



# Solid waste composition and COVID-19-induced changes in an inland water ecosystem in Turkey

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## Abstract

The composition and abundance of solid waste and the effect of COVID-19 measures were studied in an inland water ecosystem in Turkey. Solid waste items were collected annually for 5 years from 2017 to 2021 from seven stations located in Borçka Dam Lake (B1–B4) and Murgul Stream (M1–M3) in the Artvin Province. The highest densities by number and weight were recorded at M3 in 2020 (5.72 items/m<sup>2</sup>) and M1 in 2020 (0.39 kg/m<sup>2</sup>), respectively. However, no significant difference in density was recorded ( $p < 0.05$ ) between the years. Plastic was the most abundant waste material by number of items in all the stations with a percentage contribution varying between 25.47 and 88.89%. There was a considerable increase in medical items during the COVID-19 pandemic in 2020–2021. Nonmetric multidimensional scaling (NMDS) and ANOSIM results revealed visually and statistically significant differences in solid waste composition between the years and stations. The dissimilarity between the years was driven by plastic and medical waste. The main sources of solid waste were river transportation (22.93%), improper disposal (20.74%), aquaculture activities (16.42%), and recreational and tourism activities (14.72%). The results of our study can be a baseline for transportation models, local administrations, and non-governmental organizations. Besides, the current waste management measures in Turkey are not effective in preventing waste accumulation in inland aquatic systems such as the Borçka Dam Lake and Murgul Stream. Furthermore, these findings indicate that the COVID-19 pandemic influenced solid waste composition and increased its abundance in the study area.

**Keywords** Pollution · Litter · Plastic · Face mask · Single use · Tourism · Lake · River

## Introduction

Increasing population, growing urban settlements, technological developments, industrialization, and improved living standards have led to a rapid and consistent increase in solid waste production. Solid wastes are non-soluble, solid materials, discarded from industrial, municipal, and agricultural activities (Moeller 2011). Solid wastes are among the most common types of pollutants in the sea and land ecosystems (Malinauskaite et al. 2017; Lestari and Trihadiningrum 2019). They cause a wide variety of impacts on the environment

(Pujara et al. 2019), economy (Namlis and Komilis 2019), and human health (Vyas et al. 2022) by contaminating soil, air, and water sources.

By the end of December 2019, single-use personal protective equipment (gloves, masks, glasses, aprons, etc.) had become mandatory due to the COVID-19 pandemic, increasing the pressure of solid waste pollution on the environment. In this period, the use of products such as wet wipes, bottle hand sanitizers, and disinfectants has also increased (Hu et al. 2022). For hygiene reasons, the use of single-use plastic cups, plates, and cutlery considerably increased as well (Vanapalli et al. 2021). Face masks, the most common way for protection from COVID-19, are produced from petroleum-derived microfiber materials. Recent studies revealed that disposed face masks could be a source of microplastics in the long term (Aragaw 2020; Fadare and Okoffo 2020). In some states, the ban on single-use plastic bags was suspended during the COVID-19 pandemic (Hale and Song 2020). Furthermore, recycling plastic products reduced during the pandemic situation for hygiene reasons.

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Although medical waste in public health services is well managed, most of the personal medical and cleaning product wastes are being disposed of improperly (Dharmaraj et al. 2021). These wastes create human health risks since they may be a vector for viral contamination (Anand et al. 2022).

Solid waste is a multidimensional and sophisticated global problem not only for the environment but also for the economy and human health. Solid waste is generated from several human activities on land and sea (Abdel-Shafy and Mansour 2018). Accumulation of solid waste in the aquatic environment is a growing worldwide problem (Löhr et al. 2017). Plastic is the primary contaminant in the marine environment (Beaumont et al. 2019). Plastics are synthetic organic polymers that persist in the environment for hundreds of years. Synthetic polymers, including those used to produce beverage bottles, packing straps, tarps, fishing lines, and gears, can easily end up in the environment. Adaptability of plastics has led to their expansion in recent decades into many parts of daily human life. In the last quarter of the twenty-first century, plastics emerged as a major problem in the land and aquatic environments (Beaumont et al. 2019; Pehlivan and Gedik 2021). This problem is growing rapidly due to population growth, lack of public awareness, and insufficient waste collection. Several studies reported plastic pollution in Turkish aquatic ecosystems (Gedik and Gozler 2022; Terzi et al. 2022; Erüz et al. 2022). However, those studies mostly focused on the marine rather than inland ecosystems (Çevik et al. 2021). Rivers and streams in the southeastern Black Sea coast are the primary route of solid wastes into the marine environment (Güneroğlu 2010; Terzi et al. 2020). To our best knowledge, this is the first study reporting the long-term changes in solid waste composition and the effect of the COVID-19 pandemic in an inland aquatic ecosystem in Turkey.

Artvin Province, located in the northeast of Turkey, has many rivers, dam lakes, national parks, and plateaus. Solid waste pollution is an emerging problem due to intense tourism activities and insufficient infrastructure in the region. In this study, we examined the basin located approximately 25 km northwest of Artvin and the Murgul Stream, where human activities such as aquaculture and tourism are intense. Moreover, the Murgul Stream, exposed to heavy anthropogenic pollution, discharges into the Borçka Dam Lake. In addition, the lake is very close to Artvin City Center, rendering it continuously exposed to anthropogenic pollutants. In this context, our study aims to explore the extent of solid waste pollution in the last 5-year-period and the effects of the COVID-19 pandemic period in the Borçka Dam Lake and Murgul Stream.

## Materials and methods

### Study area

The Borçka Dam Lake and Murgul Stream are among the most important inland water ecosystems in the Çoruh Basin, which is one of the most important 26 basins in Turkey. The total length of the Çoruh River is 431 km, of which 410 km is within the borders of Turkey and 21 km is within Georgia. The Çoruh River, which has an average flow volume of 6.3 billion m<sup>3</sup>, is the fastest flowing river in Turkey. Borçka Dam Lake, the second biggest dam built on the Çoruh River, is located between 41° 03' 99" and 41° 21' 10" north latitudes and 41° 26' 57" and 41° 55' 26" east longitudes.

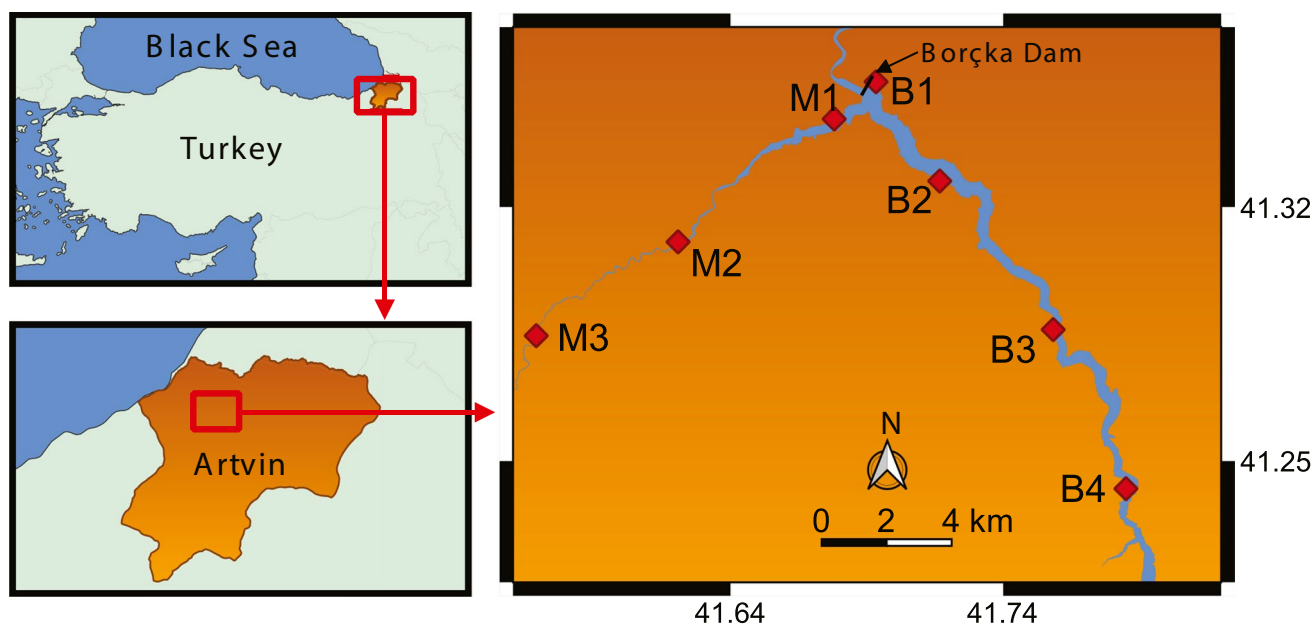
Solid waste was collected from seven stations comprising four on the Borçka Dam Lake (B1–B4) and three along the Murgul Stream (M1–M3) (Fig. 1). In choosing the stations, anthropogenic inputs, such as city centers, stream entrances, and aquaculture activities, were considered.

### Sample collection

All human-induced solid wastes were collected by hand within a 50–100 m<sup>2</sup> area from each station once a year from 2017 to 2021. Sampling was carried out in December or January when the precipitation levels are highest. The same sampling procedure was followed in all sampling surveys. However, extra precaution, including wearing gloves and face masks, was taken to prevent infection during the surveys conducted during the COVID-19 pandemic. The collected waste items were distinguished into eight categories (plastic, metal, textile, glass, paper, sanitary, medical, and wood) and forty-two subcategories following OSPAR (2010) guidelines. The collected solid waste items were sorted, counted, and weighed in the field to estimate their abundance per unit area. Afterward, all the collected solid wastes were disposed of into the nearest garbage container.

### Source assessment

The potential sources of solid waste were assessed using the Matrix Scoring Technique (MST) proposed by Tudor and Williams (2006). Six potential sources of solid waste (recreational activities, river transport, sewage discharge, ecotourism, fishing activities, landfill, and improper disposal) were identified. Scoring was done for each solid waste type. For scoring, instead of using general scoring criteria reported in previous studies (Pieper et al. 2019; Scotti et al. 2021; Chuturkova and Simeonova 2021), modified scoring criteria, representing the potential sources in the region, were used



**Fig. 1** Map of the study area and the sampling stations

to capture differences between regions. Scoring was performed by 10 experts with experience in solid waste scoring using the probability terms reported by Tudor and Williams (2006) to place each solid waste item into its subcategory. The scoring method of Tudor and Williams (2006) includes the following six qualitative definition categories: LL, very likely; L, probable; U, unlikely; UU, highly unlikely; and NC, not considered. Scores from 0 to 4 (UU:0, U:1, P:2, L:3, and LL:4) were assigned according to qualitative definitions, and calculations were done using the scoring system determined by Tudor and Williams (2006). Accordingly, a two-step approach was used to calculate the contribution of each solid waste subcategory. The contribution of each solid waste subcategory (% C) was calculated as in the following.

$$\% C = (\text{Number of items in subcategory} \times 100) / \text{Total number of litter items}$$

The percentage (%P) impact of each potential source on each solid waste category was calculated using the formula below:

$$\% P = (\% C \times \text{subcategory score}) / \text{Total score of the subcategory}$$

Besides, for comparison purposes, the clean-coast index (Alkalay et al. 2007) was calculated.

### Statistical analysis

The data were tested for normality using the Shapiro–Wilk test. The density by count data showed normal distribution but the density by weight data were not normally distributed. Thus, ANOVA and Kruskal–Wallis tests were used

for the count and weight data, respectively, to test for statistically significant differences between stations and years. To identify the group causing the difference, either Tukey HSD or pairwise Wilcoxon test with Bonferroni correction was performed. The composition by year and station was visualized and tested for significant differences using NMDS and ANOSIM. The abundance by number data was used for these analyses. The NMDS and ANOSIM analyses were conducted using metaMDS() and anosim() functions from the vegan package (Oksanen 2020). If a statistical difference was detected, SIMPER was used to determine the solid waste categories contributing to the dissimilarities the most (cumulatively > 70%). Bray–Curtis dissimilarity was used in NMDS, ANOSIM, and SIMPER. A 95% confidence interval was accepted as significant in the statistical analyses. The statistical analyses were conducted using R (ver. 4.1.0) (R Core Team 2021).

## Results

### Solid waste density

A total of 3745 solid waste items with a combined weight of 230.67 kg were collected from the seven stations. Each type of solid waste items was found at all the stations during the 5-year survey period. The abundance of litter items varied between the stations. The highest densities in terms of number and weight were recorded at M3 in 2020 (5.72 items/m<sup>2</sup>) and M1 in 2020 (0.39 kg/m<sup>2</sup>), respectively. On

the other hand, the lowest density by number was at B3 in 2021 (0.47 items/m<sup>2</sup>), and the lowest density by weight was at B1 in 2017 and 2019 (0.01 kg/m<sup>2</sup>) (Table 1). The average abundance by number and weight was the highest in 2020; however, there was no significant difference in abundance between the years both by number (ANOVA,  $F(4,30) = 1.13$ ,  $p = 0.36$ ) and weight (Kruskal–Wallis,  $\chi^2(4) = 2.81$ ,  $p = 0.59$ ). The average abundance by the station was significantly higher at M1, M2, and M3 by number (ANOVA,  $F(6,28) = 7.43$ ,  $p < 0.05$ ) and weight (K–W test,  $\chi^2(6) = 24.1$ ,  $p < 0.05$ ) (Table 1).

### Solid waste composition

The composition of the solid waste items was highly variable between the stations and years. Plastic was the most abundant material by number at all the stations. Its percentage contribution varied between 25.47 and 88.89% (Fig. 2). Plastic pieces, bags, and foams were the most commonly identified subcategories of plastics (Table 2). After plastics, metal items were the most abundant litter type contributing between 0 and 30.00%. There has been a considerable increase in sanitary and medical items during the COVID-19 pandemic (Fig. 2). The weight of the litter items was highly variable depending on the material. The high contribution of rubber in the weight composition (0 to 76.65%) was caused by car tires which were few but heavy (Fig. 2). The contribution of the plastic items by weight varied between 3.41 and 63.91%. Metal and cloth items were dominant at different stations by year (Fig. 2).

The nonmetric multidimensional scaling revealed significant separation in composition by the station (Fig. 3A) and year (Fig. 3B). A distinct clustering pattern was observed between the stations located in the Murgul Stream and the Borçka Dam Lake (Fig. 3A). On the other hand, the litter

composition in 2021 was considerably different (Fig. 3B). The composition was significantly different between years (ANOSIM,  $R = 0.19$ ,  $p < 0.05$ ) and stations (ANOSIM,  $p < 0.05$ ,  $R = 0.15$ ).

Following statistically significant ANOSIM results, the litter groups causing the difference between the stations and years were determined using SIMPER. The results with > 50% average dissimilarity are given in Table 3. Plastic was the highest contributor of dissimilarity on the pairwise comparisons by station and year. The highest dissimilarity by the station was 63.25%, explained by plastic, metal, and cloth items. The comparisons made with 2021 showed that the medical items were the second-highest contributor in the difference between the years (Table 3).

### Potential sources of solid waste

MST revealed that the main potential solid waste source in the study area was river transportation (22.93%), followed by improper disposal (20.74%), aquaculture activities (16.42%), and recreational and tourism activities (14.72%).

### Discussion

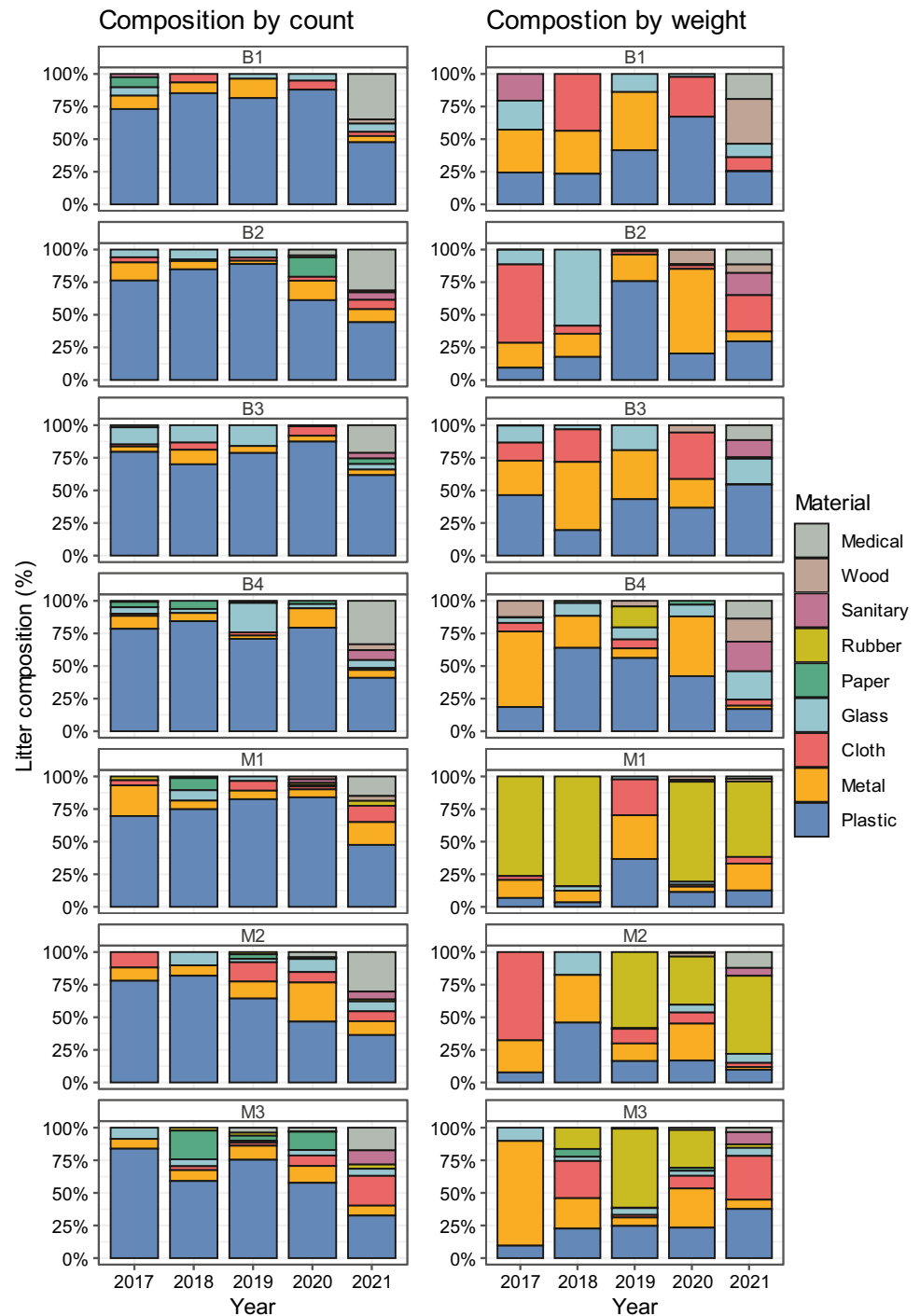
Our results indicate that solid waste densities in the inland water ecosystems of Borçka Dam Lake and Murgul Stream varied qualitatively and quantitatively during the study period. Seasonal changes are one of the main reasons for the differences observed in solid waste density (Erüz and Özşeker 2017). There is a stream habitation within the study area. Several studies suggest that rivers are one of the continuous sources and transportation ways for the terrestrially originated solid waste (Corcoran et al. 2009; Rech et al. 2014; Terzi et al. 2020). Even though the high abundance

**Table 1** The abundance of solid wastes by count and weight in each year and station

	Year	B1	B2	B3	B4	M1	M2	M3	Mean ± SE
Density (items/m <sup>2</sup> )	2017	0.78	1.01	1.22	1.21	2.04	1.18	1.86	1.33 ± 0.16 <sup>a</sup>
	2018	0.61	0.79	0.90	0.96	3.02	1.76	2.64	1.53 ± 0.34 <sup>a</sup>
	2019	0.81	0.81	0.75	1.20	4.58	2.30	2.60	1.86 ± 0.50 <sup>a</sup>
	2020	0.58	0.67	1.11	1.21	3.62	3.00	5.72	2.27 ± 0.67 <sup>a</sup>
	2021	0.63	0.70	0.47	0.66	1.60	1.32	1.84	1.03 ± 0.19 <sup>a</sup>
	Mean ± SE	0.68 ± 0.04 <sup>a</sup>	0.80 ± 0.05 <sup>a</sup>	0.89 ± 0.12 <sup>ab</sup>	1.05 ± 0.10 <sup>b</sup>	2.97 ± 0.48 <sup>b</sup>	1.91 ± 0.30 <sup>b</sup>	2.93 ± 0.64 <sup>b</sup>	
Density (kg/m <sup>2</sup> )	2017	0.01	0.04	0.03	0.08	0.31	0.04	0.04	0.08 ± 0.04 <sup>a</sup>
	2018	0.02	0.02	0.04	0.01	0.21	0.03	0.06	0.05 ± 0.02 <sup>a</sup>
	2019	0.01	0.05	0.02	0.03	0.10	0.34	0.30	0.12 ± 0.05 <sup>a</sup>
	2020	0.02	0.06	0.03	0.03	0.39	0.22	0.17	0.13 ± 0.05 <sup>a</sup>
	2021	0.02	0.03	0.02	0.03	0.29	0.15	0.09	0.09 ± 0.04 <sup>a</sup>
	Mean ± SE	0.02 ± 0.01 <sup>a</sup>	0.04 ± 0.01 <sup>a</sup>	0.03 ± 0.01 <sup>a</sup>	0.04 ± 0.01 <sup>a</sup>	0.26 ± 0.04 <sup>b</sup>	0.15 ± 0.05 <sup>c</sup>	0.13 ± 0.04 <sup>c</sup>	0.09 ± 0.03 <sup>a</sup>

Different superscript letters indicate a statistically significant difference

**Fig. 2** The composition of the collected litter items by count (left) and weight (right)



of solid waste on M1, which is located down the river, was expected, no statistically significant difference was detected in abundance by number. The highest abundances by number and weight were recorded at M3 in 2020 (5.72 items/m<sup>2</sup>) and M1 in 2020 (0.39 kg/m<sup>2</sup>), respectively (Table 1). The solid waste abundance was relatively higher in 2020 (extremely dirty: 2 stations, dirty: 3 stations, and moderate: 2 stations) than in the other years. This might be the result of river run-offs after high rainfall (Cheung et al. 2016; Terzi et al. 2020)

in that year which was 30% higher than the average of the previous 18 years. Furthermore, the study area is surrounded by an intercity highway with heavy traffic. In addition, Artvin, which has the most preferred ecotourism centers in the Black Sea Region such as Kafkasör, Borçka, Karagöl, and Hatila National Parks, is a busy stopover place for domestic and foreign tourists in Turkey. Also, the Murgul, İçkale, and Kaynarca creeks are the main water sources that flow into the Borçka Dam Lake, providing anthropogenic input.

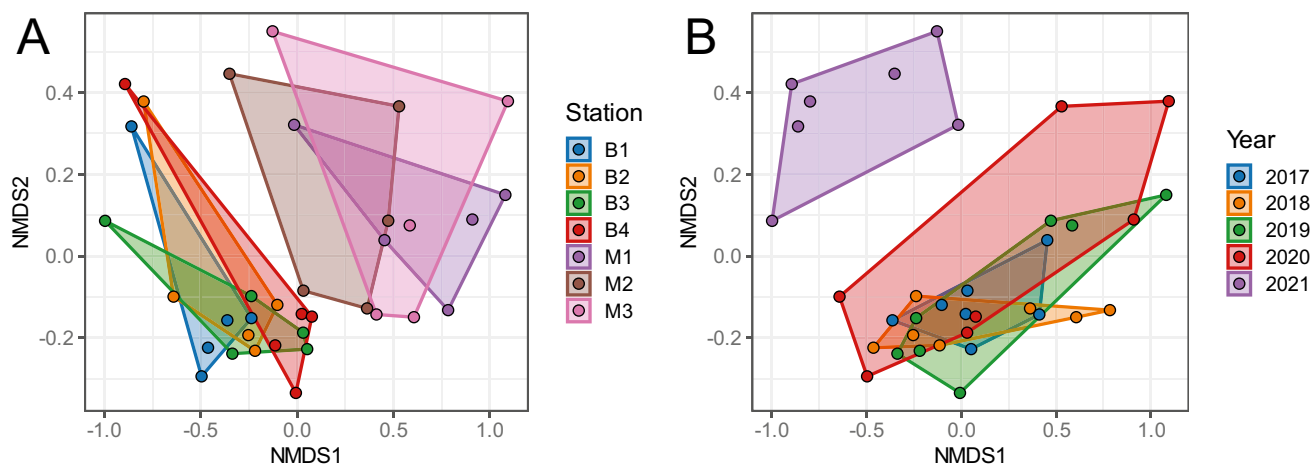
**Table 2** Percentage of the subcategories of each collected litter class during the study

Litter type	Stations						
	B1	B2	B3	B4	M1	M2	M3
<b>Plastic</b>							
Hard plastics	3.99	2.68	9.46	3.19	6.33	1.67	2.73
Fishing nets	0.28	1.46	1.72	0.53	0.13	0.42	0.27
Rope	0	0	0	0.71	0.94	0.21	1.09
Pipes	0	1.70	0.65	0.35	0	0	0
Cigarette lighters	5.41	0.73	10.54	0.35	0	0	8.46
Cups	1.14	2.92	0.65	3.90	0	0	0
Toys and party poppers	0.28	0.73	0	0.53	0.27	1.05	0.55
Caps/lids	0	0	0	0	0	0.21	0.27
Cosmetic packages	0	0.49	0	0	0	0.84	0.27
Gloves	0	0.73	0.86	0.53	2.02	1.26	0.55
Razor	1.42	0.73	0	0	0.67	0	0
Bags	17.38	14.11	14.84	17.91	16.42	15.06	16.78
Sacks	0.57	0.49	0.00	0.18	0.40	0.21	0.27
Other bottles, containers, and drums	3.13	0.73	2.58	2.66	5.11	0.42	4.50
Packages	3.70	2.19	5.38	8.69	9.69	1.46	0.68
Cleaner containers	0.57	1.22	0	0	1.08	3.97	3.14
Engine oil containers and drum	1.14	1.46	0.65	0.53	2.29	1.26	0.68
Beverage containers	7.69	4.14	1.72	0.71	2.02	11.51	3.27
Plastics pieces	12.82	24.33	17.42	15.60	18.44	14.85	11.46
Foams	13.39	9.25	7.74	11.70	9.96	5.44	6.28
<b>Metal</b>							
Drink cans	1.99	0.73	0	0.18	3.23	6.28	0.27
Food cans	0.85	0	0.65	0	0	0	3.14
Bottle caps	1.42	0	0.43	0.89	0.00	0.42	0
Electric appliances	0	0	0	0	0.67	0.21	0
Big metal pieces	0.28	0.97	0.65	0.71	2.02	0.63	0.82
Other metal pieces	3.42	7.54	3.87	5.85	4.04	9.21	6.14
<b>Textile</b>							
Clothing	0	1.70	0.65	0	1.21	1.88	1.50
Other textiles	2.28	1.22	2.15	0.89	3.23	6.07	3.96
Shoes/sandals	0.57	0.49	0.43	0.18	0.27	0.63	1.50
<b>Glass</b>							
Bottles	1.99	0.49	0.43	0.53	1.62	1.46	0.41
Other glass items	2.28	3.65	8.60	7.27	1.35	5.23	4.23
<b>Paper</b>							
Newspapers and magazines	0	0	0	1.60	1.88	0	2.05
Cigarette packets	1.71	2.43	0.43	0.89	0	0.84	8.05
<b>Rubber</b>							
Car tires	0	0	0	0.18	1.48	0.84	0.55
Other rubber pieces	0	0	0	0	0	0	0.82
<b>Sanitary</b>							
Other sanitary items	0	0.24	0	0.35	0.67	0.21	0.82
Sanitary pad	0.57	0.73	0.43	0.53	0	0.63	0.55
<b>Medical</b>							
Syringes	0.57	0.73	0	0	0	1.67	0.68
Containers/tubes/disinfectant	5.70	5.35	2.58	3.90	0.67	1.26	1.09
Medical mask	2.85	3.16	4.30	7.09	0.94	2.51	2.18
<b>Wood</b>							



**Table 2** (continued)

Litter type	Stations						
	B1	B2	B3	B4	M1	M2	M3
Processed wood	0.57	0.49	0.22	0.89	0.94	0.21	0

**Fig. 3** NMDS plots showing the composition by the station (A) and year (B)**Table 3** Results of the pairwise comparisons determined by SIMPER analysis. First three solid waste categories contributing to the dissimilarities were given

Comparison by station				Comparison by year			
<b>B1 vs M1</b>	Average dis. = 63.25%	Contrib. %	Cum. %	<b>2020 vs 2021</b>	Average dis. = 57.85%	Contrib. %	Cum. %
	Plastic	54.43	54.43		Plastic	49.76	49.76
	Metal	10.88	65.31		Medical	14.84	64.6
	Cloth	9.642	74.95		Metal	12.6	77.21
<b>B1 vs M3</b>	Average dis. = 60.75%	Contrib. %	Cum. %	<b>2019 vs 2021</b>	Average dis. = 56.20%	Contrib. %	Cum. %
	Plastic	39.72	39.72		Plastic	53.18	53.18
	Paper	21.65	61.37		Medical	17	70.18
	Metal	14.79	76.16		Cloth	8.425	78.6
<b>B2 vs M1</b>	Average dis. = 59.25%	Contrib. %	Cum. %	<b>2018 vs 2021</b>	Average dis. = 55.24%	Contrib. %	Cum. %
	Plastic	66.86	66.86		Plastic	47.61	47.61
	Metal	11.33	78.2		Medical	19.35	66.96
	Cloth	5.657	83.85		Cloth	6.955	73.92
<b>B2 vs M3</b>	Average dis. = 57.19%	Contrib. %	Cum. %	<b>2017 vs 2021</b>	Average dis. = 53.15%	Contrib. %	Cum. %
	Plastic	54.36	54.36		Plastic	49.83	49.83
	Paper	11.26	65.62		Medical	19.77	69.6
	Metal	8.863	74.48		Metal	9.059	78.66
<b>B3 vs M1</b>	Average dis. = 56.92%	Contrib. %	Cum. %				
	Plastic	65.45	65.45				
	Metal	12.73	78.18				
	Cloth	5.745	83.93				
<b>B3 vs M3</b>	Average dis. = 53.88%	Contrib. %	Cum. %				
	Plastic	53.08	53.08				
	Paper	11.71	64.79				
	Metal	10.55	75.34				

In addition, the increase observed in solid waste density in 2020 can be associated with the COVID-19 pandemic which began in 2019. The solid waste abundance and types of generated litter items during the COVID-19 varied by location (Naughton 2020). With the relaxation of the restrictions of the pandemic period in 2020, local people avoided the densely populated city centers and moved to natural environments such as villages, towns, plateaus, sea, and creek sides to ease the pressures and depressions of the pandemic period. The increase in population in such rural areas resulted in high levels of solid waste. This has also led to the change of solid waste composition in the study area. As the lockdown durations shortened, a separation on the solid waste composition in 2020 and 2021 was noticed (Fig. 3B) mainly driven by plastic and medical solid wastes (Table 3).

Several studies on the distribution, abundance, sources, and fate of solid waste in the Black Sea basin have been carried out (Topçu et al. 2013; Terzi and Seyhan 2017; Simeonova et al. 2017; Stanev and Ricker 2019; Simeonova and Chuturkova 2019; Oztekin et al. 2020; Raykov et al. 2020; Terzi et al. 2020; Miladinova et al. 2020; Erüz et al. 2022). However, these studies concentrated on coastal and benthic areas of the Black Sea, leaving a knowledge gap on solid wastes in inland water ecosystems. Similar to the findings of previous studies conducted in the marine environment, our results indicate that plastic was the most abundant solid waste item at all stations with a percentage contribution varying between 25.47 and 88.89% across the years (Fig. 2). The most abundant subcategories of plastic were plastic pieces, bags, and foams (Table 2). After plastics, metal was the most common solid waste contributing between 0 and 30.00% of the solid waste items. In 2020 and 2021, there was a significant increase in sanitary and medical supplies due to the COVID-19 pandemic. The number of discarded face masks used for protection from COVID-19 dramatically increased in our samples. The weight of the solid waste items was highly variable depending on the material. The high ratio of rubber in the weight composition (0–76.65%) was caused by disposed car tires which were few but high weight per unit. Metal and cloth items were dominant at different stations by year (Fig. 2).

During the COVID-19 pandemic, several measures and plans were implemented to reduce and control municipal solid waste (Ducoli et al. 2021; Das et al. 2021; Lan et al. 2022; Singh et al. 2022). The main idea behind the measures was to reduce the contamination risk of the virus (Cruvinel et al. 2019). Poor waste management would cause increased solid waste pollution (Mol and Caldas 2020), especially through discarded single-use COVID-19 personal protective equipment. Despite these measures, our results showed that such solid wastes occurred at a higher abundance and density in the inland water bodies during the COVID-19 pandemic. Streams are inland water resources directly related to other water resources such as lakes and seas. Therefore, it is

inevitable that lakes and seas will be adversely affected by solid waste pollution transported by streams. In this study, high solid waste input in Borçka Dam Lake and the Murgul Stream was observed. Considering their high usage rates and durability, the accumulation of plastics in inland water ecosystems is not surprising. Plastic bags were the most common litter type although a plastic bag charge was introduced in 2019 in Turkey. This measure was not that successful, resulting in only a slight decrease in the abundance of plastic bags. This is in agreement with report of a decrease in frequency of plastic bag usage in Turkey by Senturk and Dumludag (2021). Fragmented plastic pieces were the second most common solid waste collected. The fragmentation of large plastic items and the emission of microplastics by mechanical effects are known phenomena (Julienne et al. 2019) and are well documented in the Black Sea (Gedik and Eryaşar 2020; Eryaşar et al. 2021; Gedik and Gozler 2022; Terzi et al. 2022). Rivers seem to be one of the major contributors to microplastic pollution. Among plastics, foams were one of the most dominant subcategories. Solid waste composition dominated by foams has also been reported in the aquatic environment in previous studies (Topçu et al. 2013; Terzi et al. 2020). It is difficult to identify the sources of the foams because they have a wide range of uses. They are most commonly used in general packaging, construction, and aquaculture activities. It is thought that the increase in aquaculture activities in the study area has recently increased the number of foams in the area. One of the most notable findings of our study is increased medical waste in 2021, which coincided with the COVID-19 pandemic. The solid waste composition was significantly different from that of the previous years (Fig. 3), mainly due to the increased contribution of plastics and medical waste (Table 3). In the year 2021, the medical waste comprised 57% face masks, 40.58% containers/tubes/disinfectants, and 2.42% syringes by number. This was an expected result since face masks are mandatory during the pandemic.

## Conclusion

The abundance, composition, and possible sources of solid waste in inland water ecosystems, Borçka Dam Lake and Murgul Stream, located in the Artvin Province, Turkey, were determined annually from 2017 to 2021. The findings of this study show that the most common type of solid waste in the examined region was plastic, with river transportation being the primary source. In addition, with the COVID-19 pandemic, a high increase in solid waste of medical origin was observed. This increase is expected to continue as long as the pandemic persists. Although the amount of solid waste varied from year to year, there was no significant variation between the stations. A remarkable finding of this study was



a dramatic increase in the amount of solid waste of medical origin coinciding with the COVID-19 pandemic.

The results of this study highlight that the current waste management measures in Turkey are not effective in preventing solid waste accumulation in inland aquatic systems such as the Borçka Dam Lake and Murgul Stream. Furthermore, our findings indicate that the COVID-19 pandemic influenced solid waste composition and increased its abundance in the study area.

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**Author contribution** KÖ collected data, wrote the original draft, and performed statistical analyses. YT performed statistical analyses, visualized the data, and wrote and edited the original draft. CE collected data. All authors read and approved the final manuscript.

**Availability of data and materials** The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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