Environmental Science and Pollution Research (2021) 28:42196–42203
https://doi.org/10.1007/s11356-021-13705-z

RESEARCH ARTICLE

Occurrence of bisphenol A and microplastics in landfill leachate: lessons from South East Europe

Aleksandra C. Narevski[1] · Mladenka I. Novaković[1] · Maja Z. Petrović[1] · Ivana J. Mihajlović[1] · Nikola B. Maoduš[1] · Goran V. Vujić[1]

Received: 12 October 2020 / Accepted: 24 March 2021 / Published online: 2 April 2021

Abstract

In order to confirm the landfills as potential sources of microplastics and bisphenol A (BPA), the investigation of microplastics occurrence and concentration levels of BPA in landfill leachate samples from three landfills sites in the South East Europe was conducted. The landfills have been selected depending on the different waste management practice, waste amounts, operating period as well as leachate management practice. Microplastic was detected in different sizes, shapes and colours in all analysed leachate samples. The obtained average concentration values of the microplastics particles in the leachate samples from all three landfills ranged from 0.64 to 2.16 mg L^{-1}. The BPA was detected in leachate samples from all landfill sites in average concentration levels from 0.70 to 2.72 mg L^{-1} which are related to the content of microplastics.

Keywords Plastic litter · Waste management · Emerging pollutants · Wastewater · Endocrine disruptors · Micropollutants

Introduction

The microplastics (MPs) phenomenon in the environment is currently researched all over the world. Previous studies were oriented on the identification of the sources and determination of the MPs in the aquatic environment, primarily in the oceans and seas. Investigation on the presence of microplastics in the drinking water, landfill leachate, ambient air and sediment is still in the initial phase (Eerkes-Medrano et al. 2019; Koelmans et al. 2019; Liu et al. 2019a; Guo et al. 2020).

The microplastics (size below 5 mm) can be divided into 2 groups: directly produced MPs (primary microplastics) and microplastics originated from macroplastics fragmentation (secondary microplastics) (Koelmans et al. 2019; Irfan et al. 2020). Their entry routes into the landfill leachate mainly come from dumping of waste (personal care products, synthetic textiles, industrial raw materials) and landfills' poor management practice (absence of a surrounding fence on the landfill sites and the appropriate synthetic material for the waste covering) (Duis and Coors 2016; Li et al. 2020; Meng et al. 2020; Sturm et al. 2020).

Significant amount of different kind of waste in landfills where complex physical, chemical and biochemical reactions influenced by environmental conditions leads to fragmentation of plastics to microplastics (Pramila and Ramesh 2017; Imhof et al. 2013; Zettler et al. 2013). Landfill leachate can be the emission source of hazardous organic substances, such as bisphenol A (BPA), as well. According to the previous studies, BPA could be released from various plastic products through diffusion processes, hydrolysis and decomposition depending of physico-chemical properties (Liu et al. 2019b; Ficociello et al. 2020).

Van Praagh et al. (2018) monitored 11 landfills in Finland, Ireland and Norway in order to collect data on the quantities of microplastics in leachate. The main goals of this study were to determine the influence of different treatment methods on removal efficiency of microplastics and to assess the potential sources of emission. The study of He et al. (2019) was focused on determination of microplastics in 12 leachate samples from four active and two closed landfill sites in China. Kilponen (2016) conducted a pilot study to assess the occurrence of plastics and pollutants in urban atmospheric waters and leachate from closed landfill located near the coastal area. Microplastics and harmful substances, such as

Responsible Editor: Ta Yeong Wu

✉ Maja Z. Petrović
majadjogo@uns.ac.rs

[1] Department of Environmental Engineering and Occupational Safety and Health, Faculty of Technical Sciences, University of Novi Sad, Trg Dositeja Obradovića 6, Novi Sad 21000, Serbia

polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and phthalates, were detected in all collected samples as well.

In addition to these organic micropollutants, a wide range of other emerging organic compounds (EOCs) such as personal care products and pharmaceuticals (PPCPs) were detected in landfill leachate. In review study conducted by Yu et al. (2020), a detailed summary of PPCPs occurrence in landfill leachate, existing landfill leachate treatment systems and environmental risk assessment on groundwater quality was presented. The most common reported PPCPs in different landfill leachate media were diethyltoluamide (DEET), caffeine, carbamazepine and ibuprofen, belonging to different pharmaceutical groups.

Talsness et al. (2009) have identified several studies that demonstrate that BPA is leaching from products that have been disposed at landfills. Yamamoto et al. (2001) researched 10 landfill sites in Japan and found concentrations of BPA in the range from 1.3 to 17,200 μg L^{-1}.

After introduction into the aquatic ecosystem, microplastic pollutants may be subject to various phenomena due different environmental conditions such as decomposition or degradation causing the emission of emerging pollutants such as copolymers, additives or plasticizers (Alimi et al. 2018). According to previous published study (Crawford and Quinn 2017; Chen et al. 2019), it has been proven that emerging microcontaminats such as nonylphenol, phthalate acids and bisphenol A can leach from plastic materials after weathering or aging of microplastic particles. These types of chemicals are defined as endocrine disruptors; thus, they have a negative impact on water quality. Because of their hydrophobic nature and high surface area, they can interact with other present pollutants in water media (Chen et al. 2020). Bisphenol A belongs to the group of plasticizers which is used as raw material for the production of many industrial and consumer products due to unique physico-chemical properties. BPA represents one of the chemicals which is produced in large volumes worldwide. Sources of BPA in environmental media are diverse due to anthropogenic activity. BPA is introduced into aquatic matrix through wastewater discharge or through landfill leakage (Huang et al. 2012). Waste management in Serbia and Bosnia and Herzegovina is based on landfills, which receive over 90% of total waste. The waste is disposed at sanitary landfills, controlled unsanitary municipal landfills and dumpsites (Vujić et al. 2011; Stanisavljević et al. 2012). The absence of source separation, as well as of adequate practice for plastic waste disposal, is the reason why most of it ends up on landfills.

In this study, three landfill sites with different waste management practice, waste amounts and morphological composition; different operating period; as well as different leachate management practice were investigated in order to determine the content of MPs and BPA in landfill leachate, as the constituents of plastic waste. To date, no research has been conducted on the occurrence of microplastics nor BPA in leachate from landfill sites in Serbia and Bosnia and Herzegovina.

Materials and methods

Sampling locations

Leachate sampling was conducted at two sanitary landfill sites (Jagodina, Serbia and Bijeljina, Bosnia and Herzegovina) and one non-sanitary, controlled landfill in Novi Sad, Serbia.

During the implementation of leachate sampling procedure for all three selected landfills, plankton net with mesh size of 23 μm was used to collect a higher number of microplastic particles.

Landfill site "Brijesnica", Bijeljina, Bosnia and Herzegovina

Sanitary landfill "Brijesnica" is located beside the old city landfill site, about 3 km to the west from the Bijeljina city centre. The landfill is built according to the modern sanitary European landfilling standards in 2010, and it is designed for a 20-year landfilling period. Brijesnica landfill has a classical designed system for leachate collection.

The leachate collection system in Bijeljina consists of the non-perforated drainage pipe which is installed at the bottom of the landfill body (Fig. S1). The leachate is transferred to the leachate treatment plant employing reverse osmosis by pump (Fig. S2).

The permeate is being discharged into the recipient, and the concentrate is being returned to the landfill.

The leachate samples from landfill site in Bijeljina were collected from receiving basin. Due to the limitation to perform sampling directly from pipe which brings landfill leachate into equalization tank, sampling was conducted by addition of pump which brings leachate back into the basin via a hose inserted into the plankton net. The flow rate of the small pump (subsequently inserted into the receiving basin) was 0.3125 L s^{-1} or 1.125 m^3 h^{-1}.

Landfill site "Gigoš", Jagodina, Serbia

The sanitary landfill site "Gigoš" in Jagodina, Serbia, is located in the hills, about 10 km north of the Jagodina city centre and around 1.5 km west of the A1 (E75) highway. The total estimated capacity of the landfill is 1,500,000 m^3, and its estimated disposal period is 25 years. Landfill is designed according to the modern sanitary landfilling practices. Leachate collection and treatment system consist of two lagoons with leachate recirculation system. The collection of landfill leachate implies classic gravimetric system as shown in Fig. S1 for landfill site Brijesnica. Leachate sampling was

conducted from lagoon for aeration and lagoon for sedimentation.

Landfill site in Novi Sad, Serbia

The non-sanitary, controlled landfill in Novi Sad, Serbia, is located in the northern part of the city, northwest of residential area "Klisa", about 7 km from the city centre. The area for waste disposal is divided into three fields. Landfill contains certain segments which are characteristics of controlled landfills, but it is non-sanitary. Landfill does not have leachate collection system. The leachate sampling was conducted from peripheral canals 1 and 2 and from leachate lagoon (Fig. S3). An outline of the examined landfill sites is presented in Table 1.

Chemicals and reagents

Hydrogen peroxide 30% G.R (unstabilised) and iron(II) sulphate heptahydrate used in wet peroxide oxidation process were purchased from Lach:Ner company (Slovakia). Zinc chloride ACS reagent, used in density separation step, was obtained from Carl Roth (≥97%, p.a., Germany). For bisphenol A detection and quantification in leachate samples, various chemicals were used such as 85% phosphoric acid (VWR chemicals, Germany), dichloromethane (LGC Promochem, India), methanol (HPLC grade, purity ≥99.9%, Sigma-Aldrich, USA), acetic acid (Zorka Pharma, Serbia) and acetonitrile (HPLC grade, purity ≥99.9%, Fisher Chemicals, Germany). Analytical standard of bisphenol A and internal standard of bisphenol A-d_{16} were acquired from Sigma-Aldrich (purity ≥99%, USA). Milli-Q water was obtained using the Easypure II ultrapure water system (Thermo Fisher Scientific, specific resistance 18.2 MΩ × cm). Ethanol was obtained from Sigma-Aldrich (purity ≥99.8%, USA). Oasis HLC cartridges were obtained from Supelco (USA).

Sample processing

Prior to every conducted sampling, a detailed preparation of brown glass bottles for sampling was implemented. Prior to sampling procedure, brown glass bottles were cleaned with diluted nitric acid and rinsed several times with Milli-Q water, after which it was overnight dried in oven. The usage of plastic bottles was not applied in order to avoid contamination mitigation. All steps in sample preparation are provided under fume hood. In order to collect a larger number of microplastic particles, grab sampling was carried out from four sampling points at each sampling site by making one composite sample. All landfill leachate samples were collected in 2.5-L sampling bottles and subsequently filtered through a plankton net (880mm long bag, nylon mesh material with pore dimension size 23 μm). The additional rinsing with Milli-Q water was applied several times on plankton net and sample bottles in order to ensure that residual microplastic particles are removed. In order to examine procedural contamination, field blanks were also collected in each sampling point. Field blanks were collected by rinsing plankton net with 2.5 L Milli-Q water and collected in clean glass bottles. No microplastic particles were detected in field-controlled blanks.

Leachate samples for the determination of BPA were collected at each landfill site. In Bijeljina, leachate samples were collected from receiving basin, and in Jagodina landfill site, leachates were taken from aeration and sedimentation lagoons while in Novi Sad samples were taken from the lagoon.

Minimization of sample contamination

During the laboratory analysis of microplastic particles, several steps were conducted to avoid contamination of samples by airborne fibre and particles. The thorough cleaning of all used laboratory equipment was carried out, and washed equipment was instantly covered by aluminium foil. The decontamination procedure consists of rinsing three times all used materials with Milli-Q water and ethanol. In each stage of extraction process, all used materials and dishes were covered with aluminium foil. The clean laboratory coats from natural fabric and nitrile gloves were worn during sample preparation. The working laboratory place was cleaned with ethanol to minimize a risk of contamination. The following cleaning procedure was applied between preparations of samples. Also, the usage of plastic materials was avoided.

In addition, all work solutions such as zinc chloride and iron sulphate were filtered through 0.45 μm glass fibre filter prior to microplastic extraction.

Table 1 The main characteristics of landfill sites surveyed

Landfill	Operating year	Landfill type	Surface area (ha)	Waste disposal t day^{-1}	Total amount of waste (t)	Leachate treatment system
"Brijesnica", Bijeljina, B&H	2010	Sanitary	4+6	~90	317,301	Yes
"Gigoš", Jagodina, Serbia	2010	Sanitary	~4	~140	508,990	Yes
Novi Sad, Serbia	1965	Non sanitary	24	~140	~2,400,000	No

Microplastic extraction from landfill leachates

Laboratory analysis of collected samples was performed according to the proposed method defined by NOAA Marine Debris Division with slight modification of defined procedure (Masura et al. 2015).

The collected landfill leachate samples were first filtrated through stainless steel sieve (63 μm). All retained MPs content was rinsed with distilled water and transferred into glass baker and dried overnight in the drying oven (Memmert GmbH + Co. KG, Germany) at 90°C. The total weight of dried residues in samples (organic matter and MPs) is determined, and concentration of total solids (TS) was calculated. The removal of organic matter was performed with 20 mL 30% of hydrogen peroxide and 20 mL 0.05 M iron sulphate solution. The mixture was heated at 75 °C.

The density separation was performed by addition of zinc chloride (933.3 g L^{-1}; density 1.6 g cm^{-3}) to the sample, and solution was heated at approximately 75 °C (Rodrigues et al. 2020). Samples were left overnight in order to achieve a flotation of MPs in samples. The settled microplastics were collected in sieve mesh size of 63 μm, covered with aluminium foil and left overnight to dry. Extracted MPs were placed to Petri dishes. The weight of extracted microplastic particles was determined by gravimetric analysis. The same procedure was repeated for all samples.

The MPs isolated from landfill leachates were observed by stereomicroscope SteREO Discovery.V8 (Carl Zeiss Microscopy GmbH, Germany) in order to provide visual sorting of particles according to their morphological characteristics. In addition, the quick and simple testing of the burning behaviour of sample was performed (Vogel et al. 2012) in order to assess if the sample consists of plastic. This test is suitable for screening of plastic materials.

Detection of bisphenol A (BPA) in landfill leachate samples

Prior to sample preparation, the pH of the samples was adjusted to pH 3 using 85% phosphoric acid. The following procedure for determination of bisphenol A was conducted according to previous published method (Lee et al. 2017). The solid phase extraction (SPE) was carried out on Oasis HLB (60 mg/3 cc) cartridges (Supelco, USA). The column was conditioned with 5 mL of dichloromethane, 5 mL of ultrapure water and 5 mL of methanol. The 300 mL samples were loaded at flow rate of 5 mL min^{-1}. Elution was performed with 5 mL of methanol. Afterward sample was evaporated under gentle nitrogen stream. One millilitre sample was analysed by HPLC system (HPLC DAD 1260, Agilent Technologies, Germany). Separation of BPA present in leachate samples was performed on the Zorbax Extend C18 stationary phase (150 × 4.6 mm, 5 μm, Agilent Technologies, USA) with isocratic extraction in mobile phase ratio (A-50% of 0.1% of acetic acid in ultrapure water and B-50% acetonitrile). The flow rates of the mobile phases were 0.8 mL min^{-1}, and the maximum wavelength for BPA was 276 nm. Quantification of bisphenol A in landfill leachate was conducted based on previous formed linear curve with internal standard with ten calibration levels (correlation coefficient r^2=0.999) (Fig. S4). Calibration curve was based on least square linear regression model in function of peak area of BPA and internal standard vs. concentration of BPA and BPA d_{16}. The retention time of BPA analyte was t_R=3.8 min. The detection of BPA was provided by comparing UV spectrum of target analyte with HPLC offline library.

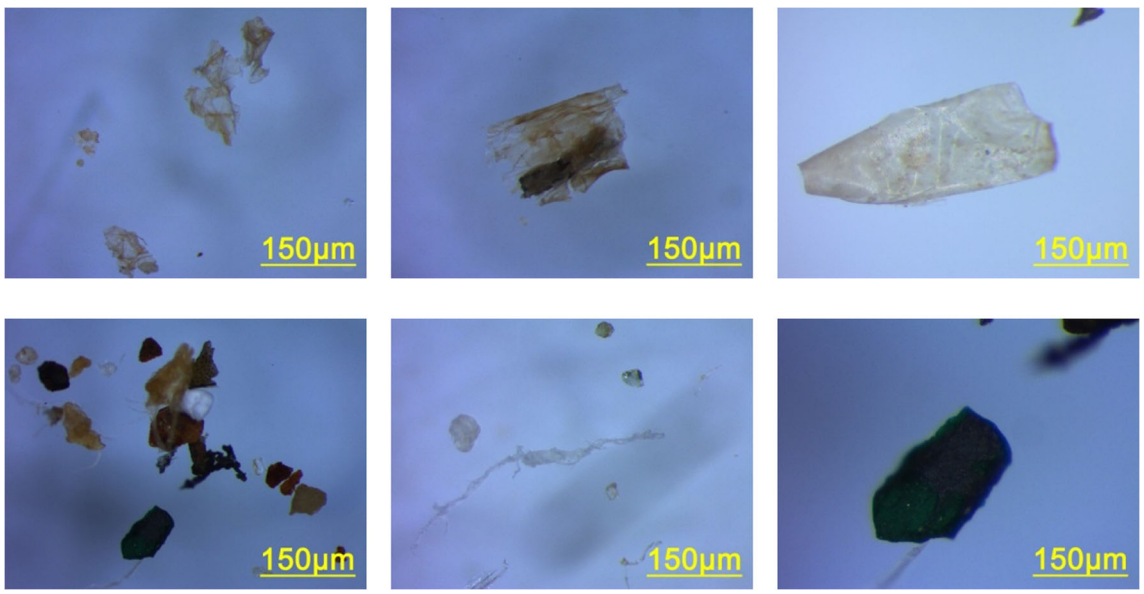

Fig. 1 Microscopic images of microplastics particles

Table 2 Results of the total solids and microplastics concentrations in the leachate samples from landfills in Bosnia and Herzegovina and Republic of Serbia

Sampling site	TS [mg L^{-1}]	MPs [mg L^{-1}]
Sanitary landfill in Bijeljina, Bosnia and Herzegovina		
Receiving basin	36±8	1.37±0.65
Sanitary landfill "Gigoš" in Jagodina, Republic of Serbia		
Aeration lagoon	1348±125	2.12±0.85
Sedimentation lagoon	136±15	2.16±0.80
Non-sanitary municipal waste landfill in Novi Sad, Republic of Serbia		
Lagoon	60±10	0.64±0.30
1. Peripheral channel	36±6	1.40±0.75
2. Peripheral channel	72±12	1.76±0.60

Results and discussion

Based on the laboratory analyses, the presence of MPs in the leachate samples from all three landfill sites was determined. In Fig. 1, microscopic images of MPs identified in landfill leachate are presented.

Comparing the obtained microscopic images of the MPs to the microscopic images from the available literature (Gray et al. 2018; He et al. 2019), the presence of microplastics particles could be suggested. Particles with different sizes, shapes and colours have been identified in all leachate samples (Fig. 1). Almost all MPs identified in landfill leachate were with irregular shape and rough edges (Fig. 1) indicating the fragmentation of larger plastics disposed at investigated landfill sites. The same findings were presented in the research of He et al. (2019) for microplastics from landfills in China. Fragmentation of larger plastic items leads to the formation of small MPs with high specific surface available for the high potential of organic micropollutants sorption not only from water but also from ambient air (Bouwmeester et al. 2015).

The obtained results on the quantities of total solids and MPs detected in the leachate samples from landfill sites in Bosnia and Herzegovina and Republic of Serbia are shown in Table 2. Also, the burning tests of sample indicated the presence of plastic materials with flammable properties.

The concentration values of the microplastics particles in the leachate samples from three landfills are in the same range. The total solids were measured in higher concentrations than MPs up to 25, 100 and 500 times, in leachate samples from all three landfill sites.

Table 3 presents the results (range, min-max) of microplastics particles in treated and untreated leachate from different countries.

Microplastics were detected in the range from 0.42 to 24.58 particles/L in leachate samples from municipal solid waste landfills in China. In the report of van Praagh et al. (2018), wide range of MPs sizes in landfill leachates in Iceland, Finland and Norway was detected. MPs concentrations ranged from 0.0000014 to 295.1 μg L^{-1}. The landfill sites were highlighted as source of MPs to the environment (Hou et al. 2021). PE and PP were the most dominant polymers in landfill leachates in China (Su et al. 2019), while in untreated leachates in Nordic countries, PE and polyurethene (PU) were the most commonly detected (van Praagh et al. 2018). MPs in the landfill leachate could be found in different sizes in the range of 50–5000 μm (van Praagh et al. 2018), according to various degradation processes of plastics which occur in landfills, such as aerobic biodegradation, transition from aerobic condition to anaerobic condition, hydrolysis, methane fermentation and final maturation. The most leachate

Table 3 Results of the microplastics concentrations in treated and untreated leachate samples from landfills in different countries

Location of landfill	Range (min-max)	Treatment	Reference
Bijeljina, B&H	0.3–2.2 mg L^{-1}	Reverse osmosis	This study
Jagodina, Serbia	2.12–2.16 mg L^{-1}	Sedimentation, aeration	This study
Novi Sad, Serbia	0.64–1.76 mg L^{-1}	None	This study
Alfsnes, Iceland	0.0047–295.1 μg L^{-1}	None	van Praagh et al. (2018)
Fiflholt, Iceland	0.000056–3.7 μg L^{-1}	Sand bed filtration	van Praagh et al. (2018)
Salo, Finland	0.0000014–94.6 μg L^{-1}	None	van Praagh et al. (2018)
Southwest Finland	0.00032–21.6 μg L^{-1}	Filtration and active carbon	van Praagh et al. (2018)
Ask, Norway	0.00095–63.2 μg L^{-1}	None	van Praagh et al. (2018)
Skedsmokorset, Norway	n.d.	SBR	van Praagh et al. (2018)
Landfills in Sweden	0–2.7 items L^{-1}	Treated leachate	Swedish Waste Association (2018)
Landfills in Southern China	0.42–24.58 items L^{-1}	None	He et al. (2019)
Landfill in China	291 ± 91 particles L^{-1}	None	Xu et al. (2020)

Table 4 Results of bisphenol A in the leachate samples from landfills in Bosnia and Herzegovina and Republic of Serbia

Sampling site	Bisphenol A (mg L^{-1})
Sanitary landfill in Bijeljina, Bosnia and Herzegovina	
Receiving basin	1.52 ±0.26
Sanitary landfill "Gigoš" in Jagodina, Republic of Serbia	
Aeration lagoon	2.72±0.85
Sedimentation lagoon	2.78±0.70
Non-sanitary municipal waste landfill in Novi Sad, Republic of Serbia	
Lagoon	0.70±0.12

treatment processes have not been designed to reduce the particles like MPs (Hou et al. 2021). However, MPs can be degraded by indirect electrochemical oxidation or by advanced oxidation processes such as photo-Fenton, O_3/UV, H_2O_2/UV, ultrasound (US), UV/US and H_2O_2/US (Gewert et al. 2015; Mandal et al. 2017).

Results in other studies (van Praagh et al. 2018; Swedish Waste Association 2018) indicated that treatment processes decreased concentration of microparticles from 3 to 100% depending on the treatment technique. In our study, aeration decreased the microparticle and total solids concentration in leachate from sanitary landfill in Jagodina, Serbia, for 2% and 90%, respectively. Also, the ranges in our study were three orders of magnitude higher than in Nordic countries (Finland, Iceland and Norway). This could be the consequence of better waste management practice in developed countries compared to developing countries such as Republic of Serbia and Bosnia and Herzegovina, where the plastic recycling and waste sorting are not completely applied. The detection of microplastic particles conducted in developing countries in the South East Europe region presents the basis for further detailed investigation on MPs type and quantity, as well as on transport phenomena and life cycle assessment in different aged landfills with different waste management practice.

The obtained results of bisphenol A in leachate samples are presented in Table 4.

The obtained results show that concentration of bisphenol A in leachate from the lagoon on non-sanitary landfill Novi Sad was 700 μg L^{-1}, while significant higher concentrations were determined in leachate samples from sanitary landfills in Jagodina and Bijeljina. The concentrations of BPA in aeration and sedimentation lagoon in Jagodina were 2.72 mg L^{-1} and 2.78 mg L^{-1}, respectively. The concentration level of BPA in leachate sample from Bijeljina was 1.52 mg L^{-1}. Obtained results indicate the high concentration of BPA comparing to the previous studies: 67 μg L^{-1} (Shindo et al. 1998), 1–100 μg L^{-1} (Yasuhara et al. 1999), 0.6–31 μg L^{-1} (Sakamoto et al. 2000) and 0.13 μg L^{-1} (Behnisch et al. 2001) in landfills in Japan. The reason for this could be the higher amount of plastic waste which could be the source of BPA leaching (Xu et al. 2011) and MPs as well.

The BPA and MPs concentrations were measured in the same range at all selected landfill sites in Serbia and Bosnia and Herzegovina and indicate the same trend, which could be noticed in Fig. 2. The data were statistical processed via Microsoft Excel program (Microsoft Office 365) and presented as mean values (the red and blue bars) with standard deviations (±SD) (error bars) (n=3).

This first scientific research of microplastics in leachate samples from landfills sites in the South East Europe present the basis for further research activities which will include the more precise MPs identification methodologies, the

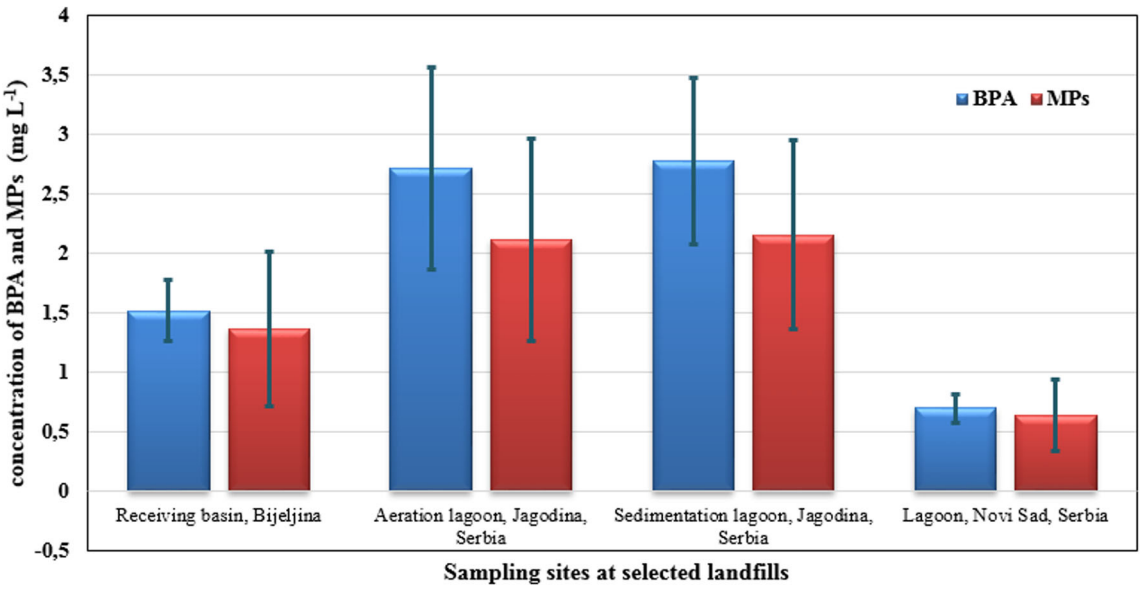

Fig. 2 BPA vs. MPs concentrations in water samples at landfills in Serbia and Bosna and Herzegovina

identification of the entire pathway of MPs from the landfill body to its final recipient as well as the identification of MPs types and compositions from different aged and managed landfills.

Conclusion

The relatively high concentration levels of BPA in leachate samples, 7 to 20.000 times higher than in the other studies, from all investigated landfills indicate the presence of significant amounts of plastic waste as the main source of this hazardous substance and MPs as well. The preliminary amounts of MPs have been determined on two sanitary landfills and one non-sanitary controlled landfill site. The concentration ranges of MPs were higher than in the other studies of landfill leachates which highlight landfill sites especially in developing countries without waste sorting as potential sources of MPs to the environment. Similar trend in the concentrations of MPs and BPA occurrence in the landfill leachates was noticed. Further studies could be conducted to investigate correlation between MPs and BPA concentrations in leachate samples. Standardization of leachate sampling techniques and methods for MPs quantification methodologies with recovery rates of MPs during extraction process is important for validated results. The sorption effects of MPs as potential transporters of hazardous organic pollutants from landfills to recipients should be investigated as well.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-021-13705-z.

Availability of data and materials All data generated or analysed during this study are included in this published article and its supplementary information files.

Authors' contribution AN was responsible for conceptualization, methodology and writing - original draft preparation. MN contributed in research by analysis and writing - review and editing. MP contributed through the conceptualization of paper, supervision and writing - review and editing. IM participated in conceptualization of research study, data curation and writing - review and editing. NM conducted the sampling methodology and analysis. GV supervised research study and was responsible for writing - review and editing.

Funding This research has been supported by the Ministry of Education, Science and Technological Development through the project no. 451-03-68/2020-14/200156: "Innovative scientific and artistic research from the FTS domain".

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

References

Alimi OS, Farner Budarz J, Hernandez LM, Tufenkji N (2018) Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport. Environ Sci Technol 52:1704–1724. https://doi.org/10.1021/acs.est.7b05559

Behnisch PA, Fujii K, Shiozaki K, Kawakami I, Sakai S (2001) Estrogenic and dioxin-like potency in each step of a controlled landfill leachate treatment plant in Japan. Chemosphere 43:977–984. https://doi.org/10.1016/S0045-6535(00)00458-6

Bouwmeester H, Hollman PCH, Peters RJB (2015) Potential health impact of environmentally released micro- and nanoplastics in the human food production chain: experiences from nanotoxicology. Environ Sci Technol 49:8932–8947. https://doi.org/10.1021/acs.est.5b01090

Chen C, Chen L, Li Y, Fu W, Shi X, Duan J, Zhang W (2020) Impacts of microplastics on organotins' photodegradation in aquatic environments. Environ Pollut 267:115686. https://doi.org/10.1016/j.envpol.2020.115686

Chen C, Chen L, Yao Y, Artigas F, Huang Q, Zhang W (2019) Organotin release from polyvinyl chloride microplastics and concurrent photodegradation in water: impacts from salinity, dissolved organic matter, and light exposure. Environ Sci Technol 53:10741–10752. https://doi.org/10.1021/acs.est.9b03428

Crawford CB, Quinn B (2017) The interactions of microplastics and chemical pollutants. In: Microplastic Pollutants, 1st edn. Elsevier, Amsterdam, pp 131–157

Duis K, Coors A (2016) Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects. Environ Sci Eur 28:1–25. https://doi.org/10.1186/s12302-015-0069-y

Eerkes-Medrano D, Leslie HA, Quinn B (2019) Microplastics in drinking water: a review and assessment. Curr Opin Environ Sci Heal 7:69–75. https://doi.org/10.1016/j.coesh.2018.12.001

Ficociello G, Gerardi V, Uccelletti D, Setini A (2020) Molecular and cellular responses to short exposure to bisphenols A, F, and S and eluates of microplastics in C. elegans. Environ Sci Pollut Res 28:805–818. https://doi.org/10.1007/s11356-020-10498-5

Gewert B, Plassmann MM, Macleod M (2015) Pathways for degradation of plastic polymers floating in the marine environment. Environ Sci Process Impacts 17:1513–1521. https://doi.org/10.1039/c5em00207a

Gray AD, Wertz H, Leads RR, Weinstein JE (2018) Microplastic in two South Carolina estuaries: occurrence, distribution, and composition. Mar Pollut Bull 128:223–233. https://doi.org/10.1016/j.marpolbul.2018.01.030

Guo JJ, Huang XP, Xiang L, Wang YZ, Li YW, Li H, Cai QY, Mo CH, Wong MH (2020) Source, migration and toxicology of microplastics in soil. Environ Int 137:105263. https://doi.org/10.1016/j.envint.2019.105263

He P, Chen L, Shao L, Zhang H, Lü F (2019) Municipal solid waste (MSW) landfill: a source of microplastics? -Evidence of microplastics in landfill leachate. Water Res 159:38–45. https://doi.org/10.1016/j.watres.2019.04.060

Hou L, Kumar D, Yoo CG, Gitsov I, L-W Majumder E (2021) Conversion and removal strategies for microplastics in wastewater treatment plants and landfills. Chem Eng J 406:126715. https://doi.org/10.1016/j.cej.2020.126715

Huang YQ, Wong CKC, Zheng JS, Bouwman H, Barra R, Wahlström B, Neretin L, Wong MH (2012) Bisphenol A (BPA) in China: a review of sources, environmental levels, and potential human health

impacts. Environ Int 42:91–99. https://doi.org/10.1016/j.envint.2011.04.010

Imhof HK, Ivleva NP, Schmid J, Niessner R, Laforsch C (2013) Contamination of beach sediments of a subalpine lake with microplastic particles. Curr Biol 23:R867–R868. https://doi.org/10.1016/j.cub.2013.09.001

Irfan T, Khalid S, Taneez M, Hashmi MZ (2020) Plastic driven pollution in Pakistan: the first evidence of environmental exposure to microplastic in sediments and water of Rawal Lake. Environ Sci Pollut Res 27:15083–15092. https://doi.org/10.1007/s11356-020-07833-1

Kilponen J (2016) Microplastics and harmful substances in urban runoffs and landfill leachates: possible emission sources to marine environment. Bachelor`s Thesis, Lahti University of Applied Sciences

Koelmans AA, Mohamed Nor NH, Hermsen E, Kooi M, Mintenig SM, France J (2019) Microplastics in freshwaters and drinking water: critical review and assessment of data quality. Water Res 155:410–422. https://doi.org/10.1016/j.watres.2019.02.054

Lee T, Park K-Y, Pyo D (2017) Simultaneous determination of bisphenol A, chlorophenols and alkylphenols by solid-phase extraction and HPLC. Anal Sci Technol 30:20–25. https://doi.org/10.5806/ast.2017.30.1.20

Li C, Busquets R, Campos LC (2020) Assessment of microplastics in freshwater systems: a review. Sci Total Environ 707:135578. https://doi.org/10.1016/j.scitotenv.2019.135578

Liu K, Wang X, Fang T, Xu P, Zhu L, Li D (2019a) Source and potential risk assessment of suspended atmospheric microplastics in Shanghai. Sci Total Environ 675:462–471. https://doi.org/10.1016/j.scitotenv.2019.04.110

Liu X, Shi H, Xie B, Liu X, Dionysiou DD, Zhao Y (2019b) Microplastics as both a sink and a source of bisphenol A in the marine environment. Environ Sci Technol 53:10188–10196. https://doi.org/10.1021/acs.est.9b02834

Mandal P, Dubey BK, Gupta AK (2017) Review on landfill leachate treatment by electrochemical oxidation: drawbacks, challenges and future scope. Waste Manag 69:250–273. https://doi.org/10.1016/j.wasman.2017.08.034

Masura J, Baker J, Foster G, Arthur C (2015) Laboratory methods for the analysis of microplastics in the marine environment: recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum No. NOS-OR&R-48

Meng Y, Kelly FJ, Wright SL (2020) Advances and challenges of microplastic pollution in freshwater ecosystems: a UK perspective. Environ Pollut 256:113445. https://doi.org/10.1016/j.envpol.2019.113445

van Praagh M, Hartman C, Brandmyr E (2018) Microplastics in Landfill Leachates in the Nordic Countries. Nordic Council of Ministers, Copenhagen

Rodrigues MO, Gonçalves AMM, Gonçalves FJM, Abrantes N (2020) Improving cost-efficiency for MPs density separation by zinc chloride reuse. MethodsX 7:100785. https://doi.org/10.1016/j.mex.2020.100785

Sakamoto H, Souta I, Fukui H (2000) Bisphenol A in leachates from solid waste landfill sites. In: Proceedings of the 11th Annual Conference of the Japan Society of the Waste Management Experts. Japan Society of the Waste Management Experts, pp 1098–1100 (in Japanese)

Shindo H, Goto H, Takahashi Y (1998) Elution of bisphenol A from food trays made of polycarbonate resin and its presence in environmental waters in Niigata Prefecture. In: Proceedings of the 17th Symposium on Environmental Chemistry. Japan Society for Environmental Chemistry, pp 72–733 (in Japanese)

Stanisavljević N, Ubavin D, Batinić B, Fellner J, Vujić G (2012) Methane emissions from landfills in Serbia and potential mitigation strategies: a case study. Waste Manag Res 30:1095–1103. https://doi.org/10.1177/0734242X12451867

Sturm MT, Herbort AF, Horn H, Schuhen K (2020) Comparative study of the influence of linear and branched alkyltrichlorosilanes on the removal efficiency of polyethylene and polypropylene-based microplastic particles from water. Environ Sci Pollut Res 27:10888–10898. https://doi.org/10.1007/s11356-020-07712-9

Su Y, Zhang Z, Wu D, Zhan L, Shi H, Xie B (2019) Occurrence of microplastics in landfill systems and their fate with landfill age. Water Res 164:1–9. https://doi.org/10.1016/j.watres.2019.114968

Swedish Waste Association (2018) Microplastics in treated leachate – a case study of eight waste treatment facilities. Avfall Sveriges Utvecklingssatsning, Malmö (in Swedish)

Talsness CE, Andrade AJM, Kuriyama SN, Taylor JA, vom Saal FS (2009) Components of plastic: experimental studies in animals and relevance for human health. Philos Trans R Soc B Biol Sci 364:2079–2096. https://doi.org/10.1098/rstb.2008.0281

Vogel C, Mueller A, Lehmann D, Taeger F (2012) Characterization of the burning behaviour of plastics by a new method. Open J Polym Chem 02:86–90. https://doi.org/10.4236/ojpchem.2012.22011

Vujić G, Batinić B, Stanisavljević N, Ubavin D, Živančev M (2011) Waste management in Serbia, status quo and strategic framework. Recycl Sustain Dev 4:14–19 (In Serbian)

Xu SY, Zhang H, He PJ, Shao LM (2011) Leaching behaviour of bisphenol A from municipal solid waste under landfill environment. Environ Technol 32:1269–1277. https://doi.org/10.1080/09593330.2010.535175

Xu Z, Sui Q, Li A, Sun M, Zhang L, Lyu S, Zhao W (2020) How to detect small microplastics (20–100 μm) in freshwater, municipal wastewaters and landfill leachates? A trial from sampling to identification. Sci Total Environ 733:139218. https://doi.org/10.1016/j.scitotenv.2020.139218

Yamamoto T, Yasuhara A, Shiraishi H, Nakasugi O (2001) Bisphenol A in hazardous waste landfill leachates. Chemosphere 42:415–418. https://doi.org/10.1016/S0045-6535(00)00079-5

Yasuhara A, Shiraishi H, Nishikawa M, Yamamoto T, Nakasugi O, Okumura T, Kenmotsu K, Fukui H, Nagase M, Kawagoshi K (1999) Organic components in leachates from hazardous waste disposal sites. Waste Manag Res 17:186–197. https://doi.org/10.1177/0734242X9901700304

Yu X, Sui Q, Lyu S, Zhao W, Liu J, Cai Z, Yu G, Barcelo D (2020) Municipal solid waste landfills: An underestimated source of pharmaceutical and personal care products in the water environment. Environ Sci Technol 54:9757–9768. https://doi.org/10.1021/acs.est.0c00565

Zettler ER, Mincer TJ, Amaral-Zettler LA (2013) Life in the "plastisphere": microbial communities on plastic marine debris. Environ Sci Technol 47:7137–7146. https://doi.org/10.1021/es401288x