiochemical properties of the pollutants, routes of absorption, the dose of pollutants and the period of exposure, temperature and humidity of the air and the state of the endocrine, immune, genetic (reproductive) systems. MPs, like chemical substances, spread to the organism through three pathways, which include the inhalatory, dermal, and oral routes. Inhalation usually means breathing in air with aerosols containing MPs. Dermal absorption takes place while using cosmetics that contain MPs or when coming in contact (build up) with contaminated water, clothes, PPE, and polluted air. Most commonly, MPs spreads to the organism via the oral route, through contaminated food products (fruits, vegetables, processed foods), fish or contaminated drinking water (Chmielewski et al. 2015, Wright et al. 2017, Bollaín Pastor, Vicente Agulló 2019, Chmielewski et al. 2020*d*, 2021).

The extraordinary vector-capacity of MPs entails the adsorption of numerous toxic contaminants, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAH), polybrominated diphenyl ethers (PBDEs), dichlorodiphenyltrichloroethane (DDT), heavy metals, and endocrine disrupting compounds (EDCs) which are proven to have an effect on the human health (Rathi et al. 2019, Reddy et al. 2019, Chmielewski et al. 2020*a*, 2021*a*).

Possible health consequences of MP exposure are dependent on their concentration in exposure pathways and their toxicity. In all biological systems, microplastic exposure may cause particle toxicity, with oxidative stress, inflammatory lesions and increased uptake or translocation. The inability of the immune system to remove synthetic particles may lead to chronic inflammation and increase risk of neoplasia. Furthermore, microplastics may release their constituents, adsorbed contaminants and pathogenic organisms. Bisphenol-A (BPA), even when used in low concentrations in plastic industries, is considered to be an EDC, exhibiting adverse effects even at low concentrations on both humans and animals. Additionally, phthalates, which are used as plasticizers for improving the flexibility of plastic products, are quite hazardous as well, which is why they are categorized as EDCs, leading to significant reproductive and developmental disorders. The perils of the ingestion of MPs include growth impediment, physical impairment, and histologic changes in the intestines as well as changes in lipid metabolism along with behavioral fluctuations. MPs exhibit cytotoxicity and translocation to other tissues, while their persistent nature limits their removal from the organism, leading to chronic inflammation, which increases the risk of cancer. Low environmental concentrations of MPs may contribute to the growth in incidence of respiratory and cardiovascular illnesses in the general population (Prata 2018, Chmielewski et al. 2020*a*, Prata et al. 2020*b*, Sharma et al. 2021, Chmielewski et al. 2021*a*).

Occupational exposure to synthetic fibers among employees working in the production of nylon may entail the exposure to haptens, causing allergic reaction which leads to occupational asthma. Meanwhile, in employees working in the production of syringes, a higher incidence of respiratory system irritations was observed in the form of interstitial lung disease, which causes coughing, dyspnea, wheezing and increased production of phlegm (Wright et al. 2017).

The occupational illnesses of employees in the synthetic textile industry and the vinyl chloride (VC) and polyvinyl chloride (PVC) industries potentially exposed to high, long-term concentrations of airborne MPs, are listed in Table 5 (Prata 2018).

CONCLUSIONS

Problems related to the presence of MPs have been neglected for years, both in environmental education and in areas concerning environmental protection. This has resulted in certain gaps in basic knowledge, which are particularly evident during the COVID-19 pandemic. If we want to improve the ability to foresee risks related to the ubiquitous pollution with MPs in the environment, it is advised to undertake a broad scope of educational activities with the aim of showing the negative impact of MPs on the environment and, consequently, on the health of people and animals.

Education in this area will ensure a better understanding of how MPs pose a threat to both aqueous and terrestrial ecosystems globally (Alimi et al. 2018, Baho et al. 2021, Ding et al. 2021).

COVID-19 contributes to an increased pollution of plastics, which are components of personal protection equipment. In the environment, plastics carried by winds, streams, rivers, currents, etc. may spread around the world, and degrade into MPs. Due to the persistence of plastics in the environment, PPE debris from the COVID-19 pandemic will probably remain in the environment for decades, potentially affecting the fauna and flora

Table 5

Occupational diseases in workers of synthetic textiles, flock, and vinyl chloride (VC) or polyvinyl chloride (PVC) industries potentially exposed to chronic high concentrations of airborne MPs (modified after Prata 2018)

Occupation	Observations
Synthetic textile workers	diffuse interstitial or granulomatous lesions in the lower airways, interstitial fibrosis (asthma-like syndrome, extrinsic allergic alveolitis, chronic bronchitis, pneumothorax, and chronic pneumonia)
	significant increase in large bowel cancer in textile workers
	a meta-analysis of cancer in textile industry workers found an increased risk for cancer in the digestive system in synthetic fiber workers and an increase in lung and nasal cavity cancer related to occupation in the textile industry (e.g., weavers)
	stomach and esophageal cancer cases may relate to occupational exposure. Evaluation revealed increased risk of stomach cancer with longer exposure to synthetic fiber dust
Flock workers	breathlessness, cough, acute respiratory failure, bilateral inspiratory crackles, and radiographic nodular interstitial densities diagnosed by biopsy as desquamative interstitial pneumonitis
	dyspnea, cough, interstitial pneumonitis lacking giant cells, restrictive patterns, increased bronchial responsiveness, weight loss and asthma, improvements as they left work and deterioration after returning
	cases of persistent interstitial lung disease that may be associated with cancer and death by pulmonary insufficiency
VC or PVC workers	three workers (meat wrapper, dental molder industry, reactor cleaning operation) with cough, dyspnea, fatigue and radiographic opacities, suggesting a high association with exposure and interstitial fibrosing pneumonitis
	association between pneumoconiosis and a small degree of lung function impairment with PVC dust exposure in workers, and the high-exposure group presented higher prevalence of radiological opacities and symptoms, such as wheezing and chest tightness possibly due to reversible airway obstruction

in different compartments of the environment and biological systems (Prata et al. 2020).

The observed changes in the natural environment caused by the COVID-19 pandemic implicate an ecological crisis, which should raise health concern. An incredibly important aim of ecological education, at every stage, is the shaping of awareness about the surrounding environment, developing respect to different forms of life, as well as adopting a proper approach towards nature and its protection. This attitude is not an innate human trait but it needs to be shaped through broad education and contact with the outside environment, which are influenced by many factors relating to pro-ecological activities and institutions established for protection of the environment. In connection with the determined MPs environmental pollution, an aim of ecological education, during and after the COVID-19 pandemic, should be to highlight the problems and to shape a proper attitude towards the surrounding environment, but also to develop a proper approach towards nature and its protection. Education about the dangers from the use of plastic products must be based on the integration of all elements of teaching and including the rational development of a general worldview through the lens of the environment, and consequently its effect on the human health.

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