



Estimation of plastic waste inputs from land into the Caspian Sea: A significant unseen marine pollution

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ABSTRACT

It has been proven that there is an extensive bulk of plastic debris in marine ecosystems. The present study analyzed solid waste generation, its management and final disposal methods in Caspian Sea coastal countries, and the amount of plastic waste entering the Caspian Sea. The results showed that, on average, more than 90% of waste in the Caspian Sea coastal countries is mismanaged. According to our estimates, 425 kilotons (Kt) of plastic waste was generated by Caspian Sea coastal countries in 2016, of which, with high probability, 58–155 Kt find their way to the Caspian Sea. It is estimated that without improved waste management infrastructures, the amount of plastic waste entering the Caspian Sea will increase to 68–182 Kt by 2030, an increase of about 15%. Accordingly, the related cumulative environmental and health problems could be more severe. All countries located in the coastal areas of the Caspian Sea should revise their solid waste and plastic waste management programs to protect that sensitive marine ecosystem.

1. Introduction

Plastics are synthetic or semi-synthetic materials produced from the polymerization process (Elias, 2018; Singh and Sharma, 2016). They are widely used because of features such as diversity, lightness, strength, and inexpensiveness (Geyer et al., 2017; Singh and Sharma, 2016). As a consequence, plastic waste pollution accrues in the environment all around the world (Eerkes-Medrano et al., 2015; van Weert et al., 2019), especially in aquatic environments, and has become a serious environmental issue and a major scientific and social concern in the 21st century (Elias, 2018; Li et al., 2018). It has been reported that the US, Europe, and Asia contribute 40%, 45%, and 15%, respectively, to the generation of plastic waste (Geyer et al., 2017; Jambeck et al., 2015). Global plastic production increased 197 times between 1950 (1.7×10^3 Kt) and 2015 (3.35×10^5 Kt) (Europe, 2015; Geyer et al., 2017). The Ellen MacArthur Foundation (2016) has reported that plastic use has increased twentyfold in the past half-century. The Foundation also predicts that plastics production will double again in the next 20 years and almost quadruple by 2050, resulting in an increase of plastic-associated waste (MacArthur et al., 2016). It is estimated that about 4 to 12 million tons of plastic waste enter marine ecosystems from land annually (Jambeck et al., 2015). It is widely cited that 80% of marine debris originates from land; however, this figure is

not well substantiated and no detailed information on the total amount of plastic waste entering the oceans is available (Jambeck et al., 2015). Plastic debris is introduced to sea and ocean environments through different ways, including direct discharge of plastic into the marine ecosystem as well as through rivers, internal waterways, sewage, wind, and tide (Geyer et al., 2017; Jambeck et al., 2015). There is still no precise method for estimating the amount of plastic waste input to marine ecosystems. Nevertheless, it can be stated that part of the mismanaged plastic waste gradually enters marine ecosystems and is then referred to as marine debris. The amount of plastics entering aquatic environments depends on (i) climatic conditions of the area, (ii) topography and vegetation, (iii) plastic management practices (e.g., recycling and waste-to-energy conversion), (iv) economic status or area income level, and (v) activities such as municipal street sweeping, beach cleaning, and preventing high discharge surface runoff (these activities aim to remove unmanaged plastic waste before it enters a marine ecosystem) (Geyer et al., 2017; Jambeck et al., 2015). The mismanagement of plastic waste can lead to many environmental, health, and economic issues, particularly the pollution of freshwater (Horton et al., 2017; Schwarz et al., 2019; Taylor et al., 2016) and marine ecosystems (Critchell et al., 2019; Wang and Wang, 2018). It has been reported that plastics can enter the aquatic life/human food chain and accumulate in tissues over time (de Sá et al., 2018). Also,

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Fig. 1. Countries studied on the coast of the Caspian Sea.

plastic-induced pollution results in the destruction of habitats, migration of some species to new habitats, extinction of some marine organism species, reduced beauty and attractiveness of coastal areas, and damage to tourism, fishing, and marine food industries (Castañeda et al., 2014; Eriksen et al., 2013; Free et al., 2014; Gregory, 2009; Islam and Tanaka, 2004).

The Caspian Sea is the largest enclosed inland body of water on the earth with an area of almost 436,000 km², a water volume of 78,000 km³ (Miller et al., 2019; Novikov et al., 2013). It is bordered by Iran on the south, Russia on the north, Russia and Azerbaijan on the west, and Turkmenistan and Kazakhstan on the east (Ivanov and Ermoshkin, 2004). Because this lake is enclosed, it is less tolerant and more vulnerable to environmental and man-made pollutants compared to similar environments. Oil and industrial pollutants, extensive oil and gas drilling in the continental shelf, the passage of tankers and ships, and discharge of toxic substances and waste have caused the Caspian Sea to face a serious environmental disaster (Korshenko and Gul, 2005; Kostianoy and Kosarev, 2005). Accordingly, it is likely one of the most polluted seas in the world (Korshenko and Gul, 2005). According to evidence and documented reports, solid waste and plastics are major pollutants entering the Caspian Sea (Ghaffari et al., 2019; Iñiguez et al., 2016). Field observations and documentary reports have shown that plastic waste can easily be seen along most coasts of the Caspian Sea (Ghaffari et al., 2019). According to a report by the World Bank (WB) in 2018 (Kaza et al., 2018) as well as other scientific documents, the generation of plastic waste has been estimated to be about 7150 Kt for Russia (Starostina et al., 2014), 1800 Kt for Iran (Khayambashi, 2016), 950 Kt for Kazakhstan (Inglezakis et al., 2014, 2017), 290 Kt for Azerbaijan (Popov, 2005), and 170 Kt for Turkmenistan annually (Kaza et al., 2018). Nevertheless, the amount of plastic which finally finds its way to the Caspian Sea has not yet been documented; however, it is considered to be a serious environmental issue, especially from the viewpoint of the marine ecosystem protection. The present study, aimed to estimate the amount of plastic waste entering the Caspian Sea from the Caspian littoral states.

2. Methodology

2.1. Study area

The Caspian Sea is surrounded by five countries, Iran, Russia, Azerbaijan, Kazakhstan, and Turkmenistan (Fig. 1), and this area was selected for the current study. According to previous scientific reports, the highest proportion of plastic waste enters the marine ecosystems along a 50-km vertical distance from the coastal line (not the whole of the sea catchment) (Jambeck et al., 2015). In this study, the amount of plastic waste entering the Caspian Sea from those countries was estimated based on the data obtained from the population (provinces, towns, and villages) living within 50 km from the coastal line. The ruler tool of Google Earth software was used to zone the study areas. With this tool, 50-km vertical distances from the Caspian Sea coastal line were separated in several points with a 10-km horizontal distance between two consecutive points. Then the population of those societies located between the 50-km distances was estimated based on online information provided by each country. Table 1 shows the population, economic status, and coastline length of the provinces and towns located within 50 km of the coast.

2.2. Quality and composition of solid waste generated in the Caspian Sea countries

The results of previous studies as well as data reported by the WB

Table 1
Population of coastal countries of the Caspian Sea in 2016.

Country	Iran	Russia	Kazakhstan	Turkmenistan	Azerbaijan
Economic status	UMI ^a	UMI	UMI	UMI	UMI
Coastline length (Km)	820	695	1600	650	600
Total pop [millions]	80.277	143.965	17.988	5.663	9.725
Coastal pop [millions] (in 50 km)	5.950	2.445	0.600	0.400	4.592

^a Upper Middle income.

Table 2

Composition and waste generation rate in the countries of the Caspian Sea in 2016.

Country	Coastal pop [millions]	Waste generation rate [kpd] ^a	Waste generation [Kt/year] ^b	% food waste	% paper and carton waste	% plastic waste	% glass waste	% metals waste	% others	Plastic waste generation [Kt/year]
Iran	5.950	0.603	1310	61.6	10.8	10.2	4.2	3.2	10	133.6
Russia	2.445	1.134	1012	30	23.5	12	11.3	2.6	20.6	121.5
Kazakhstan	0.600	0.780	171	32	16.6	18.5	10.9	2	20.1	31.6
Turkmenistan	0.400	0.274	40	49	7	3	4	3	34	1.2
Azerbaijan	4.592	0.817	1370	39	30	10	5	2	14	137
Average	–	0.764	–	44	21	11	10	3	15	–
Sum	13.99	–	3903	–	–	–	–	–	–	424.9

^a kg/person/day.^b kilo-tons per year.

were used to determine the generation rate and composition of solid waste. Based on these numbers (especially the % of plastic) and the coastal population of each country, the amounts of total waste and whole plastic generated in the coastal areas of the Caspian Sea were determined. It is noteworthy that the rates of composition and waste generated were reported for each country as a whole, and the data was assumed to be applicable to the coastal area of each country.

2.3. Status of waste management and disposal condition in the studied area

A review of pertinent literature and government documents was conducted to investigate the status of solid waste management practices and final disposal conditions in the study area. Available articles and scientific reports, especially the WB report in 2018, were examined comprehensively. According to Kaza et al. (2018), methods of waste disposal and management are classified as open dump, unspecified landfill, controlled landfill, sanitary landfill, recycling, composting, anaerobic digestion, incineration, and unaccounted for (Kaza et al., 2018).

2.4. Estimation of the amount of mismanaged waste plastic

Then the waste management practices of these areas were classified into two categories. One category included controlled landfill, sanitary landfill, recycling, composting, anaerobic digestion, and waste-to-energy, which are considered to be adequate waste management methods (Jambeck et al., 2015; Kaza et al., 2018). The other category comprised non-sanitary landfill, uncontrolled landfill, open dump, and unspecified landfill, which are inadequate waste management methods (Jambeck et al., 2015; Kaza et al., 2018). According to the Jambeck et al. (2015), for each country considered, 2% of the mass of total waste generated as littered waste (Jambeck et al., 2015). Therefore, the amount of mismanaged plastic waste is the sum of inadequately managed plus 2% littered plastic waste (Jambeck et al., 2015).

2.5. Estimation of the amount of plastic waste entering the Caspian Sea

All plastics that are mismanaged can potentially enter the marine ecosystem, and there is still no precise method to estimate the amount of plastic waste input into marine ecosystems. Jambeck et al. (2015) used three assumed conversion rates (15%, 25%, and 40%) to estimate the amount of plastic waste input into seas and oceans (Jambeck et al., 2015). Accordingly, the aforementioned assumptions were employed to estimate the amount of plastic waste entering the Caspian Sea.

2.6. Prediction of plastic waste input to the Caspian Sea for 2030

Considering population growth, gross domestic product (GDP), urbanization and economic development, degree of industrialization, inflation index, and the current waste generation rate, the World Bank forecasted solid waste generation for 2030 (Ebrahimi et al., 2016;

Hoornweg and Bhada-Tata, 2012). Due to the complexity of the subject and lack of precise data, the exact prediction of future infrastructure development, consumption patterns, advancement toward solid waste management, and composition of solid waste in the future (share of plastic in the waste stream) as well as the percentage of mismanaged plastic in 2030 is almost not feasible (Jambeck et al., 2015). Therefore, for each of the Caspian Sea littoral states, the current plastic share and percentage of mismanagement were assumed for 2030 in estimation and calculations, similar to the data achieved in 2016.

3. Results and discussion

3.1. Composition and generation of solid waste by the Caspian Sea countries in 2016

Table 2 shows the waste generation rate and composition by the Caspian Sea countries in 2016. Based on the results presented in that table, the population of the Caspian Sea littoral states in 2016 was about 14 million people, and the total amount of solid waste generated in the coastal areas of the Caspian Sea was estimated to be about 3903 Kt. As can be seen, the highest and lowest rates of waste generation in the coastal areas of these countries were attributed to Russia (1.134 kpd¹) and Turkmenistan (0.274 kpd), respectively. The mean waste generation rate in the Caspian littoral states was determined to be about 0.764 kpd. By considering the waste generation rate and the population of the coastal regions of the Caspian Sea countries, it can be inferred that the highest and lowest amounts of total waste generation belong to Azerbaijan (1370 Kt year⁻¹) and Turkmenistan (40 Kt year⁻¹), respectively. Consumption patterns, lifestyle, socioeconomic factors, social habits, awareness, and attitudes affect the quality and quantity of waste generated (Abduli et al., 2015; Damghani et al., 2008; Dangi et al., 2011; Inglezakis et al., 2014; Karak et al., 2013). The percentage of plastic waste in the composition of solid waste in Iran, Russia, Kazakhstan, Turkmenistan, and Azerbaijan was 10.2%, 12%, 18.5%, 3%, and 10% respectively (averaging 11%). In addition, total plastic waste generated in the coastal areas of this sea was estimated to be about 425 Kt. According to Table 2, in 2016, Azerbaijan with 137 Kt and Iran with 133.6 Kt were the highest producers of plastic waste, while Turkmenistan with 1.2 Kt produced the least amount. About 92% percent of the population in the Caspian Sea coastal areas resides in Iran, Russia, and Azerbaijan. Similarly, more than 92% of the waste plastic is generated by these three countries.

According to previous studies, waste generation (especially plastic waste) has been increasing in the Caspian Sea littoral states in recent years (Ghaffari et al., 2019). Moreover, there is an increasing trend in plastic waste generation around the world (with a market-driven by consumerism), especially in coastal areas (Han et al., 2019). In general, plastic consumption is inevitable; however, it can be partly prevented by adjusting consumption patterns and developing educational

¹ kg/person/day.

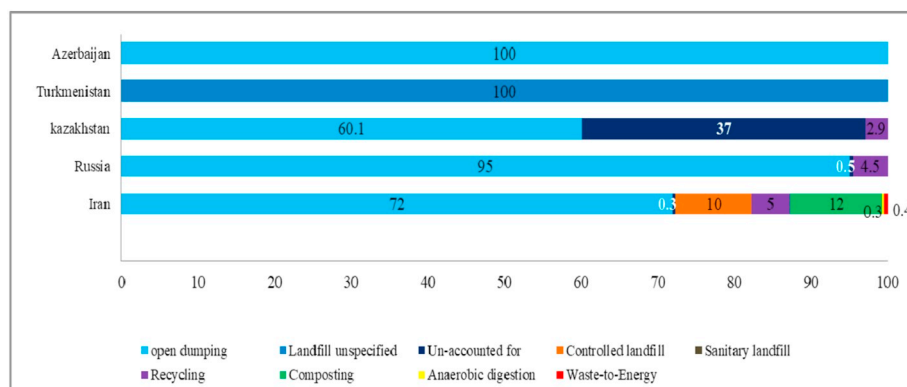


Fig. 2. Management status and final disposal of solid wastes in the countries of the Caspian Sea.

programs.

Currently, the global trend in plastic use is of great concern (Europe, 2015; Jambeck et al., 2015). Therefore, more attention should be paid to controlling plastic waste generation and encouraging people in the Caspian Sea littoral states to participate further in the reduction of plastic generation.

3.2. Status of waste management and final disposal

Fig. 2 presents the results of documentary reports on the status of solid waste management and final disposal in the Caspian Sea littoral states (Kaza et al., 2018). As can be seen, the status of solid waste management in these countries is not satisfactory. In Azerbaijan and Turkmenistan where 100% of the waste disposal is open dumping, the status of waste management is inappropriate. Waste management conditions in Kazakhstan, Russia, and Iran are also unfavorable, where 97.1%, 95.5%, and 72.3% of management practices, respectively, are not in accordance with promulgated standards (Kaza et al., 2018). On average, more than 90% of waste in the Caspian Sea countries is managed inadequately and incorrectly (Kaza et al., 2018). The main reasons for inappropriate waste management in these countries may be the lack of enforcement of regulations, weak technical and financial resources, poor infrastructure, insufficient policies and deficiency of political priorities, poor coordination between authorities, lack of education and awareness among stakeholders within the waste sector, and the lack of support for waste reduction (lack of avoidance/waste minimization) and recycling and/or reuse programs at local and national governments. In addition, the lack of qualified recycling industries, low priority of waste management, and ineffective waste collection systems have been reported in other studies as major causes of inappropriate management (Inglezakis et al., 2014, 2017; Popov, 2005).

3.3. Estimation of the amount of waste plastic entering the Caspian Sea

Considering the amount of plastic waste generated in the coastal regions of the Caspian Sea littoral states (Table 3) and the percentage of mismanagement in these countries, the mass of mismanaged plastic waste and the per capita of mismanaged plastic waste were determined. Finally, the amount of plastic waste entering the Caspian Sea in 2016 was calculated and is presented in Table 3. As indicated in the table, the mass and corresponding per capita of mismanaged plastic waste in the coastal areas of the Caspian Sea ranged from 1.2 to 137 Kt year⁻¹ and 8 to 143 gpd,² respectively. It should be noted that Kazakhstan with 143 gpd showed the highest and Turkmenistan with 8 gpd revealed the lowest per capita mismanaged plastic waste. On average, the amount of

mismanaged per capita plastic waste in the five Caspian Sea littoral states was 76 gpd. Accordingly, the total amount of mismanaged plastic waste in the coastal areas of these countries was about 387 Kt year⁻¹.

Based on three assumed conversion rates (15%, 25%, and 40%), the total input of plastic waste into the Caspian Sea in 2016 is estimated to have been between 58 and 155 Kt. Among the five countries, Azerbaijan with 35.4% (21–55 Kt year⁻¹) and Turkmenistan with less than 1% (0.18–0.48 Kt year⁻¹) showed the highest and lowest shares of plastic input into the Caspian Sea, respectively. The large variation in the amount of mismanaged waste and, consequently, plastic waste entering the Caspian Sea across the studied countries can be attributed mainly to different population numbers living in the coastal areas in each country and to the various waste generation rates among them. It should be noted that the water in the Caspian Sea flows from northwest to southeast (Iranian coasts) (Sharbaty, 2012). Moreover, the water depth along the Iranian coast results in slow water flow and, probably, the greater accumulation of various pollutants along the Iranian coast than along the coastlines of other countries. Nonetheless, all of the Caspian Sea littoral states should pay more attention to pollution control.

Table 4 shows the results of a comparison of the current findings with those reported by other studies. As indicated in the table, the rate of waste generation and share of plastic in the waste stream differ in various areas of the world. Consequently, the plastic waste generated and the amount of plastic marine debris also differ. It can be inferred that the average waste generation rate as well as plastic waste generation is directly affected by level of income (Zia et al., 2017). In Kenya (low-income level) and the US (high-income level), for example, the waste generation rates are equal to 0.3 and 2.58 kpd, respectively, representing the lowest and highest amounts, respectively, among those countries listed in Table 4.

The current findings revealed that the amount of plastic marine debris from coastal areas of the Caspian Sea ranges from 1.2 to 57.2 gpd. In other areas of the world, the amount of plastic marine debris has been reported to range from 0.3 to 53.6 gpd, which is in good agreement with the present study. The variation in plastic marine debris in different areas of the world can be attributed to consumption patterns, socioeconomic factors, social habits and, consequently, the waste generation rate and share of plastics in the waste stream, and finally, waste management practices (Damghani et al., 2008; Dangi et al., 2011; Karak et al., 2013). Among these, the role of waste management practices is clearly more important than the others. As indicated in Table 4, the waste generation rate in high-income countries is higher than in those countries with low- and middle-income levels; however, the amount of plastic marine debris is much less in the former than the latter. In Somali (low income), Iraq (lower middle income), Caspian Sea coastal countries (upper middle income), and the US (high income), the amount of plastic marine debris is reported to be between 7.1–18.8 gpd, 10.1–26.8 gpd, 1.2–57.2 gpd, and 1.1–2.8 gpd, respectively.

² g/person/day.

Table 3
Amount of mismanaged plastic waste and plastic waste entering the Caspian Sea in 2016.

Country	Plastic waste generation [Kt/year] ^a	% inadequately managed waste	% littered waste	% mismanaged	Inadequately managed plastic waste [Kt/year]	Plastic waste littered [Kt/year]	Mismanaged plastic waste [Kt/year]	Mismanaged plastic waste [gpd] ^b	Plastic waste entering the Caspian Sea [Kt/year]			Share of plastic waste entering the Caspian Sea
									%15	%25	%40	
Iran	133.6	% 72.3	% 2	74.3	96.6	2.67	99.27	46	14.9	24.8	39.7	% 25.6
Russia	121.5	% 95.5	% 2	97.5	116	2.43	118.43	133	17.8	29.6	47.4	% 30.6
Kazakhstan	31.6	% 97.1	% 2	99.1	30.68	0.63	31.31	143	4.7	7.8	12.5	% 8.1
Turkmenistan	1.2	% 100	% 0	100	1.2	0	1.2	8	0.18	0.3	0.48	% 0.3
Azerbaijan	137	% 100	% 0	100	137	0	137	82	20.5	34.3	54.8	% 35.4
Sum	424.9	-	-	-	381.48	5.73	387.2	-	58.1	96.8	154.9	%100

^a Kilo-tons per year.

^b g/person/day.

Nevertheless, it is noteworthy that plastic marine debris is considered a major environmental challenge all around the world (Thompson et al., 2011).

3.4. Prediction of plastic waste inflow to the Caspian Sea in 2030

Table 5 shows total solid waste and plastic waste generation, mismanaged plastic waste, and plastic waste entering the Caspian Sea in 2030. As indicated in the table, plastic waste inflow to the Caspian Sea will follow an increasing trend from 2016 to 2030. It is estimated that in 2030, the amount of plastic waste from Iran, Russia, Kazakhstan, Turkmenistan, and Azerbaijan into the Caspian Sea will increase by 17%, 11%, 26%, 37%, and 13%, respectively. The total input of plastic waste into the Caspian Sea is likely to reach 68 to 182 Kt in 2030. Population growth, change in GDP, and increasing waste generation rate could be the main reasons for this variation. As mentioned previously, due to some difficulties and uncertainties, the amount of plastic in the waste stream and the percentage of mismanaged plastic waste for 2030 were assumed to be constant in each of the Caspian Sea littoral states. Complications in the prediction of future infrastructure development, the prediction and contribution of behavioral change, and future advancements in waste management practices are among those limitations of this part of the study.

It is estimated that between 4 and 12 million tons (Jambeck et al., 2015) of generated plastic waste enters marine ecosystems from land annually. The current findings indicated that the inflow of plastic waste from the Caspian Sea littoral states into the sea was about 58 to 155 Kt in 2016. The massive production and consumption of plastics began decades ago; therefore, the total cumulative mass of plastic debris in the Caspian Sea has probably reached several millions of tons by now. It is estimated that the inflow of plastic waste will probably reach 68 to 182 Kt in 2030. Thus, it can be stated that the inflow of plastic waste into the Caspian Sea may increase by 15% by 2030, and the related aggregated environmental and health difficulties could grow more acute over the decades. One of the main aims of the Sustainable Development Goal (SDG) 14 is to achieve the sustainable management and protection from pollution of marine and coastal ecosystems (Bowen et al., 2017; Van Assche et al., 2013).

Given the sensitive ecosystem of the Caspian Sea (as an enclosed lake between dry areas), its suitability for growing the world's most valuable sturgeon, and its lower salinity compared with other seas and oceans, there is an urgent need for regional and transregional interaction in order to reduce its pollution (Pettipas et al., 2016; Xanthos and Walker, 2017). The Caspian Sea littoral states should have accurate and regular plans for the management of plastic waste, including source reduction, enforcement of incentives (e.g., reduction of governmental tax on the manufacture of permanent bags, biodegradable polymers, cellulose disposable tableware, and so on), governmental support for investment in degradable plastic manufacturing, prohibition of the use of single-use plastics, replacing plastics with glass, aluminum, and natural fibers, Extended Producer Responsibility (EPR³), plastic recycling, and management to reduce the inflow of plastic waste into the sensitive ecosystem of the Caspian Sea (Critchell et al., 2019; Pettipas et al., 2016; Xanthos and Walker, 2017). If the Caspian Sea countries are able to change their policies and strategies and improve the condition of their waste management, they can reduce the volume of plastics entering the marine ecosystem. As presented in Table 6, if the Caspian Sea coastal countries improve their mismanaged plastic waste by about 40% by 2030, consequently, the plastic waste inflow into the sea will be reduced to 23–62 Kt year⁻¹.

³ EPR is a waste management strategy of brand owners and manufacturers taking environmental responsibility for their products and the associated packaging when they become waste.

Table 4

Comparison of the amount of plastic waste entering the Caspian Sea by coastal countries with other areas of the world.

Reference	Country	Economic status	Coastal pop [millions]	Waste generation rate [kpd] ^a	% plastic in waste stream	Plastic waste generation [Kt/year] ^b	% mismanaged waste ^c	Mismanaged plastic waste [Kt/year]	Mismanaged plastic waste-generation rate [gpd] ^d	Plastic marine debris [gpd]		
										15%	25%	40%
This study	Iran	UMI ^e	5.950	0.603	10.2	133.6	74.3	99.27	46	6.9	11.5	18.4
	Russia	UMI	2.445	1.134	12	121.5	97.5	118.43	133	20.0	33.3	53.2
	Kazakhstan	UMI	0.600	0.780	18.5	31.6	99.1	31.31	143	21.5	35.8	57.2
	Turkmenistan	UMI	0.400	0.274	3	1.2	100	1.2	8	1.2	2	3.2
	Azerbaijan	UMI	4.592	0.817	10	137	100	137	82	12.3	20.5	32.8
	Bangladesh	LI ^f	70.88	0.43	8	884.3	89	787.33	30	4.5	7.5	12
	Somalia	LI	5.97	0.6	9	117.0	87	101.53	47	7.1	11.8	18.8
	Kenya	LI	2.73	0.3	9	26.8	85	22.66	23	3.5	5.8	9.2
	India	LMI ^g	187.5	0.34	3	686.4	87	599.82	9	1.4	2.3	3.6
	Iraq	LMI	0.640	0.79	13	23.9	65	15.56	67	10.1	16.8	26.8
Jambeck et al. (2015)	Pakistan	LMI	14.58	0.79	13	544.5	88	480.49	90	13.5	22.5	36
	Vietnam	LMI	55.86	0.79	13	2085.8	88	1834	90	13.5	22.5	36
	Bosnia and Herzegovina	UMI	0.586	1.2	12	30.6	42	12.96	61	9.2	15.3	24.4
	Brazil	UMI	74.7	1.03	16	4479.1	11	471.4	17	2.6	4.3	6.8
	Bulgaria	UMI	1	1.28	12	56.0	33	18.74	51	7.7	12.8	20.4
	China	UMI	262.9	1.1	11	11,557.9	76	8820	92	13.8	23	36.8
	Malaysia	UMI	22.9	1.52	13	1644.6	57	936.8	112	16.8	28	44.8
	Palau	UMI	0.0235	1.2	12	1.2	58	716	84	12.6	21	33.6
	South Africa	UMI	12.9	2	12	1125.3	56	630	134	20.1	33.5	53.6
	Thailand	UMI	26.05	1.2	12	1363.1	75	1028	108	16.2	27	43.2
	Turkey	UMI	34.05	1.77	12	2628.2	18	486	39	5.9	9.8	15.6
	Australia	HIC ^h	17.24	2.23	5	694.4	2	13.9	2	0.3	0.5	0.8
	Belgium	HIC	4.75	1.33	6	137.1	2	2.74	2	0.3	0.5	0.8
	Japan	HIC	115.23	1.71	10	7156.1	2	143.12	3	0.5	0.8	1.2
	Saudi Arabia	HIC	3.6	1.3	12	203.8	10	20.6	16	2.4	4	6.4
	United Arab Emirates	HIC	2.02	1.66	12	146.1	2	3.02	4	0.6	1	1.6
	United States	HIC	112.93	2.58	13	13,771.2	2	275.4	7	1.1	1.8	2.8

^a Kg/person/day.^b kilo-tons per year.^c Mismanaged waste is the sum of inadequately managed waste plus 2% littering.^d g/person/day.^e Upper Middle income.^f Low income.^g Lower Middle income.^h High income.**Table 5**

Prediction of waste generation, plastic waste generation, plastic waste mismanaged and waste plastic entering the Caspian Sea in 2030.

Country	Coastal pop [millions]	Waste generation rate [kpd]	% plastics waste	Plastic waste generation [Kt/year]	% mismanaged	Mismanaged plastic waste [Kt/year]	Mismanaged plastic waste [gpd]	Plastic waste entering the Caspian Sea [Kt/year]		
								15%	25%	40%
Iran	6.586	0.657	10.2	161.1	74.3	119.7	50	18	29.9	47.9
Russia	2.387	1.31	12	136.9	97.5	133.5	153	20	33.4	53.4
Kazakhstan	0.677	0.925	18.5	42.3	99.1	41.9	170	6.3	10.5	16.8
Turkmenistan	0.478	0.358	3	1.9	100	1.9	11	0.29	0.48	0.76
Azerbaijan	5.043	0.854	10	157.2	100	157.2	85	23.6	39.3	62.9
Sum	15.171	–	–	499.4	–	454.2	–	68.2	113.6	181.8

4. Conclusions

The results of the current study showed that the amount of plastic waste generated by the Caspian Sea littoral states in 2016 was about 425 Kt. It is estimated that 58–155 Kt of plastic waste, referred to as plastic debris, entered the Caspian Sea in that year. Assuming that plastic waste management will not improve, the research team predicts that the inflow of plastic waste into the Caspian Sea will reach 68–182 Kt by 2030, which is equivalent to a 15% increase over 2016. Because of the entry of plastic waste into the Caspian Sea over the past decades, the health and environmental sensitivity of the Caspian Sea, and Sustainable Development Goal 14, the Caspian Sea littoral states should

pay more attention to pollution control by implementing effective strategies and applying integrated management of plastic waste.

CRediT authorship contribution statement

Medhi Ghayebzadeh: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Hassan Aslani:** Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing. **Hassan Taghipour:** Conceptualization, Writing - original draft, Writing - review & editing. **Saeid Mousavi:** Conceptualization, Formal analysis.

Table 6

Presumptive improvement of mismanaged waste in Caspian Sea Coastal Countries and consequent reduction in waste plastic inflow into the sea.

Caspian Sea Coastal Countries	Presumptive improvement of mismanaged waste	15% marine debris [Kt/year]	25% marine debris [Kt/year]	40% marine debris [Kt/year]
Iran	40%	8.94	14.88	23.82
Russia		10.68	17.76	28.44
Kazakhstan		2.82	4.68	7.5
Turkmenistan		0.11	0.18	0.29
Azerbaijan		12.3	20.58	32.88
Sum		34.85	58.08	92.93

Declaration of competing interest

No conflict of interest exists.

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