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A toxic-free environment ambition in the light of the Polish Baltic Sea coastal zone pollution by heavy metals

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ABSTRACT

The European Green Deal highlights the need for anthropogenic pressure reduction according to the toxic-free environment ambition. Heavy metals are the largest threat to the food sector sustainability while they are easily bioaccumulated by living organisms, especially aquatic species. Cadmium (Cd) and mercury (Hg) introduced to the food chain were proven to have a toxic impact on human health causing serious diseases such as Parkinson's disease, kidney and heart failure, osteoporosis, etc. Lead(Pb) can be accumulated by humans from contaminated plants and water resulting in mental retardation and birth defects. The study analyzes the sources of the above heavy metals pollution in the Polish coastal zone of the Baltic Sea which is the main fishing area for the fishing industry in Poland. Available data on the atmospheric deposition and riverine loads of Cd, Pb, Hg were analyzed to present the current trends of heavy metals contamination in 3 basins located in the Polish coastal zone: Bornholm Basin (BB), Eastern Gotland Basin (EGB) and Gdańsk Basin (GB). The results show that in the BB and EGB the limits for all 3 heavy metals were exceeded even by 139.58% in terms of Cd in 2018 in both basins. Pb limit was exceeded in 2018 by 84.62% in BB and by 123.08% in 2017 in EGB. On the contrary, values below the limit for Cd and Hg were observed in GB during the entire monitoring period, while the limit for Pb was only temporarily exceeded.

Keywords: Heavy metals; Cadmium; Lead; Mercury; Toxic-free environment; European Green Deal; Baltic Sea; Coastal waters; Marine pollution

1. Introduction

Creating a toxic-free environment is one of the main objectives of the newest strategy for economic growth in the European Union (EU) which is the European Green Deal (EGD) [1]. The reduction of anthropogenic pressure according to the zero pollution ambition requires more initiatives to prevent pollution and new measures to remedy it [2]. The European Commission (EC) indicates that there is a strong need for better monitoring, reporting, prevention and removal of pollution from physical constituents of the environment, including air, water and soil. Special attention has been given to the water environment which restoration of its natural functions is strongly recommended, both for surface and underground waters. The key initiatives should aim to preserve and restore biodiversity which is threatened by pollution from urban runoff and other sources such as microplastics and chemicals [3]. Moreover, the problem of aquatic environment pollution also results from large industrial plants activity, which will be regulated by the EU Industrial Strategy in the coming years [4].

One of the greatest pollutants in the aquatic environment are heavy metals, defined as any metallic chemical elements that have a relatively high density and are toxic or poisonous at low concentrations. Among heavy metals

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cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni), chromium (Cr), copper (Cu), zinc (Zn) and arsenic (As) have the largest impact on the water environment quality [5]. Heavy metals are naturally occurring substances in the environment that have been used by humans for centuries. However, they are the largest threat to the sustainability of the food sector through the ease of bioaccumulation by living organisms, especially aquatic species [2]. The level of toxicity of some selected metals for human health follows the sequence Co < Al < Cr < Pb < Ni < Zn < Cu < Cd < Hg [6]. Among heavy metals often present in the water ecosystems Cd, Pb and Hg are considered the most toxic elements for living organisms without a beneficial biological function [7]. Furthermore, Cd and Hg biomagnify, implying that the toxic effect may be enhanced at higher levels in the food chain. Organic Hg form – methyl-mercury (MeHg) is more toxic than elemental mercury and is readily bioaccumulated [8]. The MeHg content in industrial wastewater was the reason for the Minamata disease which occurred in Japan in the 1950s due to the toxic MeHg accumulation in the local seafood [9]. It caused general muscle weakness, loss of peripheral vision and hearing and speech impairment [10]. Cd toxicity for children damages their respiratory, renal, skeletal and cardiovascular systems and increases the risk of cancers [11,12]. Exceedance in the Cd limit values were reported in canned fish in Iran which was a result of a highly contaminated wastewater discharge into the water ecosystem [13]. Pb accumulates in the human and animal tissues including aquatic species. Its toxic effect causes serious anemia, kidney failure, brain damage and intellectual disability [14]. Pb poisoning was observed in the Upper Silesia Region in Poland during the 1960–1970s among children living near the metal smelters, which were responsible for significant emissions to the atmosphere [15].

The sources of heavy metals in the water ecosystem can originate from natural sources (volcanic eruptions, fires, rock weathering), riverine sources (wastewater discharge, corrosion, agriculture and forestry) or atmospheric sources (atmospheric deposition due to emissions from metallurgical industries, waste disposal, fossil fuel combustion, mining and smelting) [16].

Limiting heavy metals emission to the aquatic environment (lakes, rivers, wetlands and estuaries) is the main challenge in achieving the zero pollution ambition set out in the EGD [17]. This is important not only due to the water reservoirs pollution but also because of aquatic organisms, which accumulate pollutants in their cells and thus can enter the food chain of people and endanger their health or life. To prevent this, the EC has published in 2020 the “Farm to Fork” Strategy [18] which aims to achieve a fair, healthy and environmentally-friendly food system. One of the recommended actions to achieve climate neutrality (the main goal of the EGD) is to increase the amount of farmed fish and seafood for consumption purposes while its production has a lower carbon footprint than animal husbandry on land. This is another incentive to take actions for a clean water environment, free of pollutants, especially from anthropogenic sources.

One of the most polluted water reservoirs in Europe for which zero pollution ambition has particular importance is the Baltic Sea. A high concentration of heavy metals in such marine environment is mainly caused by pollution loads originating from land-based sources [19]. The state of the Baltic Sea waters in terms of heavy metals content and other threats (such as biogenic substances) is systematically monitored and reported by the Helsinki Commission (HELCOM) [20,21]. A study carried by HELCOM from 2006 showed that about 87% of Cd, 54% of Pb, and 76% of Hg entered the Baltic Sea via rivers or as direct waterborne discharges, while the rest originated from atmospheric deposition [22]. The entry of heavy metals into the food chain of Europeans can have significant consequences for the quality of food, health and life of people. According to the latest reports, the sources of anthropogenic origin from Poland have the largest impact on the Baltic Sea pollution [23]. Therefore, in this region, the greatest action should be taken to implement the EGD objectives.

This paper aims to analyze the possibility of achieving the toxic-free environment ambition in the Polish Baltic Sea coastal zone polluted by heavy metals. The specific objectives include the detailed analysis of heavy metals sources occurring in this zone (including atmospheric deposition and riverine sources), comparison of the content of heavy metals in the sea to the limits indicated in legal regulations and discussion on the possible further actions to reduce the pollution discharge from the Polish Baltic Sea coastal zone in the context of the strategies toward the EGD implementation.

2. Materials and methods

Within the current study, relevant databases available online were used to analyze the sources of the Polish Exclusive Economic Zone (EEZ) pollution with heavy metals. The atmospheric deposition of heavy metals from Poland was categorized (Table 1) and based on the EU’s emission inventory report 1990–2018 by the European Environmental Agency (EEA) under the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) [24]. Data on the riverine loads of discharged heavy metals to the Polish EEZ were obtained from the HELCOM compilations of pollution loads database of nutrients and selected hazardous substances for the maximum available period (1995–2017) [25]. Monitoring data obtained from HELCOM required basic statistical processing, which allowed to present Cd, Pb and Hg riverine loads transported to the Baltic Sea by 12 major Polish rivers (Table 2).

To refer the emission and discharge of the analyzed heavy metals to the actual state of the Baltic Sea coastal zone, monitoring data from 3 basins located in the Polish EEZ were investigated using the newest environmental assessment annual report published by the Polish General Inspectorate of Environmental Protection for the 2008–2018 decade [26].

Heavy metals limits exceedance (LE_{HM}) in the Polish EEZ waters were presented in Fig. 5 using a heat map according to the calculations for Cd, Pb and Hg limit exceedance according to Eq. (1).

$$LE_{HM} = \frac{HM_{conc}}{HM_{limit}} \times 100\% \qquad (1)$$

Table 1
Sectors responsible for heavy metals atmospheric deposition in Poland (own Table, based on [24])

Public electricity and heat production	Industrial processes and product use	Commercial, institutional and households	Road transport	Non-road transport	Agriculture	Waste	Other
• Fossil fuels based power plants	• Cement production • Copper production • Ferroalloys production • Glass production • Iron and steel production • Lead production • Manufacture of solid fuels and other energy industries • Petroleum refining • Zinc production • SCMIC: chemicals • SCMIC: food processing • SCMIC: iron and steel • SCMIC: non-ferrous – metals • SCMIC: non-metallic – minerals • SCMIC: pulp	• Commercial/ institutional: stationary • Residential: stationary	• Traffic emissions, fluids leakages, tire and brakes wear	• National navigation (shipping)	• Agriculture/ forestry/fishing: stationary • Field burning of agricultural residues	• Clinical waste incineration • Industrial waste incineration • Municipal waste incineration • Open burning of waste • Sewage sludge incineration	• Cremation • Fugitive emission from solid fuels transformation • Other product use

SCMIC – Stationary combustion in manufacturing industries and construction where HM_{conc} – concentration of Cd, Pb or Hg in the tissues of the analyzed organism (mg/kg m.m.), HM_{limit} – limit for the concentration of Cd, Pb or Hg (mg/kg m.m.).

3. Results

The results of the study were analyzed in the following order: atmospheric deposition from heavy metals emission sources located in Poland during 1990–2017 (section 3.1) and riverine loads of heavy metals during 1995–2018 (section 3.2). The pollution with Cd, Pb and Hg of the Polish Baltic Sea coastal zone was studied in section 3.3.

3.1. Analysis of atmospheric deposition of heavy metals

According to the pollution assessment in the Baltic Sea region by HELCOM atmospheric deposition is responsible for aquatic ecosystem pollution by heavy metals in approx. 13% of Cd, 46% of Pb, and 24% of Hg [22]. The knowledge about potential sources of heavy metals emission is the key to mitigate the negative effect of those elements on the aquatic ecosystem and human health. Therefore, the sources responsible for atmospheric deposition of Cd, Pb and Hg were analyzed based on the data available in the EU's emission inventory report 1990–2018 by the EEA under the UNECE Convention on LRTAP [24]. The emissions have been categorized according to the following categories presented in Table 1: (i) public electricity and heat production, (ii) industrial processes and product use, (iii) commercial, institutional and households, (iv) road transport, (v) non-road transport, (vi) agriculture, (vii) waste and (viii) other.

Based on the data available for Poland in the LRTAP it was possible to present the Cd, Pb and Hg atmospheric depositions by sectors during 1990–2017 (Fig. 2).

Atmospheric deposition of Cd was caused mainly by sources from industrial processes and product use category such as iron and steel industry (13.86% of total average) and non-metallic industry (11.98% of total average). The Cd atmospheric emissions are unique compering to Pb and Hg due to the observed peak value in 1995 which can be explained by the rapid increase in the heavy industry development in Poland after the political transformations started in 1989.

The Pb atmospheric emission was also caused mainly by the industrial processes and product use sources with the biggest contribution by the iron and steel production (26.43% of total average) and Pb production (11.93% of total average), however, also public electricity and heat production was a significant Pb source (13.71% of total average). A decreasing trend is observed in the analyzed period referring to total Pb emissions, with some examples of major Pb emission reductions, for example, in public electricity and heat production from 105 Mg in 1990 to 26.21 Mg in 2017 and road transport from 13.43 Mg in 1990 to 8.40 Mg in 2017, while the number of registered vehicles in Poland raised 3 times in this period [27].

Public electricity and heat production was the main source of Hg emission in Poland (57.55% of total average) with 10.18 Mg in 1990 and 5.26 Mg in 2017. A stable decreasing trend is observed for total Hg emission in the analyzed period. This is mainly caused by the content of Hg in coal used in Poland as the main source of energy for decades (both heating and electric energy) [28]. The second Hg emission sources are industrial processes and product use with 4.52 Mg in 1990 and 3.06 Mg in 2017 which is mainly caused by iron, steel (9.24% on total average) and zinc production (9.23% on total average).

3.2. Riverine sources of heavy metals

Heavy metals enter the rivers mainly by wastewater discharges from municipal and industrial wastewater treatment plants (WWTPs) and illegal discharges [29]. Although, agriculture, forestry and corrosion of hydrotechnical facilities such as dams and river bank entrenchments are among the difficult to monitor sources of heavy metals in the water environment [30]. Within the investigation on the share of riverine heavy metals loads entering the Polish EEZ basins, 12 rivers were analyzed for their annual average Cd, Pb and Hg loads (Table 2) including Oder, Parsęta, Rega, Słupia, Wieprza, Ina, Grabowa, Łeba, Łupawa, Vistula, Pasłęka and Reda as shown in Fig. 3. Within the Polish EEZ 3 basins have been analyzed: Bornholm Basin (BB), Eastern Gotland Basin (EGB) and Gdańsk Basin (GB).

The largest impact regarding heavy metals pollution in the Polish EEZ is connected with the flow of the analyzed rivers. Vistula River with its estuary in the GB is the largest Polish river with approx. $3.4 \times 10^{10}\,m^3$ flow per year (61.3%), while the Oder is the second largest river with approx. $1.7 \times 10^{10}\,m^3$ flow per year (30.6%) to the BB. The rest of the analyzed rivers contribute to approx. 8% of the total river flow the Polish part of the Baltic Sea catchment. In terms of loads distribution among EEZ 3 basis, over 62.6% of heavy metals are discharged to the GB, 36.2% to the BB while only 1.2% to the EGB. However, an in-depth analysis of Cd, Pb and Hg loads shows differences in particular metals entering each part of the EEZ (Fig. 4).

The annual average of riverine heavy metals load discharged to the Polish EEZ was 0.96 Mg of Cd, 48.81 Mg of Pb and 5.34 Mg of Hg. In terms of the analyzed basins, GB received the largest riverine load of Cd (64%), Pb (57%) and Hg (47%). The BB received 32%, 37%, 42% load of Cd, Pb and Hg receptively, while the lowest load of Cd (4%), 6% (Pb) and Hg (11%) were received by the EGB.

3.3. Heavy metals limit exceedance

Water contamination with toxic heavy metals remains among the most severe global issues by affecting water resources. Therefore, in many countries, different methodologies have been used to allow for contamination monitoring and set accurate threshold values [16,32]. To evaluate the actual Polish EEZ water state in terms of heavy metals pollution the measurements conducted by the General Inspectorate of Environmental Protection were referred to the threshold values which are the limit between a good environmental status (GES) and an inadequate environmental status (subGES). The threshold values are usually set on the EU level, however, there are also limits set by regional authorities such as HELCOM for the Baltic Sea [33].

Table 2
Characteristic and heavy metal loads distribution among Polish EEZ basins (annual average during 1995–2018) [own table based on 24]

River	River estuary	Basin	Flow, million m^3/y	Cd		Pb		Hg	
				Load, mg/y	Share	Load, mg/y	Share	Load, mg/y	Share
Oder	Szczeciński Reservoir	BB	17,030.92	0.659	12.34%	11.686	23.94%	0.132	17.87%
Parsęta	Bay of Gdańsk	BB	854.27	0.522	9.78%	1.374	2.81%	0.035	4.67%
Rega	Bay of Gdańsk	BB	610.85	0.043	0.80%	0.534	1.09%	0.035	4.68%
Słupia	Dąbie Lake	BB	528.96	0.149	2.79%	2.195	4.50%	0.048	6.53%
Wieprza	Open Baltic	BB	508.19	0.188	3.52%	1.436	2.94%	0.023	3.16%
Ina	Szczeciński Reservoir	BB	459.90	0.032	0.60%	0.253	0.52%	0.026	3.48%
Grabowa	Open Baltic	BB	219.44	0.124	2.32%	0.376	0.77%	0.010	1.29%
Łeba	Wiślany Reservoir	EGB	400.49	0.123	2.31%	1.900	3.89%	0.034	4.63%
Łupawa	Bay of Puck	EGB	272.83	0.074	1.38%	1.109	2.27%	0.046	6.23%
Vistula	Bay of Gdańsk	GB	34,102.16	3.190	59.78%	25.893	53.05%	0.297	40.28%
Pasłęka	Bay of Gdańsk	GB	511.01	0.222	4.15%	1.952	4.00%	0.010	1.41%
Reda	Bay of Gdańsk	GB	142.10	0.012	0.22%	0.104	0.21%	0.042	5.75%
Total	–	–	55,641.13	5.34	100%	48.81	100%	0.74	100%

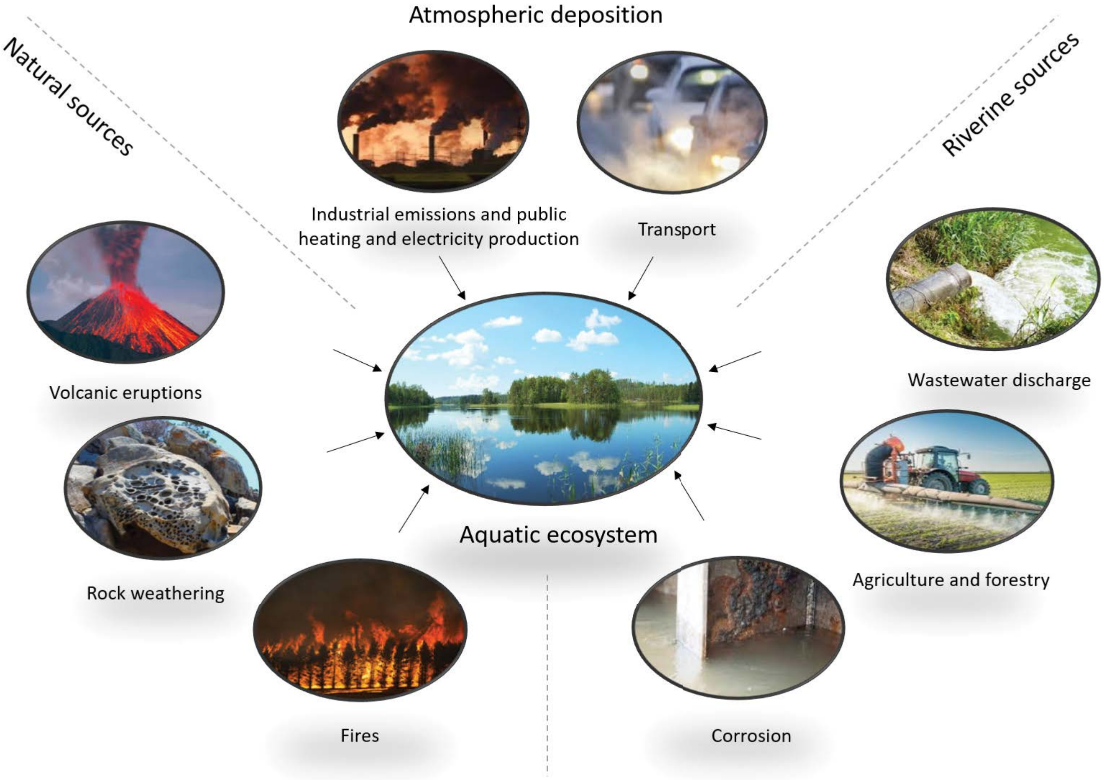


Fig. 1. Sources of heavy metals in the aquatic environment.

Furthermore, to include the specific conditions of different basins of the Baltic Sea, national threshold values are also used for water pollution monitoring [26].

The content of heavy metals in the Polish EEZ waters is set according to the EU and HELCOM threshold values at 0.026 mg/kg m.m. (muscle mass) for Pb and at 0.02 mg/kg m.m. for Hg in the tissues of the tested organism. Limits for Cd were set at 0.288 mg/kg m.m. according to a national methodology based on a series of herring liver tests [26]. The heavy metals concentration was measured in GB in mussels tissues while in BB and EGB in herring tissues (Fig. 5).

Heavy metals limits exceedance (LE_{HM}) in the Polish EEZ is presented in Table 3 using a heat map according to the

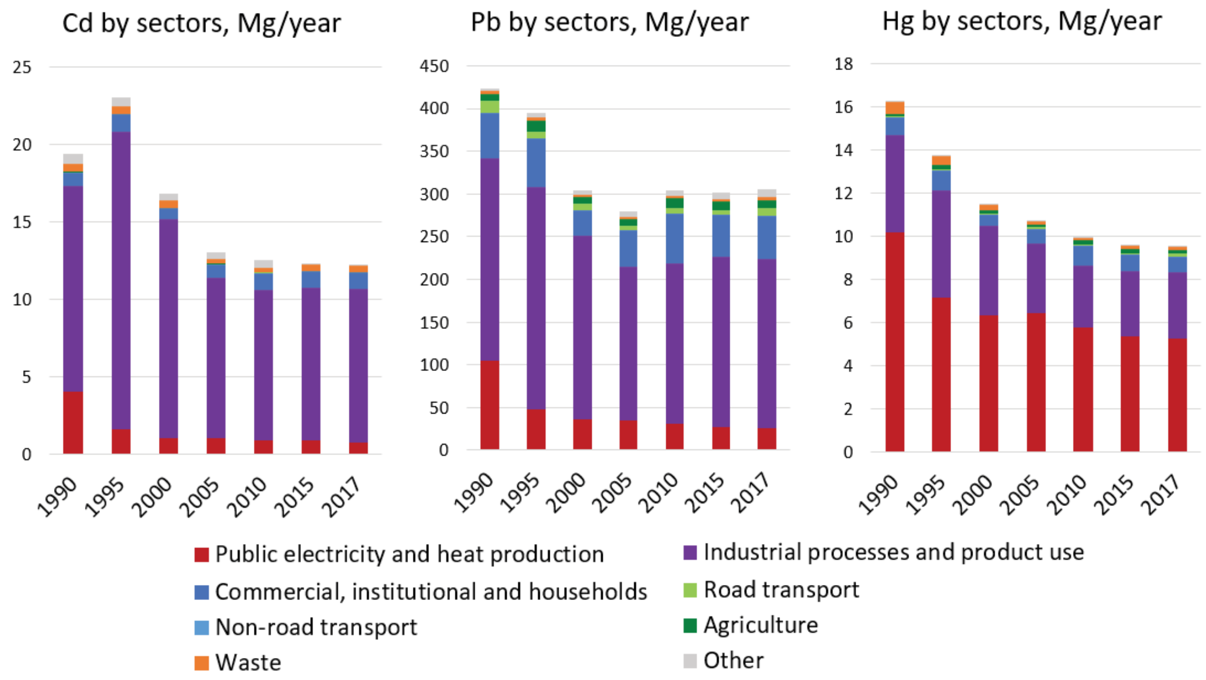


Fig. 2. Cd, Pb and Hg atmospheric depositions by sectors during 1990–2017 (own figure, based on [24]).

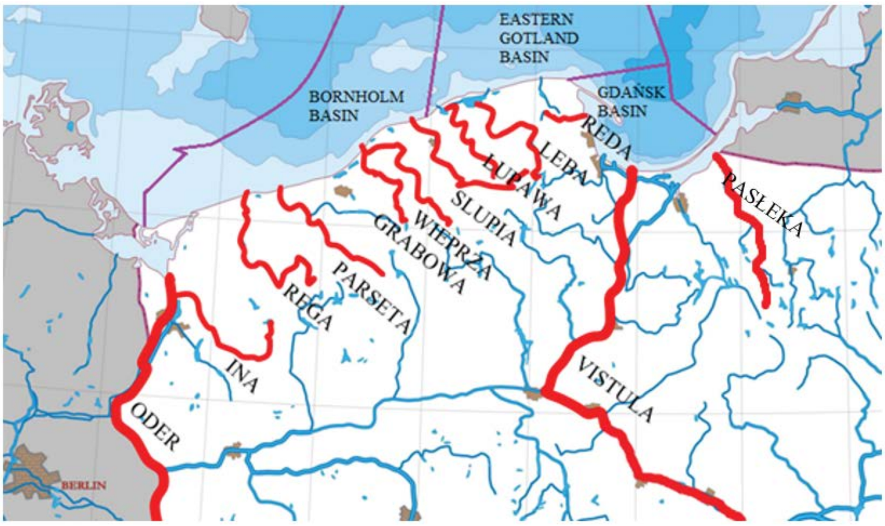


Fig. 3. River estuaries in the Polish Baltic Sea coastal zone [own elaboration based on 30].

calculations for Cd, Pb and Hg limit exceedance according to Eq. (1).

During the analyzed period (2008–2018) in the EGB, the LE_{HM} were on average 90.18% for Cd, 46.50% for Pb and 42.27% for Hg respectively. LE_{HM} was also observed for all analyzed heavy metals in BB by 67.46% for Cd, 53.15% for Pb and 33.86% for Hg on average respectively. The only basin where the limits were not exceeded based on the 10-y average for Cd (LE_{Cd} = –35.61%) and Hg (LE_{Hg} = –49.32%) was the GB. However, the average content of Pb was slightly over the limit (LE_{Pb} = 3.50%).

Trend analysis suggests that in the EGB there is a rapidly increasing trend observed for Cd contamination from 2014. In the BB we can also observe a dynamically increasing trend for Cd pollution since 2014 and a moderate but still increasing trend for Pb from 2014 with substantial acceleration in 2017. Waters of the GB show a much more stable trend in terms of all analyzed heavy metals content. Moreover, GB is the only basin that Cd and Hg values were below the limit, including particularly high reserves for Hg pollution which is the most severe threat for the entire food system. Since 2014 there are Hg concentrations observed from 82.50% (2016) to 52.50% (2018) below the limit. Cd pollution is very stable and any limit exceedance has not been observed during 2008–2018. Pb is the biggest concern in the GB with limit exceedance during

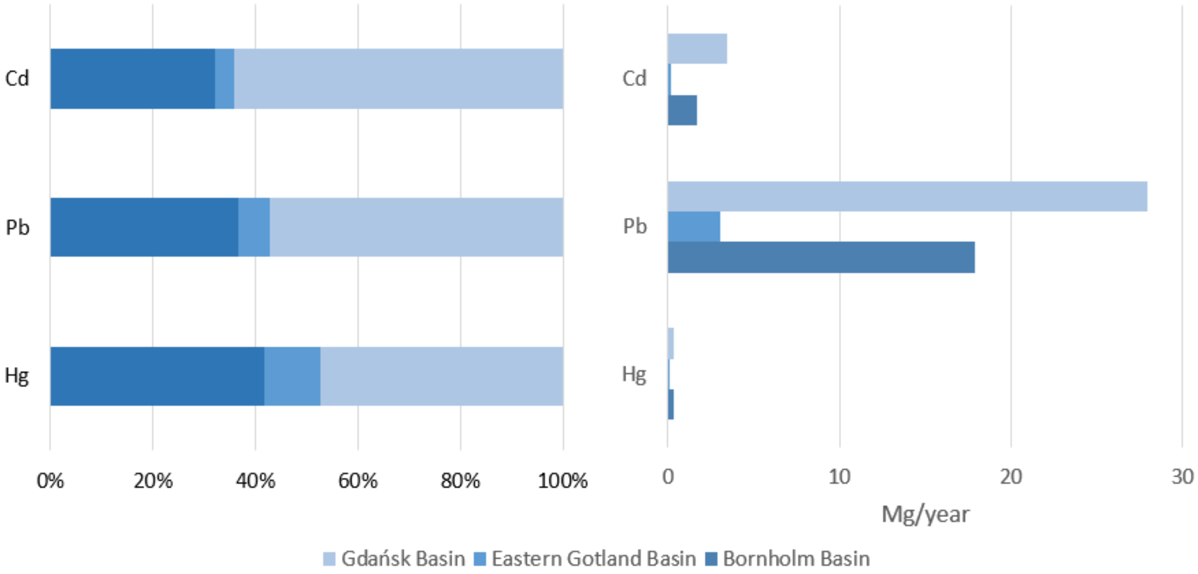


Fig. 4. Discharged heavy metals (share and actual amount) to the Polish EEZ parts [own figure based on 24].

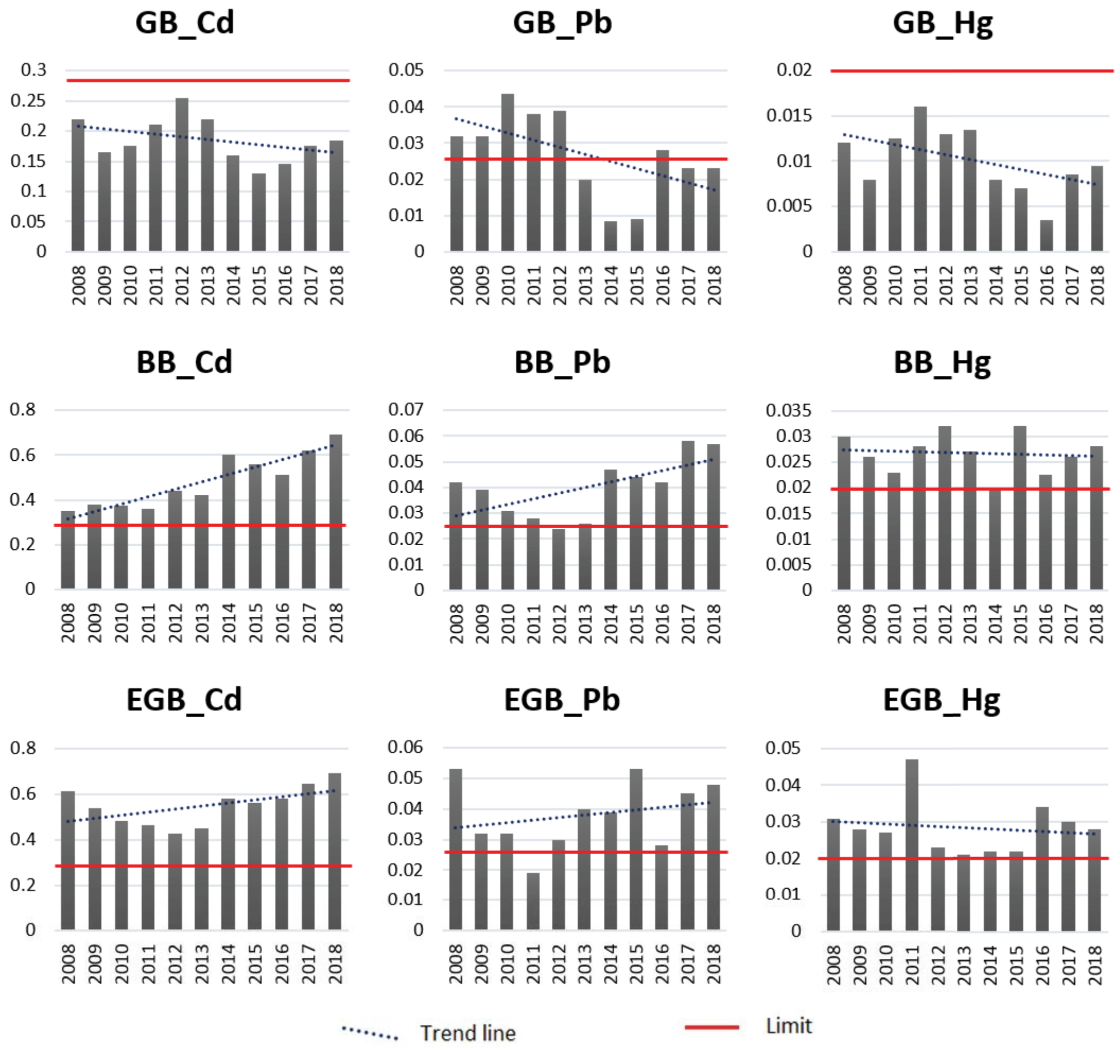
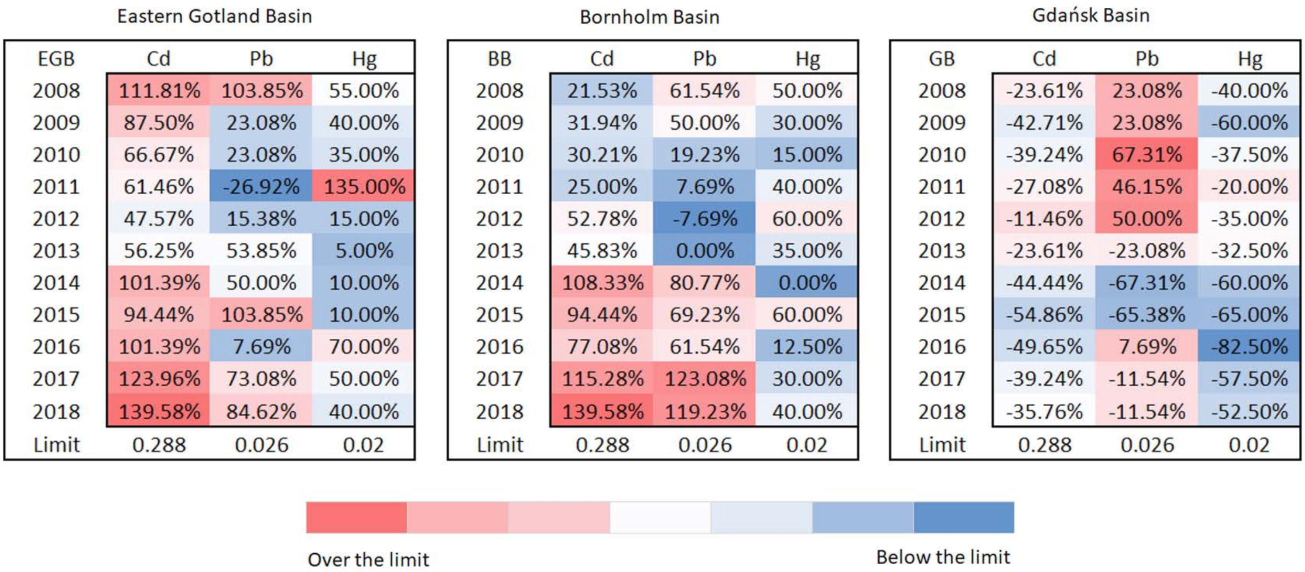


Fig. 5. Cd, Pb and Hg concentration in the analyzed fish species [own figure based on 25].

Table 3
Heavy metals limits exceedance in the 3 analyzed basins in the Polish EEZ



Eastern Gotland Basin

EGB	Cd	Pb	Hg
2008	111.81%	103.85%	55.00%
2009	87.50%	23.08%	40.00%
2010	66.67%	23.08%	35.00%
2011	61.46%	-26.92%	135.00%
2012	47.57%	15.38%	15.00%
2013	56.25%	53.85%	5.00%
2014	101.39%	50.00%	10.00%
2015	94.44%	103.85%	10.00%
2016	101.39%	7.69%	70.00%
2017	123.96%	73.08%	50.00%
2018	139.58%	84.62%	40.00%
Limit	0.288	0.026	0.02

Bornholm Basin

BB	Cd	Pb	Hg
2008	21.53%	61.54%	50.00%
2009	31.94%	50.00%	30.00%
2010	30.21%	19.23%	15.00%
2011	25.00%	7.69%	40.00%
2012	52.78%	-7.69%	60.00%
2013	45.83%	0.00%	35.00%
2014	108.33%	80.77%	0.00%
2015	94.44%	69.23%	60.00%
2016	77.08%	61.54%	12.50%
2017	115.28%	123.08%	30.00%
2018	139.58%	119.23%	40.00%
Limit	0.288	0.026	0.02

Gdańsk Basin

GB	Cd	Pb	Hg
2008	-23.61%	23.08%	-40.00%
2009	-42.71%	23.08%	-60.00%
2010	-39.24%	67.31%	-37.50%
2011	-27.08%	46.15%	-20.00%
2012	-11.46%	50.00%	-35.00%
2013	-23.61%	-23.08%	-32.50%
2014	-44.44%	-67.31%	-60.00%
2015	-54.86%	-65.38%	-65.00%
2016	-49.65%	7.69%	-82.50%
2017	-39.24%	-11.54%	-57.50%
2018	-35.76%	-11.54%	-52.50%
Limit	0.288	0.026	0.02

Values in the shades of red – limits exceedance, values in shades of blue – under the limit.

2008–2012. However, since 2013 the Pb content is below the limit with only one exception in 2016 (LE_{Pb} = 7.69%).

The results analysis shows that GB has more stable and optimistic conditions in terms of heavy metals pollution while it receives the largest load of the analyzed heavy metals. This paradoxical situation can be explained by the fact that GB as the only embayed water body is less affected by upwelling phenomena and lifting the bottom sediments where heavy metals can be deposited [34,35]. Heavy metals present in the bottom sediments can be released if the level of turbidity will increase or with the water pH decrease due to natural organic matter decomposition [36].

4. Discussion

The environmental and health risks related to heavy metals exposure has been investigated in various regions of the globe with significant scientific contribution from the Yellow Sea [37], East China Sea [38], Red Sea [39], Black Sea [40], Persian Gulf [41], Cananéia-Iguape-Peruíbe Environmental Protected Area in Brasil [41], Caspian Sea [42], Mediterranean Sea [43] and the Baltic Sea [44–47]. The above and numerous other relevant publications highlight the great importance of the studied issue and indicate its global scale. The present study has shown that despite the decreasing heavy metals atmospheric deposition originating from land-based emission in Poland is not reflected by a decreasing content of Cd, Pb and Hg in water organisms tissues tested in the Polish EEZ. A similar occurrence was identified in other water reservoirs sensitive to riverine loads of pollutants, for example, the Taihu lake in China [48,49] and Lake Bafa in Turkey [50]. Moreover, the Baltic Sea has very limited water exchange possibilities with the nearest water body – the North Sea by the Danish Strait which gives favorable conditions for pollution accumulation [51]. Furthermore, a low average depth, estimated at 52.3 m results in a high sensibility to riverine pollution loads, especially taking into account a relatively large catchment area of 1.7 million km^2 with a high share of agricultural lands (in Denmark and Poland) and population density in the largest bays (Bay of Finland, Gulf of Riga, Gdańsk Bay and Fehmarn Belt [52].

To mitigate the above issue the river-borne or direct discharges to marine water can be significantly reduced by efficient wastewater treatment in the pollution hotspots such as industrial sites with the biggest outflow of toxic substances including heavy metals [53]. During the wastewater treatment process heavy metals are removed within the biological or chemical treatment process and accumulated in the sewage sludge what can result in several difficulties in their further recovery in agriculture [54]. Phosphorus recovery from sewage sludge or its ashes is considered as the most promising method for phosphorus recovery which is a critical raw material for the European economy due to its limited primary resources in the EU countries [55]. To increase the heavy metals removal efficiency, advanced technologies could be considered for the identified hot-spots with severe heavy metals content in wastewater. Additional chemical precipitation, absorption with waste-based absorbents or industrial by-products, membrane filtration, electrocatalysis or photocatalysis have proven to provide high removal efficiency of heavy metals from wastewater [56].

On the other hand, atmospheric emissions of heavy metals should be minimalized at source, however, the legal regulations in the area need to be reviewed to promote environmental-friendly technologies in the most polluting industries [57–59]. Difficulties in reducing the heavy metals deposition after 2005 seem to be irreversibly connected with the industrial production and fossil fuels-based energy production in Poland which are continuously being reduced but still have a significant environmental footprint. However, industrial sources of toxic heavy metals should become less severe in the future as the EGD sets the objective of creating new markets for climate-neutral and circular products, such as steel, cement and basic chemicals. Moreover, the announced new chemicals strategy for sustainability by the EC should support the protection of human health and the environment against hazardous chemicals and encourage innovation in the sector to develop safe and sustainable alternatives [4]. Currently, the biggest remaining barrier to overcome on the way towards a toxic-free environment ambition in Poland is the energy and heat production sector which demands a significant transformation in terms of used energy sources and high investments in renewable and zero-emission energy production infrastructure. Furthermore, as the present study has shown public electricity and heat production are responsible for a significant part of the atmospheric deposition of heavy metals, especially Hg which is the most toxic element to the aquatic environment. Unfortunately, the municipal energy sector in many EU counties such as Poland, Germany, Czech Republic, Bulgaria, Romania and Greece still depends on coal as the main energy source [60], which contains heavy metals impurities [61] it is even more important to implement the EGD goals.

Therefore, following the waste management hierarchy the prevention "at its source" of the heavy metals release into the informant should be the first tool to achieve one of the EGD ambitions – a toxic-free environment.

5. Conclusions

The article has shown that demanding challenges are still on the way towards the toxic-free environment ambition of the EGD by using the example of the Polish coastal zone of the Baltic Sea pollution by heavy metals. Based on the available data obtained from HELCOM and EEA reports it was possible to present the main sources of the most hazardous heavy metals to the aquatic environment. In terms of the Polish EEZ water protection, the contamination with Cd, Pb and Hg was analyzed in 3 basins. In the BB and EGB the limits for all 3 heavy metals were exceeded even by 139.58% in terms of Cd in 2018 in both basins. Pb limit was exceeded in 2018 by 84.62% in BB and by 123.08% in 2017 in the EGB. Moreover, the monitoring data from BB and EGB show increasing trends since 2014 especially in Cd and Pb contamination, while Hg values were over the limit for the whole monitoring period without a stable trend. On the contrary, the embayed part of the Polish EEZ, the GB receiving the largest load of heavy metals presents the lowest contamination by the analyzed heavy metals. Values below the limit in GB for Cd and Hg were observed during the entire monitoring period, while the limit for Pb was only temporarily exceeded. The assessment results show the complexity of the analyzed issue. Heavy metals can be accumulated in the bottom sediments in favorable conditions with low turbidity, characteristic for embayed water bodies as GB. Monitoring of heavy metals in marine waters is increasing its importance as heavy metals access the food chain by seafood. As one of the EGD's ambitions is a toxic-free environment it is expected that limiting water pollution with heavy metals will become one of the main targets in the nearest policy framework.

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