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Sources, concentrations, distributions, fluxes and fate of microplastics in a hypersaline lake: Maharloo, south-west Iran

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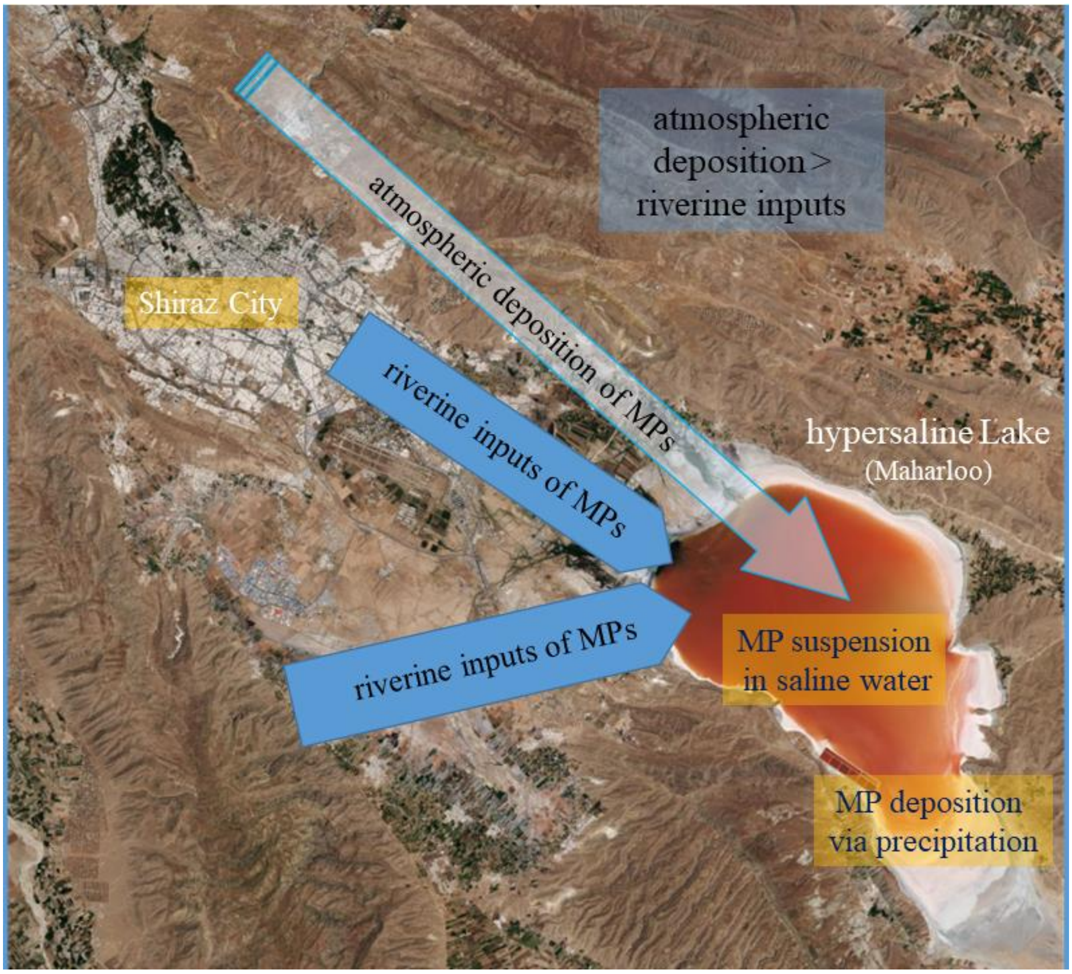
Graphical Abstract



Abstract

Hypersaline lakes support unique ecosystems and biogeochemistries but are often subject to anthropogenic pressures from pollution, water abstraction-diversion and climate change. Less understood, however, are the inputs, distributions and impacts of microplastics (MPs) in hypersaline environments. In this study, MPs are determined in water and sediment cores of Maharloo Lake, south-west Iran, and in the anthropogenically-impacted rivers that recharge the lake. MP concentrations in river water ranged from 0.05 MP L^{-1} in the headwaters to about 2 MP L^{-1} downstream of industrial effluents, with intermediate (but elevated) concentrations observed in the lake. The maximum surface concentration in lake sediment cores was about 860 MP kg^{-1}, and concentrations displayed a progressive reduction with increasing depth down to 50 cm that are qualitatively consistent with temporal changes in plastic production. The size distribution of MPs was skewed toward the finest fraction (< 100 μm) and the most abundant polymer types were polyethylene terephthalate, polyethylene and nylon. Flux calculations using river water data and published atmospheric deposition data for the region reveal that the atmosphere is, by at least an order of magnitude, the more important source. MPs added to the lake appear to be maintained in suspension by high density water but are subsequently deposited to sediments by encapsulation and nucleation as salts precipitate. In addition, it is proposed that direct atmospheric deposition to sediment takes place on areas that seasonally dry out and are subsequently inundated. The impacts of MPs on hypersaline ecosystems and biomass resources are unknown but warrant investigation.

Keywords: rivers; sediments; polymers; brine; density; deposition

1. Introduction

Microplastics of < 5 mm in size are generated during the manufacture, usage and disposal of plastic products and through the breakdown of plastic waste in the environment. Because of their low density and slow degradation, MPs are ubiquitous and pervasive contaminants that have been detected in regions far remote from any industrial or human use (Allen et al., 2019; Bergmann et al., 2019; Abbasi et al., 2021).

An understanding of the transport, fluxes and impacts of MPs has relied on monitoring and empirical studies in aquatic and terrestrial environments and in the atmosphere and an understanding of the interplay between these different compartments (Allen et al., 2020; Liu et al., 2020). To this end, surface aquatic systems appear to have received the most attention, and in particular oceans, rivers, lakes, estuaries and the coastal zone (Rezania et al., 2018; Akdogan and Guven, 2019; Fu et al., 2020; Manbohi et al. 2021). One type of aquatic system that has received very little study, however, is coastal and inland hypersaline environments (Pashaei et al., 2021; Quesadas-Rojas et al., 2021).

Hypersaline lagoons and lakes represent a significant volume of inland water and are common in, but not exclusive to, arid and semi-arid climates. Here, evaporation exceeds precipitation and salt concentrations can approach or exceed saturation. In addition to high and variable salinities, environmental stressors can include high levels of UV radiation, high temperatures and low oxygen concentrations. Consequently, hypersaline environments host rather low microscopic and macroscopic biodiversities (Naghoni et al., 2017). Despite these conditions, hypersaline systems support important resources, such as salts for various industrial end-users and brine shrimp (Artemia) cysts for aquaculture (Sorgeloos et al., 2001). Hypersaline environments also serve as natural laboratories for studying the biology and biogeochemistry of evolution and adaptation and for exploring novel approaches to biotechnology and bioremediation (Paul and Mormile, 2017).

Contaminated hypersaline lakes and lagoons also afford an opportunity to study the behaviour of MPs under these unique conditions. For example, it is hypothesized that the high density of hypersaline water allows a greater range of polymers to be suspended and dispersed, while seasonal, evaporative loss of water means that hypersaline environments are predicted to be net accumulators of MPs. In a recent study, Pashaei et al. (2021) determined the concentrations and visible characteristics of MPs in a limited number of samples from Urmia Lake, north-west Iran, and its tributary rivers, with one of the principal objectives centred around the testing of different methods for MP detection. The authors found that the main source of MPs to the lake was from rivers and that the lake itself acted as a sink of MPs through both physical and biological processes. In the present study, and to improve our understanding of the sources, pathways and fates of MPs in hypersaline environments, we conduct a more comprehensive investigation of the quantities and characteristics of MPs in the water and sediment of a contaminated hypersaline lake in south-west Iran (Maharloo Lake). Specifically, MPs sampled from lake water, tributary rivers impacted by urban and industrial wastewaters and lake sediment cores are characterised by size, colour and polymer type according to established techniques, and both riverine and atmospheric fluxes of MPs are calculated from measurements in the tributaries and published depositional data for the region.

2. Methods

2.1. Study site

Maharloo Lake is a shallow, ephemeral saline lake covering an area of about 250 km^2 to the south-east of the city of Shiraz and is one of the most important aquatic ecosystems in Iran (Sigaroodi et al., 2014; Figure 1). The catchment area of the lake is about 4300 km^2 and has an average elevation of about 1500 m. The region encompasses both arid and semi-arid climates and an annual rainfall that ranges from 150 to 650 mm but that mainly falls between November and May (Amiri et al., 2019). The bedrock of the lake is underlain by silty limestone and marl from the Oligo-Miocene age, and the high salinity lake is due to the presence of Late Proterozoil salt domes in the catchment (Forghani et al., 2012). Sediments consist of successive layers of halite, black, organic rich sediment, green-grey sulphates, halite and carbonates, and fine, brown aluminosilicates, with the depths of each layer exhibiting considerable spatial variation throughout the lake (Khosravi et al., 2020).

Maharloo Lake is recharged by direct precipitation on the surface, a series of springs along the northern and western reaches, and two seasonal rivers: the Khoshk from the north-west and the Chenar-Rahdar from the west. The Khoshk passes through the urbanised region of Shiraz and receives direct inputs of treated and untreated sewage and industrial wastewater, while the Chenar-Rahdar drains the industrial zone to the south of the city (established in 1992) and receives considerable quantities of industrial wastes, including those from chemical and textile manufactures (Moore et al., 2019). Over recent years, water supply to the lake has been declining because of consecutive droughts, decreasing vegetative cover in the catchment and exploitation of water resources by agriculture and industry (Daribi et al., 2021), and nowadays wastewater is often the dominant input to the lake (Moore et al., 2019).

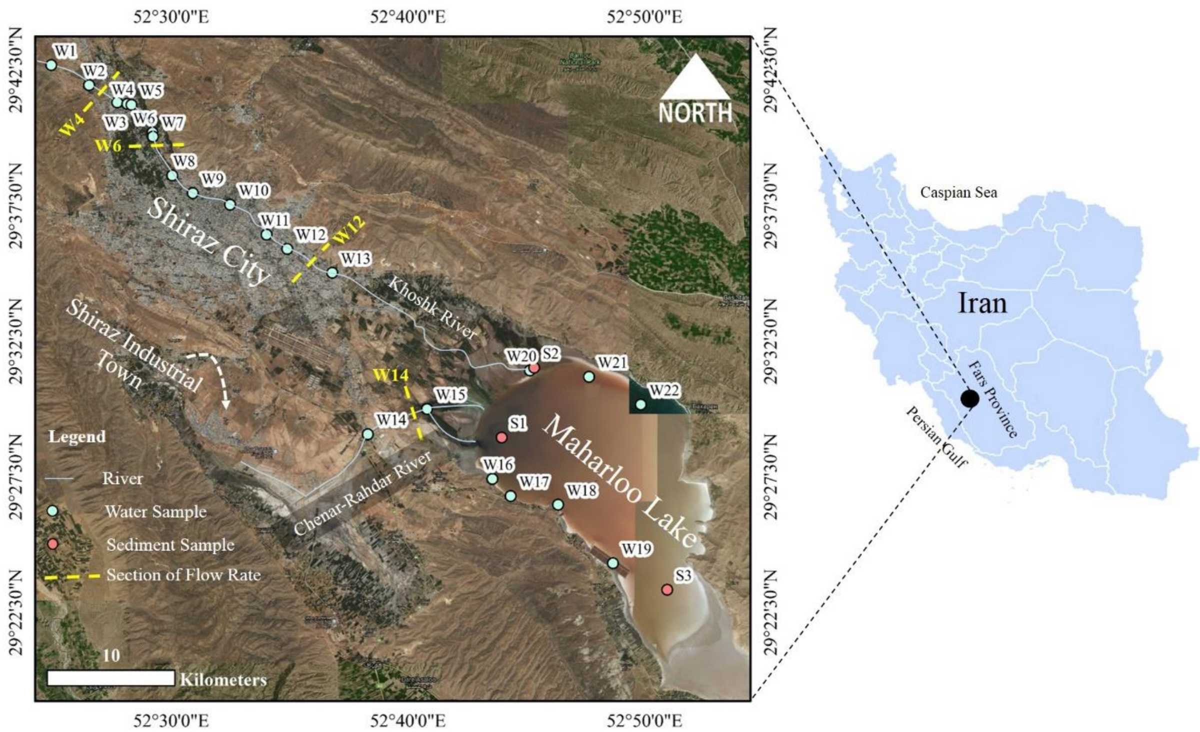


Figure 1: Location of the sampling sites in Maharloo Lake and the Khoshk and Chenar-Rahdar Rivers. W = water, S = sediment; broken yellow lines denote locations where the water flow was measured.

2.2. Water sampling and processing

A total of 22 sites were selected for sampling MPs from water (Figure 1). W1 and W2 were in the Khoshk River above the city of Shiraz and are considered as background sites in the catchment, W3 to W13 were on the same river but within the urban area of the city, and W14 and W15 were on the Chenar-Rahdar River downstream of the industrial centre of Shiraz. W16 to W19 were located along the southern shores of Maharloo Lake and W20 to W22 were sampled from the northern shores. At four sites on the rivers (W4, W6, W12 and W14), current velocity was measured in the central channel using Valeport Model 001 rotating element current meter. Water flow at each site was calculated from the current velocity (in m s^{-1}) and estimated cross sectional area (in m^2).

Prior to sampling, all containers and equipment were washed with filtered tap water (0.45 µm Whatman Nylon membranes) and stored in aluminium foil, and during sampling, cotton clothing and nitrile gloves were worn by operators. The shallow, central channels of the rivers and the lake extending to about 1 km from the shoreline were accessed on foot in January 2021. Conductivity, temperature and pH were measured with a Eutech Instrument PCD 650 probe and floating and suspended MPs were collected from the top 25 cm of water in a 1-litre, wide-necked glass bottle. The contents of the bottle were subsequently passed through a 37 µm Nylon mesh net and the procedure repeated until 20 L had been processed. With the aid of filtered water, material captured by the net was transferred to a clean glass bottle as a suspension. In the laboratory, organic matter was destroyed with a solution of filtered, saturated potassium hydroxide (Luo et al., 2019). Specifically, a volume of KOH solution (KimiaExir) that was ten times the volume of the suspension was added to the bottle, and the contents were covered with aluminium foil and left at room temperature for 24 to 48 h before being filtered through a 1 μm-pore size Johnson cellulose test membrane which was subsequently dried at room temperature in a covered glass Petri dish.

2.3. Sediment sampling and processing

Three sites were selected in Maharloo Lake for sediment core collection. S1 and S2 were located near to the mouths of the Chenar-Rahdar River and the Khoskhk River, respectively, and where riverine influence and sediment deposition are greatest. S3 was situated towards the southernmost extremity of the lake in a region remote from any riverine inputs and where sediment deposition is lowest. At each site, and within an area of about 4 m^2, five cores were taken manually using a custom-made, 5 cm diameter, 50 cm stainless steel corer. On site, cores were dissected using a stainless steel spatula into five depths (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm) and sediment from each depth was combined to provide a series of composites.

In the laboratory, sediment samples (n = 15) were homogenised using a glass spatula, dried at room temperature in a clean room and sieved through a 5-mm stainless steel sieve before MPs were isolated according to Abbasi et al. (2021). Thus, 100 g of each sample were digested with 100 mL of 35% H_2O_2 (Arman Sina) for 7 d in a series of 150 mL glass beakers covered with aluminium foil. The remaining contents were vacuum-filtered through 2 μm S&S filter paper (blue band, grade 589/3), washed with filtered tap water and dried in a sand bath at 60 °C in clean beakers. Seventy mL of $ZnCl_2$ solution (KimiaExir; density ~ 1.6 to 1.8 g cm^{-3}) was added to each sample before the contents were agitated for 5 min at 350 rpm and subsequently allowed to settle for 90 min. The remaining solution was decanted, centrifuged for 3 min at 4000 rpm and vacuum filtered through 2 μm. Density separation, centrifugation and filtration was then repeated twice more. No background contamination was found by replicating the procedure in the absence of sediment.

2.4. Identification and characterisation of microplastics

MPs retained on filters arising from the processing of water and sediment samples were identified, counted and characterised under a binocular microscope (Carl-Zeiss, Köln, Germany) at up to 200-x magnification with the aid of a 250 µm-diameter stainless steel probe and ImageJ software (Abbasi and Turner, 2021). MP identification was based on visible characteristics (shininess, thickness, hardness, surface and cross sectional structures) and reaction to the heated probe according to protocols outlined elsewhere (Abbasi et al., 2019). Classification was based on shape (fibre, film, fragment or spherule), length of the longest axis, L ($L < 100$ µm, $100 \leq L < 250$ µm, $250 \leq L < 500$ µm, $500 \leq L < 1000$ µm, $L \geq 1000$ µm; and with a size detection limit of 30 to 50 µm depending on shape), and colour (black-grey, yellow-orange, white-transparent, red-pink or blue-green).

The polymeric makeup of 48 MPs of a range of shapes, sizes and colours and isolated from water (n = 24) and sediment (n = 24) from different locations was determined using a micro-Raman spectrometer (µ-Raman-532-Ci, Avantes, Apeldoorn, Netherland) with a laser of 785 nm and Raman shift of 400-1800 cm^{-1}.

3. Results

3.1. Water characteristics and river discharge

The physico-chemical characteristics of the water samples are shown in Figure 2 as a function of distance from the entrance of the River Khoshk or River Chenar-Rahdar to Maharloo Lake. Electrical conductivity (EC), as specific conductance, exhibits a clear downstream increase in the rivers from about 1.8 mS cm^{-1} in the upper reaches of the Khoshk River to about 4 mS cm^{-1} near to the mouth of the Chenar-Rahdar River, and is two orders of magnitude greater in the lake (averaging about 480 mS cm^{-1}). Temperature exhibits an increase of about 2°C from the upper Khoshk River to Maharloo Lake while the distribution of pH is more variable and the highest values are in the lower Chenar-Rahdar River.

Also shown in Figure 2 are the four estimates of water flow in the rivers. For the Khoshk River, estimates are 0.5 m^3 s^{-1} in the upper catchment and decline to 0.3 m^3 s^{-1} in the city of Shiraz, while in the Chenar-Rahdar River, the single estimate is 2.5 m^3 s^{-1}. According to the Fars Regional Water Authority data, the monthly average flows for January recorded between 1988 and 2015 in the upper and lower Khoshk River and in the Chenar-Rahdar River are 1.9, 1.4 and 4.3 m^3 s^{-1}, respectively, with minima and maxima of 0.1, < 0.1 and 0.5 m^3 s^{-1} and 4.6, 8.2 and 22.8 m^3 s^{-1}, respectively.

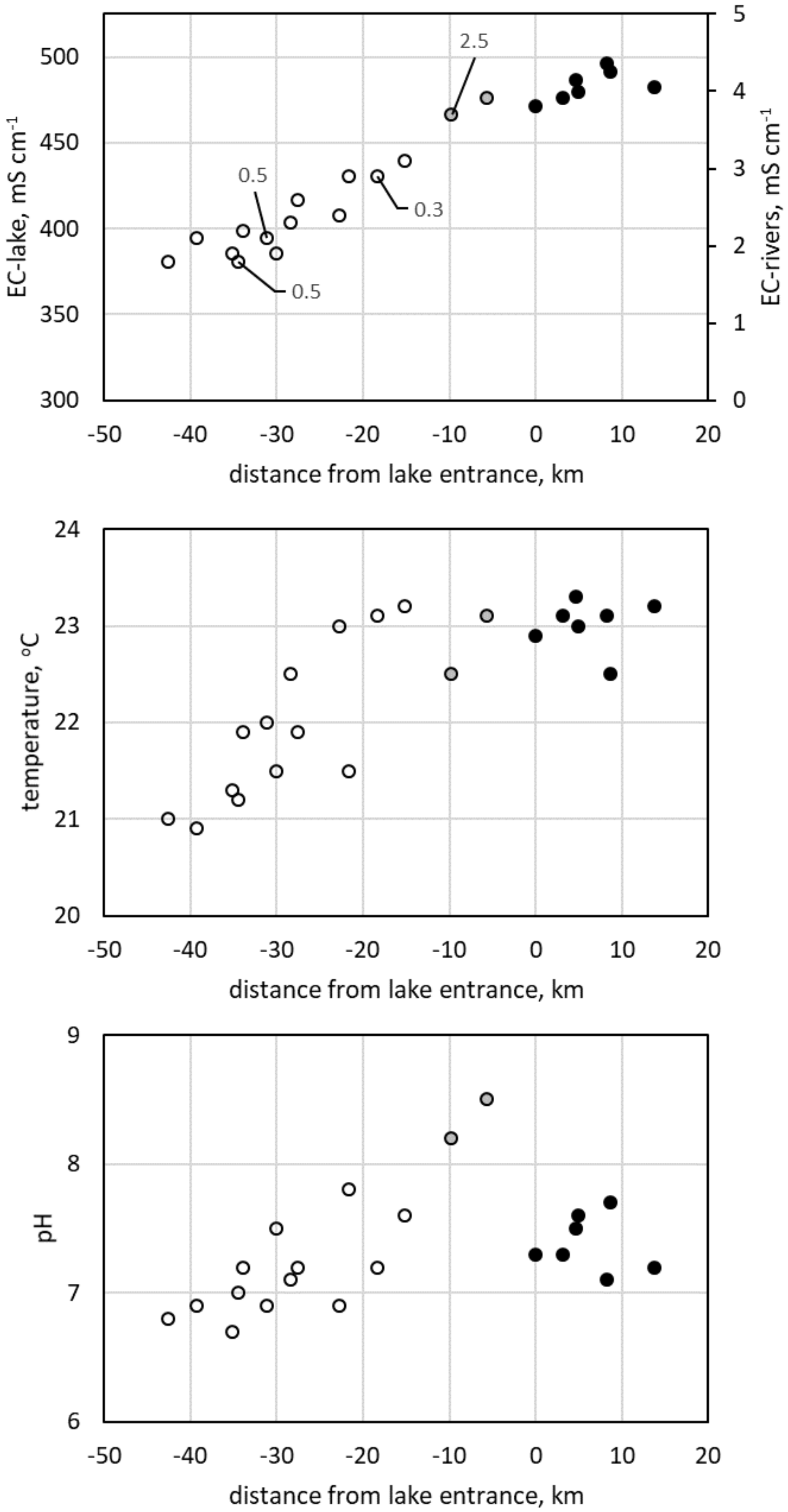


Figure 2: Electrical conductivity (EC), temperature and pH of the water samples from which MPs were isolated. Data are shown as a function of axial distance upstream (negative values: Khoshk River, open circles; river Chenar-Rahdar River, grey circles) and direct distance downstream (positive

values: Maharloo Lake, black circles) from the lake entrance, with the latter defined as the mouth of the corresponding river and where downstream distance in the lake is measured from the nearest river mouth. Note the change of scale for EC from river water to lake water. Annotated on the EC-distance chart are estimates of water flow in $m^3 s^{-1}$.

3.2. Microplastics in water samples

Overall, 298 MPs were isolated from the 22 water samples, and of these 181 (or 60.7%) were fibres that were roughly equally distributed amongst the different colour categories. Spherules totalled 65 (or 21.8%) of MPs, and all but three detected were black-grey in colour. Films and fragments represented 11.4% and 6.0% of MPs and all colour categories were represented by both shape types. The distribution of MP as a function of size, illustrated in Figure 3a, reveals a declining number with increasing length category. However, and as annotated in the figure, the proportion of fibrous MPs increases with increasing length.

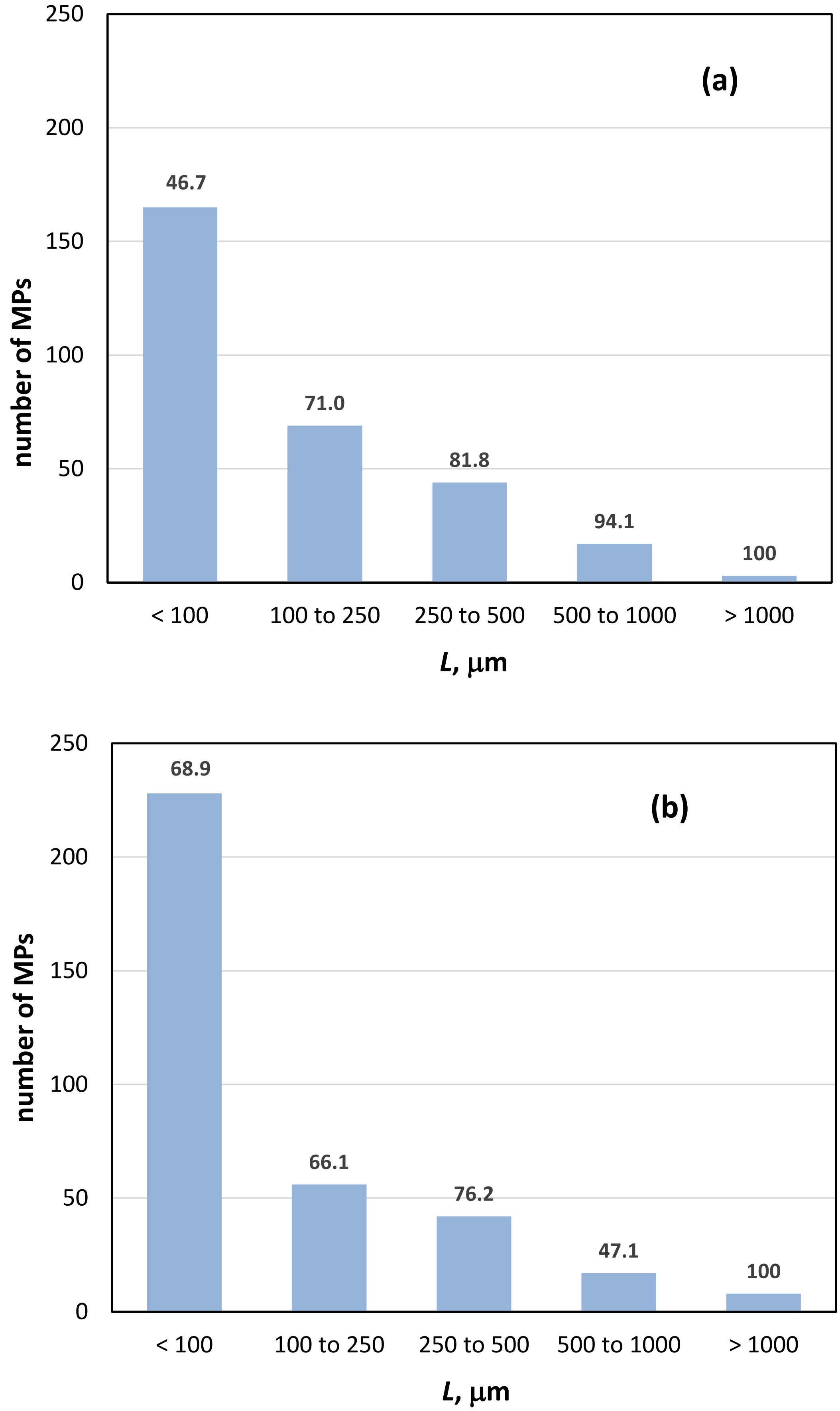

(a)
number of MPs
250
200
150
100
50
0
46.7
71.0
81.8
94.1
100
< 100
100 to 250
250 to 500
500 to 1000
> 1000
L, µm
(b)
number of MPs
250
200
150
100
50
0
68.9
66.1
76.2
47.1
100
< 100
100 to 250
250 to 500
500 to 1000
> 1000
L, µm

Figure 3: Overall size distribution of MPs isolated from (a) water samples in the Khoshk and Chenar-Rahdar Rivers and Maharloo Lake and (b) sediment samples from Maharloo Lake. Numbers annotated are the percentages of fibres in each size category.

Figure 4 shows the distribution of MP concentrations in surface waters of the rivers and lake as a function of distance from Maharloo Lake entrance. In the Khoshk River, concentrations exhibit a progressive increase from 0.05 MP L^{-1} in the reaches above the influence of the city of Shiraz (W1 and W2) to about 1.3 MP L^{-1} at site W12 within the urban district. The concentration thereafter declines as the river leaves Shiraz and nears the lake entrance. The highest MP concentrations were found at the two sites in the Chenar-Rahdar River, and concentrations in the lake were between the lowest and highest riverine concentrations (but always greater than nine river samples) and exhibited a broad reduction with increasing distance from the riverine inputs.

3.3. Microplastics in sediment cores

Regarding the sediment cores, 351 MPs were retrieved and 242 (68.9%) were fibres, of which about 60% were black-grey or white-transparent. Films and fragments of various colours represented 8.5% and 17.7% of MPs but spherules comprised only 4.8%. Consistent with MPs in the water samples, and illustrated in Figure 3b, the size distribution of sediment MPs exhibits a reduction in number (albeit more pronounced) and an overall increase in the proportion of fibres with increasing length. The vertical distributions of MPs in the three sediment cores (with each derived from combining five individual cores) are shown in Figure 5. There is a decline in MP number with increasing sediment depth in all cores, and MPs below 100 μm in length make the largest contribution to the MP pool in each case; note also the absence of MPs in larger size categories in the deepest section of each core.

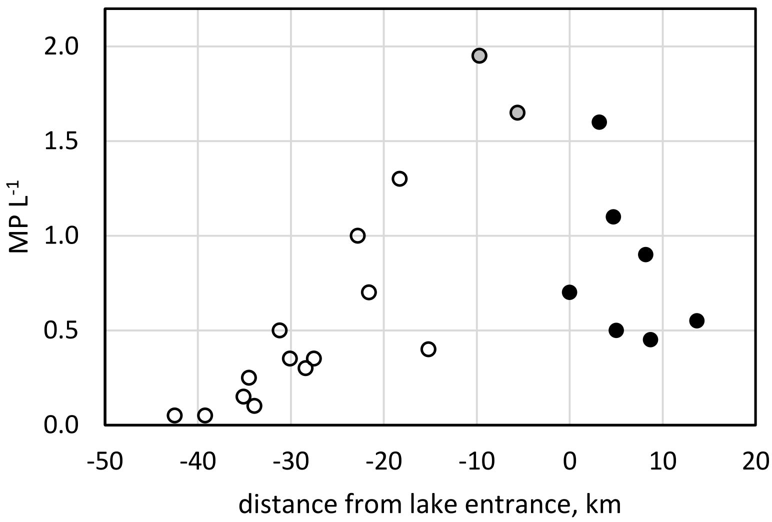


Figure 4: Concentration of MPs per L of water in as a function of axial distance upstream (Khoshk River, open circles; river Chenar-RahdarRiver, grey circles) and direct distance downstream (Maharloo Lake, black circles) from the lake entrance, with the latter defined as the mouth of the corresponding river and where downstream distance in the lake is measured from the nearest river mouth.

3.4. Microplastics by polymer type

The results of the μ-Raman analysis of MPs retrieved from the water samples and sediment cores are presented in Table 1. The same six polymer types (whose densities are also indicated) were detected in both sets of MPs, with polyvinyl chloride (PVC) notably more abundant in the sediment than suspended in the water and nylon most abundant overall. With the exception of polyethylene, all polymer types were detected in both fibrous and non-fibrous MPs.

Table 1: Distribution of MPs retrieved from water and sediment samples (that were analysed by μ-Raman spectroscopy) by polymer type and shown in order of decreasing polymer density.

polymer	density, g cm^{-3}	water		sediment	
		total	fibres	total	fibres
polyvinyl chloride	1.38	1	0	4	3
polyethylene terephthalate	1.38	4	4	6	5
nylon	1.15	8	6	5	4
polystyrene	1.05	4	4	3	2
polyethylene	0.86 to 0.98	5	5	5	5
polypropylene	0.89 to 0.92	2	1	1	1

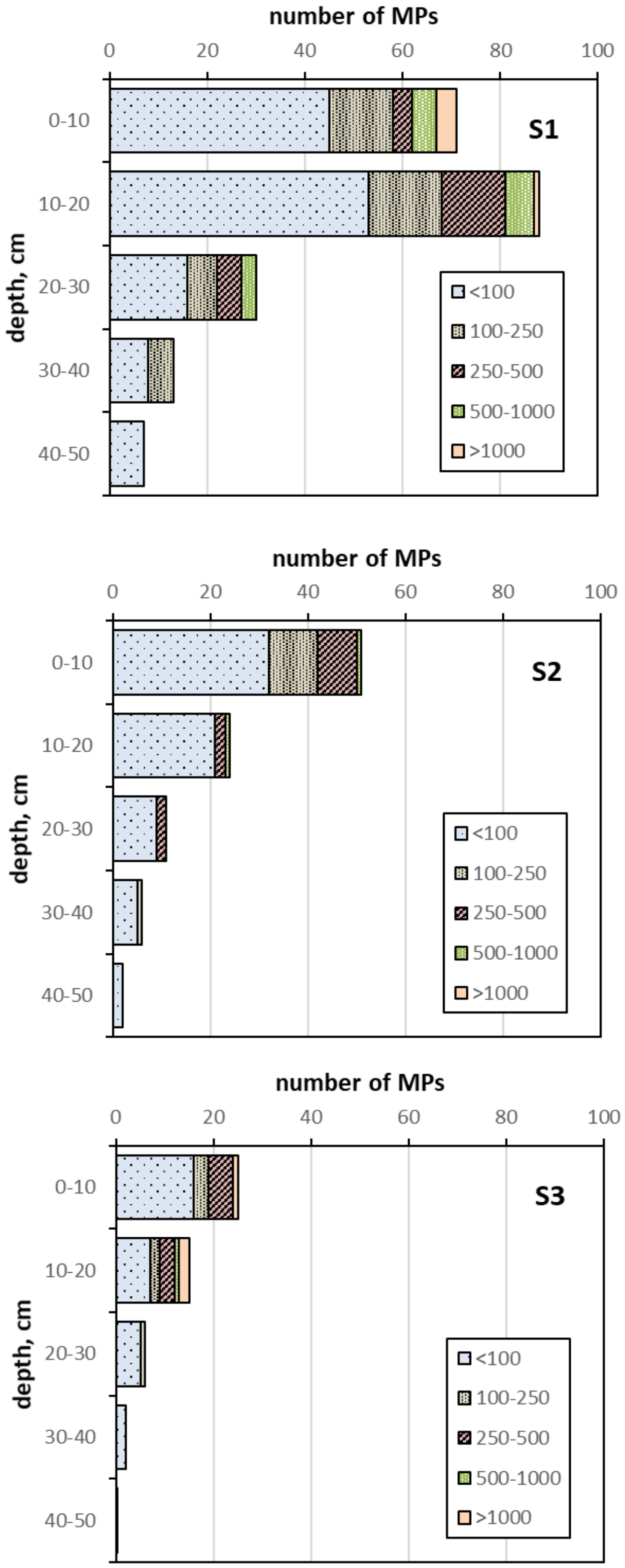


Figure 5: Number and size distribution (in μm) of MPs in combined 100-g sediment samples as a function of core depth.

4. Discussion

The results of the study reveal that industrial and urban inputs dramatically increase the concentrations of MPs in river water. Specifically, a background concentration of 0.05 MP L^{-1} in the headwaters that most likely reflects atmospheric deposition and inputs form agricultural practices in the catchment is augmented up to about 2 MP L^{-1} downstream of anthropogenic inputs by MPs of a greater diversity of shapes and sizes. The concentrations of MPs on a number basis in other rivers reported in the literature are highly variable, being dependent on factors like climate, hydrology, land use, anthropogenic activities, sampling design and means of MP identification (Kapp and Yeatman, 2018; Mani and Burkhardt-Holm, 2020; Zhang et al., 2021). Nevertheless, the highest concentration determined in the present study is close to the maximum concentrations reported for a number of urbanised rivers in China (4 to 7.2 MP L^{-1}; Luo et al., 2019) and an urbanised river in Portugal (1.3 MP L^{-1}; Rodrigues et al., 2018), and to the median concentration reported for various polluted Dutch rivers (0.86 MP L^{-1}; Mintenig et al., 2020). That MP concentrations throughout Maharloo Lake are higher than concentrations in seven river samples impacted by wastewater inputs requires additional, non-riverine sources of MP to the lake and/or mechanisms by which MPs accumulate and evade ready removal from the water column.

The concentrations of MPs and water discharge rates measured towards the mouths of the Khoshk and Chenar-Rahdar Rivers (see Figures 2a and 4) yield respective riverine fluxes into the lake of about 400 and 5000 MP s^{-1}, or about 3 x 10^7 and 4 x 10^8 MP per day. Extrapolating to an annual basis is more uncertain because of significant seasonal variations in river flow and, likely, MP inputs from urban and industrial sources. Nevertheless, using the long-term mean monthly discharges of the Khoshk and Chenar-Rahdar Rivers of 0.84 and 2.1 m^3 s^{-1} and the MP concentrations determined herein results in MP flux estimates of 3.4 x 10^{10} and 1.3 x 10^{11}, respectively, or a total annual riverine input of MPs about 1.6 x 10^{11}.

For comparative purposes, the daily and annual fluxes of MPs to Lake Maharloo from the atmosphere can be estimated from monthly dry and wet depositional data reported for both the city of Shiraz and Mount Derak, a remote area 20 km to the north west of Shiraz, by Abbasi and Turner (2021). Specifically, data for Shiraz are representative of conditions when wind carries air from the city to the south east, while data for Mount Derak are more representative of calmer conditions or when winds are from a more southerly direction. Shiraz data for January indicate a total (dry and wet) deposition of MPs of about 1000 per m^{-2}, resulting in a deposition of about 2.5 x 10^{11} for the average area of Lake Maharloo (250 km^2), and a daily deposition of about 8.3 x 10^9 MP at this time of year. The annual deposition of MPs from the atmosphere at Shiraz is about 24000 per m^{-2}, yielding a total deposition over the average lake area of about 6.0 x 10^{12} per annum. Mount Derak data for January indicate a total deposition of about 230 MP per m^{-2}, yielding monthly and daily deposition rates of about 5.7 x 10^{10} and 1.9 x 10^{9}, respectively, for Lake Maharloo. The annual deposition of MPs over Mount Derak is about 5000 MP m^{-2}, resulting in a total annual deposition of MPs of about 1.3 x 10^{12}. It is likely, therefore, that the atmospheric flux to Lake Maharloo is somewhere between these estimates, but with dominant north-westerly winds suggesting a value closer to that derived from Shiraz data. Nevertheless, both estimates indicate an atmospheric flux that is at least an order of magnitude greater than the riverine flux and which can at least partly explain the apparent enrichment of MPs in the lake waters relative to the inflowing rivers.

The fate of MPs derived from the rivers and atmosphere, or any other sources around the lake itself (e.g. tourism, recreation, agriculture and traffic), will be determined to a large extent by buoyancy. To this end, therefore, the density of Maharloo Lake water itself is a critical factor. The specific conductance of the lake samples averages about 480 mS cm^{-1}, and this is equivalent to a salinity of about 385 parts per thousand. Assuming that halite is the principal salt present in the lake (Khosravi et al., 2020), the water is saturated with a density of about 1.2 g cm^{-3} (Sigma-Aldrich, 2018). Such a high density inhibits the settlement of four out of six polymer types detected, or, according to Table 1, about 80% of the MPs in lake water. This also accounts for the abundance of MPs in the waters of Maharloo Lake, as well as the diversity of polymers observed. By comparison, a recent global review of MPs in lakes undertaken by Dusaucy et al. (2021) revealed that, overall, the dominant polymers were polyethylene and polypropylene, whose presence was attributed to global demand but would also be anticipated based on buoyancy considerations in fresh water.

In an environment as saline as Maharloo Lake, the accumulation of a range of MP types (and densities) in the sediment requires mechanisms other than inherent settlement through the water column. Aggregation with denser particulates or packaging in faecal matter of plastic-ingesting organisms such as the brine shrimp (*Artemia parthenogenetica*) may accelerate the settlement and deposition of some MPs (Hafezieh, 2003; Pashaei et al., 2021). However, the more general deposition is likely to proceed via the nucleation of and the encapsulation with salts that are super-saturated in the lake, and in particular during late summer when insolation is high and rainfall low (Pashaei et al., 2021). Inundation of salt deposits in wetter months may subsequently lead to the partial release of MPs back into the water column, while remaining MPs and salts become trapped in the sediment layer by depositing particulate matter. In addition to these processes, MP accumulation on sediment and salt crystals exposed in the dry months may also take place more directly via atmospheric deposition.

The decrease in MP concentrations in the sediment cores from locations S1 to S3 is likely due to the increasing distance from both the mouths of the tributaries (as a riverine source) and the city of Shiraz (as an atmospheric source), while the decline in MP concentrations with increasing sediment depth in each core reflects temporal changes in the supply of MPs. Estimates based on ^{137}Cs activities in Maharloo Lake sediment suggest average depositional rates of about 1 cm per year (Mesbah and Amidi, 2006) and that our 50 cm cores, therefore, encompass a 50-year period of deposition. Within this timeframe, there has been a general, exponential increase in the production and environmental emission of plastics (Geyer et al., 2017), and since 1992 there has been an increase in MP fluxes to the lake associated with the construction of the industrial centre to the south of Shiraz. Similar distributions of MPs in sediment cores from many temperate and subtropical (but not seasonal) urban lakes and estuaries have been attributed to increasing plastic use and disposal over the past few decades (Willis et al., 2017; Fan et al., 2019; Turner et al., 2019). An additional factor that may accentuate the vertical reduction in MP concentrations in Maharloo Lake sediment cores is a gradual decline in the delivery of water and sediment to the lake that act to dilute MPs in both river water and depositing particulate matter.

More generally, the present study suggests that, through riverine and atmospheric inputs and seasonal, evaporative loss of surface water, hypersaline lakes are likely to act as accumulators of MPs. Moreover, the high density of these lake waters is able to disperse and deposit a wider range of polymer types than freshwater lentic environments. To this end, sediment cores in hypersaline lakes could provide a more representative, historical record of plastic uses and their inputs to the environment and any relationships with shifting climate than those obtained in other settings. The accumulation of a broad range of MPs in hypersaline lakes may also present specific threats to halophilic ecosystems, including those used to understand fundamental biological concepts and improve various biotechnologies, and to economic and non-economic resources (e.g., minerals, biomass and wading birds) (Gündoğdu, 2018; Pashaei et al., 2021).

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References

Abbasi, S., Turner, A., 2021. Dry and wet deposition of microplastics in a semi-arid region (Shiraz, Iran). Science of the Total Environment 786, 147358.

Abbasi, S., Keshavarzi, B., Moore, F., Turner, A., Kelly, F.J., Dominguez, A.O., Jaafarzadeh, N., 2019. Distribution and potential health impacts of microplastics and microrubbers in air and street dusts from Asaluyeh County, Iran. Environmental Pollution 244, 153–164.

Abbasi, S., Turner, A., Hoseini, M., Amiri, H., 2021. Microplastics in the Lut and Kavir Deserts, Iran. Environmental Science and Technology 55, 5993-6000.

Akdogan, Z., Guven, B., Microplastics in the environment: A critical review of current understanding and identification of future research needs. Environmental Pollution 254, 113011.

Allen, S., Allen, D., Phoenix, V.R., Le Roux, G., Jimenez, P.D., Simonneau, A., Binet, S., Galop, D., 2019. Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nature Geoscience 12, 339-344.

Allen, S., Allen, D., Moss, K., Le Roux, G., Phoenix, V.R., Sonke, J.E., 2020. Examination of the ocean as a source for atmospheric microplastics. PLoS ONE 15, e0232746.

Amiri, M., Pourghasemi, H.R., Ghanbarian, G.A., Afzali, S.F., 2019. Assessment of the importance of gully erosion effective factors using Boruta algorithm and its spatial modeling and mapping using three machine learning algorithms. Geoderma 340, 55-69.

Bergmann, M.; Mützel, S.; Primpke, S.; Tekman, M.B.; Trachsel, J.; Gerdts, G. White and wonderful? Microplastics prevail in snow from the Alps to the Arctic. Sci. Adv. 2019, 5, eaax1157.

Darabi, H., Moradi, E., Davudirad, A.A., Ehteram, M., Cerda, A., Haghighi, A.T., 2021. Efficient rainwater harvesting planning using socio-environmental variables and data-driven geospatial techniques. Journal of Cleaner Production 311, 127706.

Dusaucy, J., Gateuille, D., Perrette, Y., Naffrechoux, E., 2021. Microplastic pollution of worldwide lakes. Environmental Pollution 284, 117075.

Fan, Y.J., Zheng, K., Zhu, Z.W., Chen, G.S., Peng, X.Z., 2019. Distribution, sedimentary record, and persistence of microplastics in the Pearl River catchment, China. Environmental Pollution 251, 862-870.

Forghani, G., Moore, F., Lee, S., Qishlaqi, A., 2009. Geochemistry and speciation of metals in sediments of the Maharlu Saline Lake, Shiraz, SW Iran. Environmental Earth Sciences 59, 173-184.

Fu, Z.L., Chen, G.L., Wang, W.J., Wang, J., 2020. Microplastic pollution research methodologies, abundance, characteristics and risk assessments for aquatic biota in China. Environmental Pollution 266, 115098.

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Scientific Advances 3, e1700782.

Gündoğdu, S., 2018. Contamination of table salts from Turkey with microplastics. Food Additives & Contaminants: Part A 35, 1006-1014.

Hafezieh, M., 2003. Some biological aspects and biomass estimation of *Artemia* in Maharloo Lake. Iranian Scientific Fisheries Journal 11, 11-28.

Kapp, K.J., Yeatman, E., 2018. Microplastic hotspots in the Snake and Lower Columbia rivers: A journey from the Greater Yellowstone Ecosystem to the Pacific Ocean. Environmental Pollution 241, 1082-1090.

Khosravi, R., Zarei, M., Sracek, O., 2020. Hydraulic and geochemical interactions between surface water and sediment pore water in seasonal hypersaline Maharlu Lake, Iran. Hydrological Processes 34, 3358-3369.

Liu, K., Wang, X., Song, Z., Wei, N., Haoda, Y., Cong, X., Zhao, L., Li, Y., Qu, L., Zhu, L., Zhang, F., Zong, C., Jiang, C., Li, D., 2020. Global inventory of atmospheric fibrous microplastics input into the ocean: An implication from the indoor origin. Journal of Hazardous Materials 400, 123223.

Luo, W., Su, L., Craig, N.J., Du, F., Wu, C., Shi, H., 2019. Comparison of microplastic pollution in different water bodies from urban creeks to coastal waters. Environmental Pollution 246, 174-182.

Manbohi, A., Mehdinia, A., Rahnama, R., Dehbandi, R., 2021. Microplastic pollution in inshore and offshore surface waters of the southern Caspian Sea. Chemosphere 281, 130896.

Mani, T., Burkhardt-Holm, P., 2020. Seasonal microplastics variation in nival and pluvial stretches of the Rhine River - From the Swiss catchment towards the North Sea. Science of the Total Environment 707, 135579.

Mesbah, S.H., Amidi, J., 2006. Annual sedimentation rate of Maharloo Lake using ^{137}Cs (in Persian). Persian National Conference on Sediment, Iranian Watershed Management Association.

Mintenig, S.M., Kooi, M., Erich, M.W., Primpke, S., Redondo-Hasselerharm, P.E., Dekker, S.C., Koelmans, A.A., van Wezel, A.P., 2020. A systems approach to understand microplastic occurrence and variability in Dutch riverine surface waters. Water Research 176, 115723.

Moore, F., Birami, F.A., Keshavazri, B., Kamali, M., 2019. Potentially toxic elements contamination in sediment, surface and pore water of Maharlu Saline Lake, South – West Iran. Geopersia 9, 111-124.

Naghoni, A., Emtiazi, G., Amoozegar, M.A., Cretoiu, S., Stal, L.J., Etemadifar, Z., Abolhassan, S., Fazeli, S., Bolhuis, H., 2017. Microbial diversity in the hypersaline Lake Meyghan, Iran. Scientific Reports 7, 11522.

Pashaei, R., Loiselle, S.A., Leone, G., Tamasi, G., Dzingelevič, R., Kowalkowski, T., Gholizadeh, M., Consumi, M., Abbasi, S., Sabaliauskaite, V., Buszewski, B., 2021. Determination of nano and microplastic particles in hypersaline lakes by multiple methods. Environmental Monitoring and Assessment 193, 668.

Paul, V.G., Mormile, M.R., 2017. A case for the production of saline and hypersaline environments: A microbiologial perspective. FEMS Microbiology Ecology 93, fix091. doi: 10.1093/femsec/fix091

Quesadas-Rojas, M., Enriquez, C., Valle-Levinson, A., 2021. Natural and anthropogenic effects on microplastic distribution in a hypersaline lagoon. Science of the Total Environment 776, 145803.

Rezania, S., Park, J., Din, M.F.M., Taib, S.M., Talaiekhozani, A., Yadav, K.K., Kamyab, H., 2018. Microplastics pollution in different aquatic environments and biota: A review of recent studies. Marine Pollution Bulletin 133, 191-208.

Rodrigues, M.O., Abrantes, N., Gonçalves, F.J.M., Nogueira, H., Marques, J.C., Gonçalves, A.M.M., 2018. Spatial and temporal distribution of microplastics in water and sediments of a freshwater system (Antuã River, Portugal). Science of the Total Environment 633, 1549-1559.

Sigaroodi, S.K., Chen, Q., Ebrhimi, S., Nazari, A., Choobin, B., 2014. Long-term precipitation forecast for drought relief using atmospheric circulation factors: a study on the Maharloo Basin in Iran. Hydrological Earth Systems Science 18, 1995-2006.

Sigma-Aldrich, 2018. 71376, 71386 Sodium chloride (halite, common salt or table salt, rock salt). https://www.sigmaaldrich.com/deepweb/assets/sigmaaldrich/product/documents/179/430/71386dat.pdf accessed 11/21.

Sorgeloos, P., Dhert, P., Candreva, P., 2001. Use of the brine shrimp, Artemia spp., in marine fish larviculture. Aquaculture 200, 147-159.

Turner, S., Horton, A.A., Rose, N.L., Hall, C., 2019. A temporal sediment record of microplastics in an urban lake, London, UK. Journal of Paleolimnology 61, 449-462.

Xu, Y., Chan, F.K.S., Johnson, M., Stanton, T., He, J., Jia, T., Wang, J., Wang, Z., Yao, Y., Yang, J., Liu, D., Xu, Y., Yu, X., 2021. Microplastic pollution in Chinese urban rivers: The influence of urban factors. Recycling 173, 105686.

Willis, K.A., Eriksen, R., Wilcox, C., Hardesty, B.D., 2017. Microplastic distribution at different sediment depths in an urban estuary. Frontiers in Marine Science 4, 419.

Zhang, Z.Q., Deng, C.N., Dong, L., Liu, L.S., Li, H.S., Wu, J., Ye, C.L., 2021. Microplastic pollution in the Yangtze River Basin: Heterogeneity of abundances and characteristics in different environments. Environmental Pollution 287, 117580.