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Impact of extreme weather events on floating marine litter pollution in Burgas Bay - Black Sea

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Abstract: This study investigated the spatio-temporal dynamics of floating marine litter (FML) in the Burgas Bay (SW Black Sea) between 09.2021 and 11.2023. Regular bimonthly visual monitoring along fixed transects in the Southern Burgas Bay revealed areas of accumulation of FML, with pronounced seasonal and interannual variations. FML concentrations in the study varied between 9 and 1481 Items.km^{-2}. The highest concentrations of FML were observed during extreme weather events in November 2023 (1481 ± 1459 Items.km^{-2}), which correlated with heavy rainfall events during this period. Results highlight the dual role of rivers and coastal lakes as pathways and reservoirs for marine litter, which is particularly evident during periods of elevated river water levels. The findings show the complex interplay of meteorological and hydrological factors in FML distribution and accumulation, and emphasize the need for comprehensive monitoring and mitigation strategies to address the effects of the ongoing increase in plastic pollution in the Black Sea.

Keywords: Marine litter, plastic, extreme weather, Black Sea, Burgas Bay

1. INTRODUCTION

Floating marine litter (FML) comprises items that have been produced and used by humans and have been discarded, lost, or forgotten along the coast or at sea, or transported there by wind, sewage, rain, or rivers (Wenneker et al., 2010). They can be made of plastic, wood, rubber, textiles, paper, metal, or glass, and have various negative economic, environmental, and aesthetic impacts (Acoleyen et al., 2014; Brouwer et al., 2017; Kuhn et al., 2015; Werner et al., 2016). Marine litter is a subject of investigation

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under the Marine Strategy Framework Directive, and is one of the indicators of ecological status of marine ecosystems under Descriptor 10 'Marine litter'. This is also reflected in the new guidance on marine litter in European seas, which improves and harmonizes monitoring across the EU (Galgani et al., 2023).

Several models have shown the accumulation of floating marine litter in the southeastern Black Sea (Zlateva et al., 2024; Castro-Rosero et al., 2023; Miladinova et al., 2020; Stanev & Riecker, 2019). However, in-situ data for many regions of the Black Sea, including the coastal zone of Bulgaria, is lacking. The aim of this study was to gather seasonal in-situ data on the presence and concentrations of FML in the coastal zone of the Burgas Bay, Bulgaria, and to investigate the temporal and spatial dynamics of this emerging threat to marine ecosystems.

2. STUDY AREA

The study area includes the southern part of the Burgas Bay, from the city of Burgas in the north to cape Maslen nos in the south (Figure 1). The marine water mass circulation in this coastal zone of the bay is determined by wind direction and strength, and by the orography of the coastal region. The main direction of the eddy current is anti-clockwise for N, NE and E winds, and clockwise for W, SW and S winds, which results in a longer retention time of the water in the bay (Trukhchev et al., 2004). The surface water flow velocity varies between 5-10 cm.s-1 under calm conditions and 35-40 cm.s-1 under stronger winds (Trukhchev et al., 2004).

Maximum rainfall in the study area is observed in autumn and winter (September-March), minimum in the summer season (June-August) (Rojdestvenskij, 1986; Trukhchev, 2005).

Three major rivers flow into the southern part of the study area - Ropotamo, Karaagach, and Diavolska. Their catchment areas account for only 7.01%, and their average annual runoff - for just 7.23% of those for all 13 rivers flowing directly into the Bulgarian part of the Black Sea (Jaoshvili, 2002).

Table 1. Catchment and outflow of the rivers in the study area flowing directly into the Black Sea (Jaoshvili, 2002)

River	**Area of basin, km^2**	**Outflow**		
		Average annual outflow, m^3/s	Unit discharge, l/s·km^2	Annual volume, km^3
Ropotamo	248.7	1.17	4.70	0.037
Karaagach	224.3	0.96	4.28	0.030
Dyavolska	133.2	0.57	4.28	0.018

While the rivers in the southern part of the study area flow directly into the Black Sea, smaller rivers in the northern part drain into the lakes Mandrensko, Vaya and Atanasovsko, which act as a buffer for the accumulation of floating marine litter.

3. METHODOLOGY

Bimonthly visual monitoring of FML in the south-western Black Sea was carried out between September 2021 and December 2023. The monitoring was conducted following the methodological guidelines of the MSFD Technical Subgroup on Marine Litter (Hanke et al., 2013; Vighi et al., 2022). Eight coastal transects parallel to the shore were set up, each with a length of 2250 m and area of 13500 m^2. Monitoring took place in February, April, June, September, and November. Cloudiness, wave height, wind strength and direction were recorded during each transect observation.

Visual monitoring of FMLs was conducted from a boat by the same observer for all monitoring missions. The observer monitored a 6 m wide transect on one side of the boat. The height of observation above sea level was 2.2 m, and the boat speed was 12 $km.h^{-1}$. Observations were recorded in standard paper protocols and later entered in an MS-Excel spreadsheet. 21 monitoring missions were completed, with a total of 84 transects covered.

Data on daily precipitation the region for the study period was downloaded from the National Centers of Environmental Information's Integrated Surface Hourly (ISH) dataset for weather station №: 15655099999, Burgas (BGR) (NOAA, 1999) and summed for different periods prior to the day of the in-situ FML surveys (7, 14 and 30 days). Correlations between measured average FML for each period and the total precipitation for these periods were tested in order to verify the link between rainfall events and changes in marine debris concentrations.

Point data for marine litter concentrations were interpolated into spatial fields using the IDW Interpolation function in QGIS v. 3.36.0 (distance coefficient P = 2, WGS84 UTM zone 35 N) (QGIS Development Team, 2024) and Ocean Data View (ODV 5.7.2) (Schlitzer, 2018).

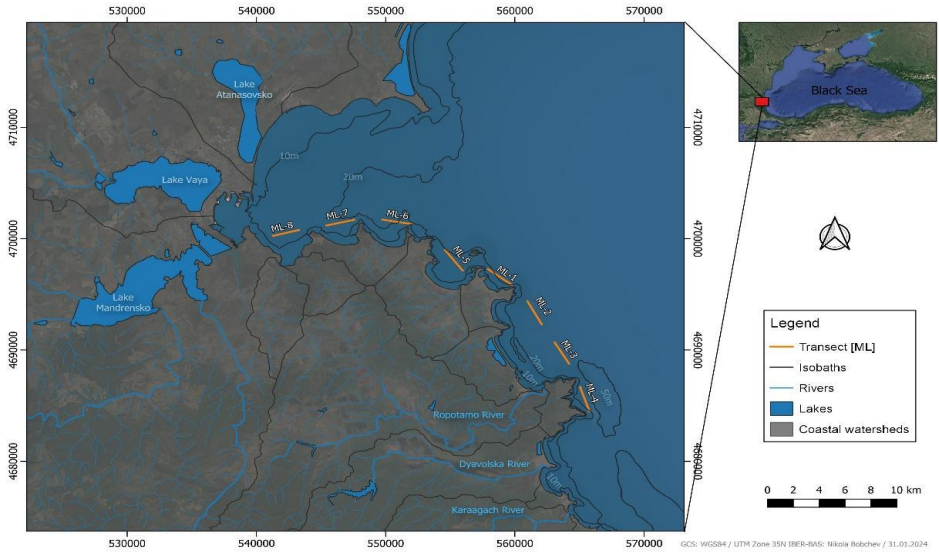


Fig. 1. Transects, coastal catchments, rivers and lakes in the study area

4. RESULTS AND DISCUSSION

A total of 502 objects were described. 88.72 % of the FML consists of plastic, with plastic pieces 2.5 > < 50 cm, plastic packaging and plastic bags as the most common litter types (Figure 2). The amount of FML varied between transects; overall, the concentrations ranged between 168 and 730 Items.km^{-2}. The average amount of FML over the entire monitoring period was 403 ± 692 Items.km^{-2} (mean ± SD).

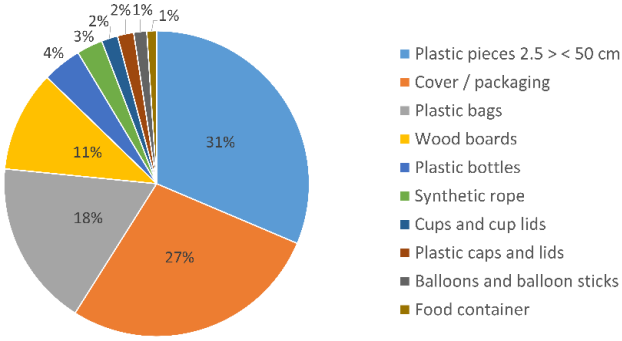
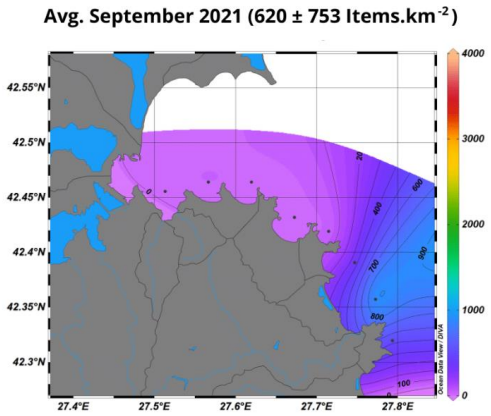


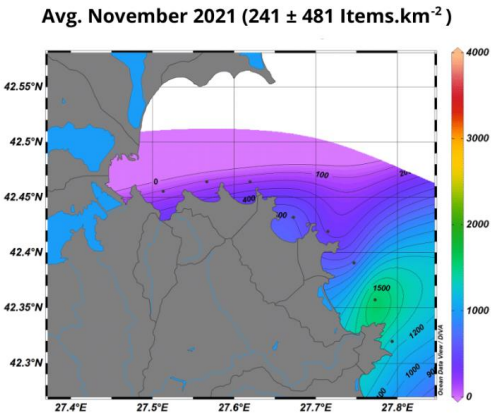
Fig. 2. The most common types of floating marine litter for the entire monitoring period

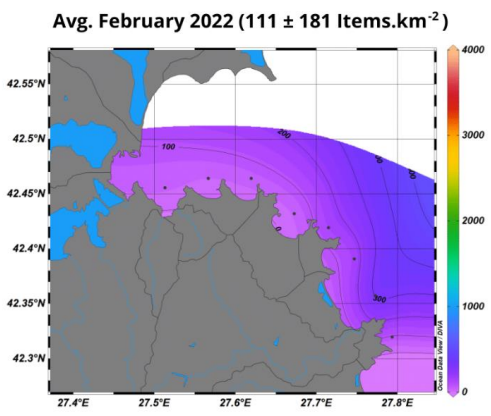
Seasonal and annual differences in FML concentrations were observed. In 2022, the number of floating debris varied between 0 and 252 Items.km^{-2}, with an average of 120 ± 191 Items.km^{-2}. In 2023, the FML concentrations ranged between 352 - 1407 Items.km^{-2}, with an average of 791 ± 957 Items.km^{-2}. Increased concentrations of floating marine debris were observed in September and November in both 2021 and 2023 (Figure 3). The transects with overall highest concentrations of FML were those in the southernmost parts of the study area, between Cape Agalina, Cape Korakia and Cape Maslen nos. These areas of maximum FML correspond well with simulations of the movement and accumulation of drifting particles released in the marine environment by coastal cities in the Burgas Bay (Zlateva et al., 2024).

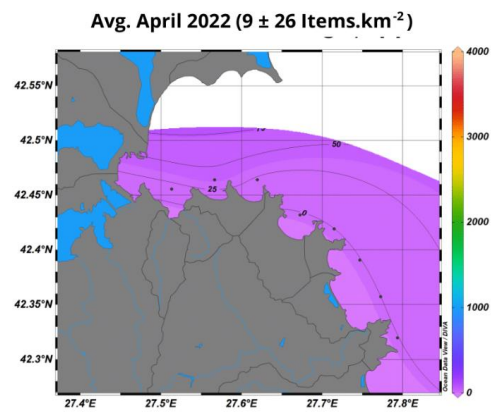
We found a strong positive correlation between the average amount of FML in the area and the amount of precipitation over a 14-day period prior to the monitoring date (Pearson correlation coefficient = 0.81; $p < 0.026$). This indicates that periods with high precipitation and subsequent increase in freshwater outflow from the rivers in the study area is probably the main process driving the dynamics of FML pollution in the Burgas Bay coastal zone. This correlation is most clearly visible in the periods with highest rainfalls and subsequent increased pollution of coastal waters - namely September and November 2023.

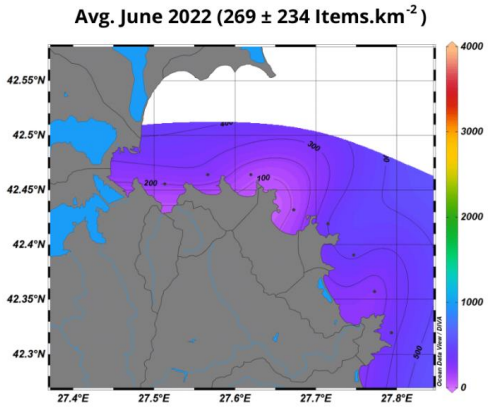
Between September 4th and 6th, 2023, with the passage of a cyclone through south-eastern Bulgaria, rainfalls of up to 350 mm, or over 400 % of the monthly norm for the area, were recorded at weather stations along the southern Black Sea coast (NIMH 2023a). A state of calamity was declared in the southeast of the country. As a result of the high waters of rivers in the area, the walls of two dams were damaged, and thirteen bridges were destroyed partially or completely.

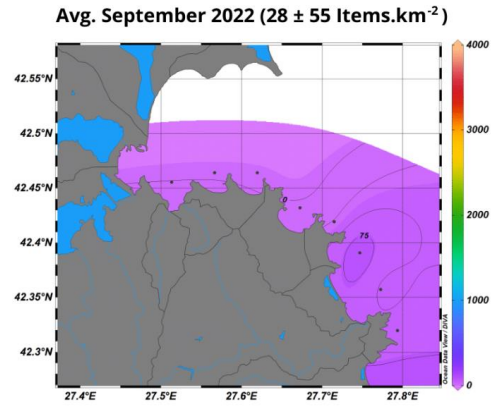

Avg. September 2021 (620 ± 753 Items.km-2)
42.55°N
42.5°N
42.45°N
42.4°N
42.35°N
42.3°N
27.4°E
27.5°E
27.6°E
27.7°E
27.8°E
4000
3000
2000
1000
0
Ocean Data View / DIVA


Avg. November 2021 (241 ± 481 Items.km-2)
42.55°N
42.5°N
42.45°N
42.4°N
42.35°N
42.3°N
27.4°E
27.5°E
27.6°E
27.7°E
27.8°E
4000
3000
2000
1000
0
Ocean Data View / DIVA


Avg. February 2022 (111 ± 181 Items.km-2)
42.55°N
42.5°N
42.45°N
42.4°N
42.35°N
42.3°N
27.4°E
27.5°E
27.6°E
27.7°E
27.8°E
4000
3000
2000
1000
0
Ocean Data View / DIVA


Avg. April 2022 (9 ± 26 Items.km-2)
42.55°N
42.5°N
42.45°N
42.4°N
42.35°N
42.3°N
27.4°E
27.5°E
27.6°E
27.7°E
27.8°E
4000
3000
2000
1000
0
Ocean Data View / DIVA


Avg. June 2022 (269 ± 234 Items.km-2)
42.55°N
42.5°N
42.45°N
42.4°N
42.35°N
42.3°N
27.4°E
27.5°E
27.6°E
27.7°E
27.8°E
4000
3000
2000
1000
0
Ocean Data View / DIVA


Avg. September 2022 (28 ± 55 Items.km-2)
42.55°N
42.5°N
42.45°N
42.4°N
42.35°N
42.3°N
27.4°E
27.5°E
27.6°E
27.7°E
27.8°E
4000
3000
2000
1000
0
Ocean Data View / DIVA

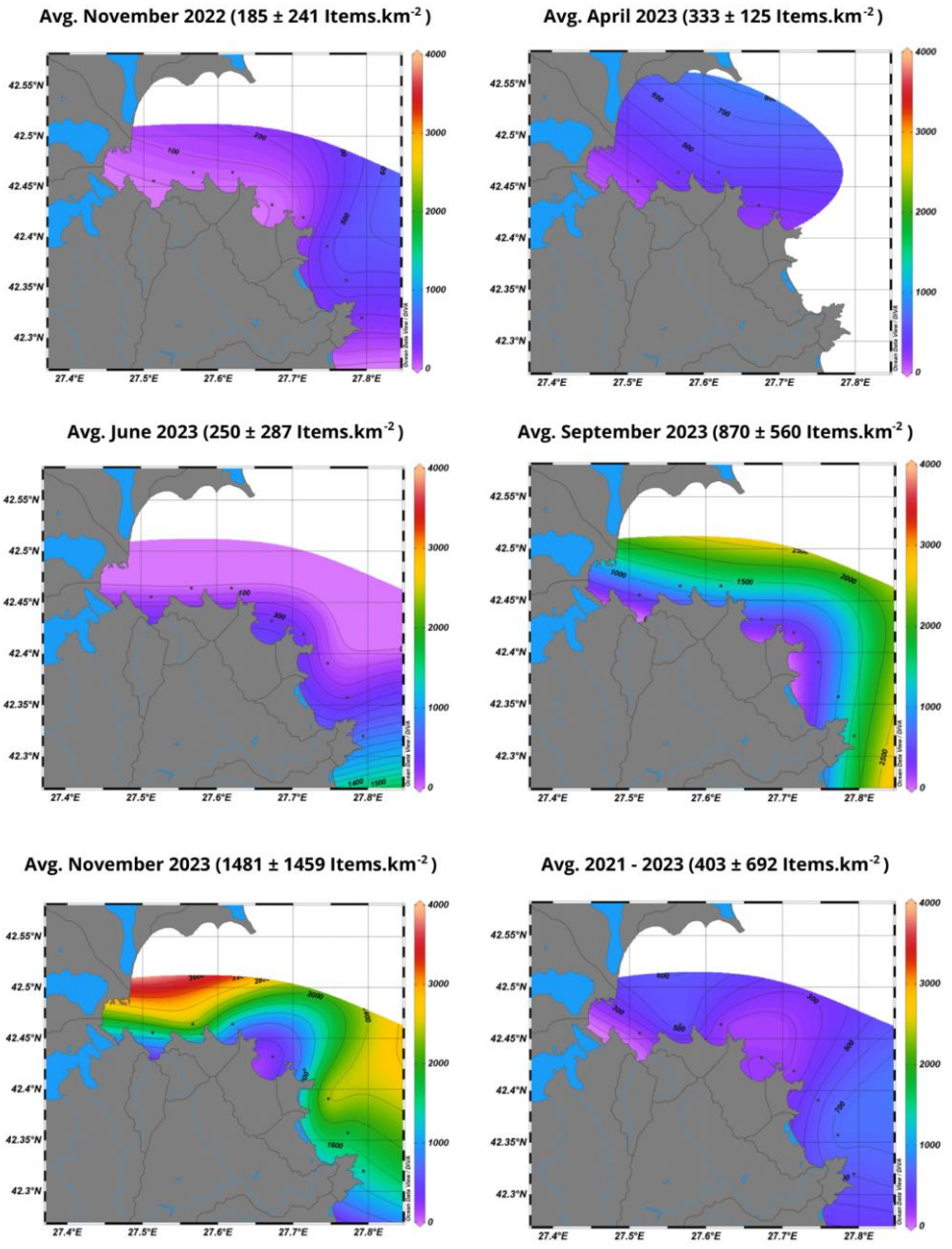


Fig. 3. Monthly distribution of floating marine litter at the study area over the entire monitoring period (mean ± SD)

Following these major rainfall events, the average concentration of FML in the study area reached 870 ± 559 Items.km^{-2} (mean ± SD), varying between 150 - 1700 Items.km^{-2} across transects (Figure 5) - 1.7 times more than the average for the autumns of 2021 and 2022, and 2.2 more than the average for the entire monitoring period. One-third of the floating marine debris in September 2023 was treated wood; plastic bags (29%) and plastic packaging (18%) were the second and third most common waste types. As rivers are not only a pathway for litter to the sea, but also a reservoir that is activated when river levels rise (Emmerik et al., 2023), we could speculate that the majority of the observed increase in FML was brought in the sea by the coastal rivers in the area.

The observed differences in FML concentrations between the inner and outer parts of the Burgas Bay during this extreme weather event (see Figure 4) could be attributed to the buffering of debris by the three lakes in the northern part of the area - Mandra, Vaya and Atanasovsko. It is possible that rain waters carrying debris from the urban area of Burgas did not flow directly into the Black Sea, but rather accumulated in these coastal lakes.

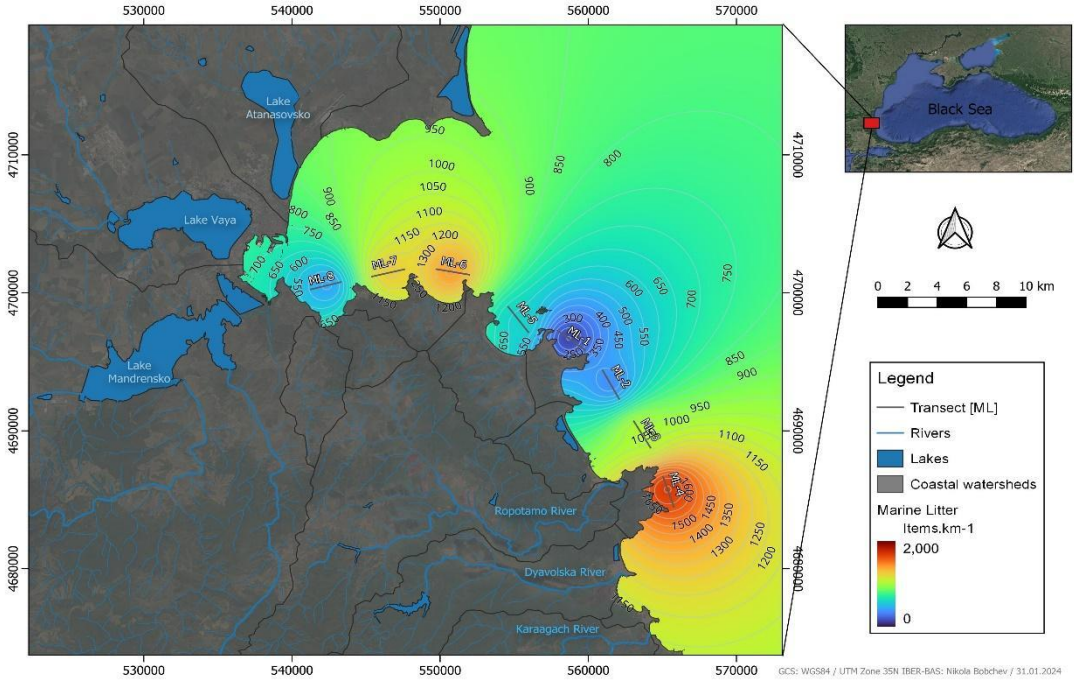


Fig. 4. Concentration of floating marine litter in September 2023

November 2023 was the rainiest month in Bulgaria since 2008, with monthly rainfall totals for the country ranging between 100% and 415% above the monthly average (NIMH 2023b). Within the Black Sea catchment area, the river runoff volume for

November was 69.10^6 m^3, nearly three times the previous month's, and three times the November 2022 volume (NIMH 2023b). This was also the period when the largest amount of FML, 1481 ± 1458 Items.km^{-2}, was recorded (Figure 6). The amount of FML varied between 150 and 4000 Items.km^{-2}in different parts of the bay. This was 2.3 times more than the average for November 2021 and 2022, and 3.7 times more than the average for the entire monitoring period. Treated wood accounted for 33% of floating marine litter in November 2023, followed by plastic fragments (30%) and plastic packaging (13%). Models show that over one-third of the annual river transport of floating debris occurs within six days of extreme water level rise, and the number of recorded debris can increase 100-fold compared to non-flood conditions (Emmerik et al., 2023), which corresponds well with the time frame of our observations.

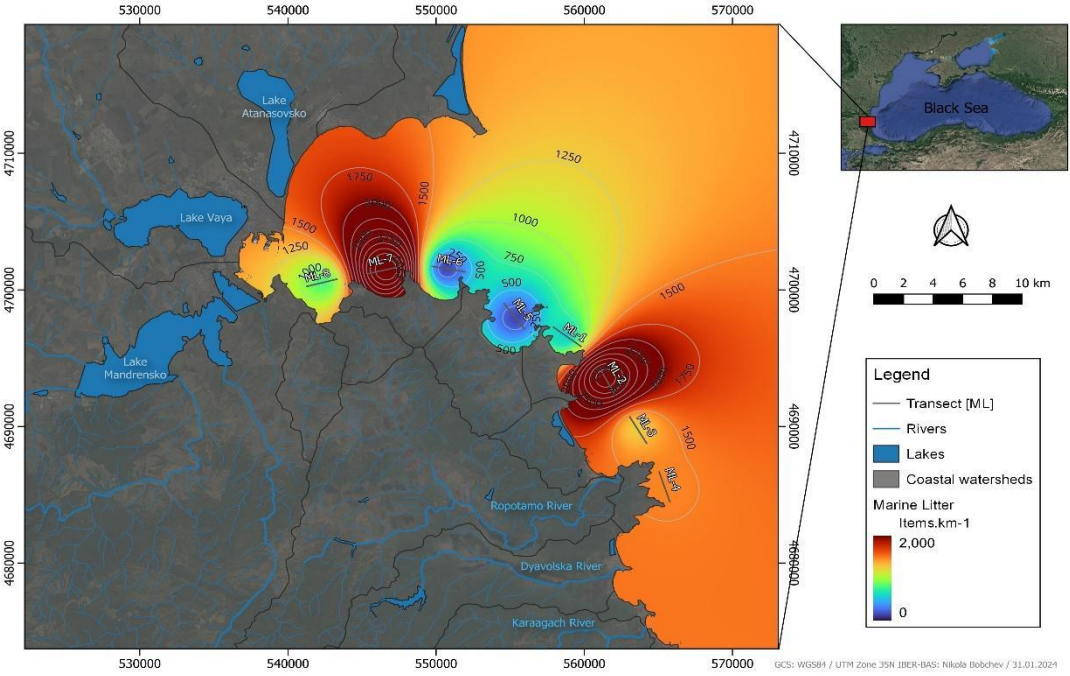


Fig. 5. Concentration of floating marine litter in November 2023

The process of fragmentation and secondary introduction of FML from the beaches into the sea seems to be an additional source of FML during extreme weather events, and could explain the large amount of wood and plastic fragments observed during the November 2023 survey. Besides extreme rainfalls, the weather event in November 2023 caused high winds and storm swells at sea. On the 18th and 19th of November 2023, the maximum wind speed reached 22.1 m.s^{-1} from the NW, and the wave height in open sea was up to 4 m (NIMH 2023b). As a result, many of the beaches in the southern part of the Burgas Bay were completely or partially flooded for two days. This led to the transport of already accumulated beach litter from the coast and dunes back into the sea.

Beaches and coastal dunes along the coastline of the southern Burgas Bay have the highest amounts of plastic pollution and represent a significant reservoir of marine litter that could be brought back into the sea during such storm surges (Bekova & Prodanov, 2024).

The observed combination of rising river flows, strong onshore to offshore winds, and strong swells is a precondition for the transport of litter from the shore to the sea, its mechanical fragmentation by wave action, and accumulation in coastal and offshore areas where it becomes a source of pollution of the marine environment with macro- and microplastics.

5. CONCLUSION

This study provides valuable data on the dynamics of floating marine litter in the coastal regions of the SW Black Sea, highlighting the seasonal and spatial variability in distribution and areas of potential impact of plastic litter. The two-year monitoring reveals significant seasonal and annual variations. The highest concentrations of litter were observed in November 2023, which correlated with extreme weather events with heavy rainfall and strong winds. The study highlights the role of rivers and coastal lakes as pathways and reservoirs for marine litter, which is particularly evident during periods of increased water levels. The complex interaction of meteorological and hydrological factors is highlighted, indicating the need for comprehensive monitoring and mitigation strategies to address the marine litter problem in the Black Sea.

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DATA AVAILABILITY

Data is available in SEANOE under https://doi.org/10.17882/98351 (Bobchev et al., 2023)

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