Pollution, 6(2): 295-306, Spring 2020
DOI: 10.22059/poll.2020.290410.695
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

The Effectiveness of the Ballast Water Exchange Method in Removal of the Heavy Metals in the Ballast Tanks of the Ships, Bushehr Port- Persian Gulf

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Received: 09.10.2019 Accepted: 16.02.2020

ABSTRACT: Ships transport about 80 percent of world trade and transfer approximately three to five billion tons of ballast water internationally every year. Due to the likely presence of pollutants, the ballast water discharged by ships can have negative effects on aquatic ecosystems. This study was conducted on 10 ships that entered the Bushehr port to determine the effectiveness of the ballast water exchange method and also to specify the contents of heavy metals (Ni, Cd, Pb and Cu) in the water and sediment of the ships' ballast tanks. The samples were collected from January 2017 to July 2018 during a cold and a hot season. The results indicate the values of heavy metals in the samples in this order: Ni> Cu > Pb > Cd. The heavy metals concentrations in the sediment samples did not exceed the standard of the National Oceanic and Atmospheric Administration (NOAA). Whereas, Cu and Ni in all water samples and Cd in samples 2 and 7 exceeded the NOAA quality standard value. A correlation analysis of the metals showed that the sources of heavy metals vary in water and sediment samples, except for Pb and Cu in sediment samples which a positively significant relationship were observed. The results also revealed that the ballast water exchange method cannot by itself be effective and an efficient management together with continuous monitoring seems to be essential to prevent pollution of the ballast tanks of the ships entering the Bushehr port.

Keywords: Pollution; Ballast water; Sediment, Marine environment.

INTRODUCTION

The maritime transportation industry accounts for more than 80% of goods transportation around the world and plays a critical role in the global trade. Ships carry about 3–5 billion tons of ballast water every year (Rahman, 2017). Ballast water is necessary for the safety and preservation of the ship balance while sailing in adverse weather conditions (Endersen et al., 2004). Many researchers have reported that water

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and sediment in ballast tanks contain heavy metals and different physicochemical factors which could enter the aquatic environment as they are discharged and bring about substantial economic losses (Govind & Madhuri, 2014; Feng et al., 2016; Tjahjono et al., 2017).

Heavy metals are generated from two natural and anthropogenic origins in nature (Zhou, et al., 2008). Natural sources of heavy metals found in coastal areas are rivers and wind. Among the anthropogenic sources are mining, petrochemical, oil, industrial and agricultural activities, and urban sewage disposal (Gao et al., 2016; Tjahjono et al., 2017). Due to toxicity, stability and bioaccumulation, heavy metals pose serious threats to the human health, and natural ecosystems. With most organisms, a very low amount of these metals can be really harmful (Giller et al., 1998). Many researchers have demonstrated that ballast tanks water and sediment of ships' ballast water can contain heavy metals and different chemical and physical factors which could enter the aquatic environment as they are discharged (Feng et al., 2016; Maglic et al., 2016; Nosrati-Ghods et al., 2017; Tjahjono et al., 2017).

To preserve the aquatic ecosystems against the risk of invasive species and to ensure the safety of navigation, the International Maritime Organization (IMO) enacted the Ballast Water Management Convention in 2004 (Firestone & Corbett, 2005; Kozai et al., 2006).

This Convention was put into effect since 8 September 2017 (Liu et al., 2019). This Convention includes two parts: ballast water exchange and ballast water treatment (Balaji & Yaakob, 2011). According to the ballast water exchange method, ships should exchange the ballast water that they have loaded in the port of origin, 200 miles away from destination port in a depth of 200 m with 95% efficiency (David et al., 2016). Ballast water treatment is a technique based on killing, inactivating and removal of organisms and other pollutants by various treatment systems like physical and chemical treatment methods (Taylor et al., 2002; Holm et al., 2008).

One of the most important water basins in the Middle East is the Persian Gulf. This unique marine environment has an area of 241,000 km2 and a mean depth of 35 m (Agah et al., 2009). Persian Gulf is surrounded by the United Arab Emirates (UAE), Iran, Kuwait, Iraq, Bahrain, the Kingdom of Saudi Arabia (KSA), Qatar and Oman. Among the valuable living creatures in this marine ecosystem are whales, dolphins, turtles, sea birds and over 500 fish species (Gollasch, 1997; Naser, 2013). More importantly, people living in these eight countries and other valuable marine creatures are highly dependent on this marine environment. It is also noticeable that, turnover and the flushing time of water in the Persian Gulf are 5 years and pollutants remain in it for a long time (Pourang et al., 2005). Therefore, a proper and supervised implementation of the convention related to this marine environment to keep it clean against pollutants is necessary.

Bushehr is one of the important ports in the south of Iran along the coast of Persian Gulf (Figure 1). Bushehr port has 15 jetties with 2300 m in length that specialized for containers, general cargo and terminals for minerals and oil. In view of the close distance between the port facilities and the public swimming area and the beach resort in Bushehr, it is essential to identify the factors which threaten this marine environment's ecological efficiency, especially when it concerns people's health. However, after enforcement of the Ballast Water Management Convention, this is the first study that have discussed the efficiency of this Convention in removal of heavy metals in the water and sediment of ballast tanks of the ships that enter the Bushehr port-Persian Gulf. Since most of the research and articles on water balance in the Persian Gulf have focused on the water part and in this study the sediments of the reservoirs have been analysed for the first time, this can be considered as an innovation, the present study pointed out.

MATERIALS AND METHODS

This study was conducted on 10 ships that arrived at the Bushehr port, whose characteristics are given in Table 1. The ports of call of these ships are shown in Figure 1. The water and sediment samples were collected from the 10 ships (numbers 1 to 10 as listed in Table 1) in two cold and hot seasons from January 2017 to July 2018 from the fore peak tanks (FPT) (Hallegraeff, & Bolch, 1991). The collection and analysis of the samples were made based on the MEPC 173 (58) standard (Basurko & Mesbahi, 2011). After opening the manholes, the water samples were collected from the upper, middle and lower sections of the tanks amounting to 15 L (Murphy et al., 2008; Nosrati–Ghods et al., 2017). The water samples were taken using portable pumps (Wilden Pro–Flo P.025). Water samples were collected and transported to the laboratory, they were filtered using the whatman grade 42 filter then their pH reached below 2 with nitric acid (Murphy et al., 2008). Then the samples were kept in the refrigerator to be analysed later. Using a grab sampler, 2 kg of sediment samples were collected from the bottom of each ship tank (Figure 2 and 3) and transported to the laboratory the same day that they were taken, then freeze dried and then powdered and sieved through a 0.5 mm nylon mesh and stored in a brown bottle in 4°C for future analysis (Triska et al., 1994). The pH of water was measured by pH meter. The Total Organic Carbon (TOC) was measured by a SHIMADZU device, model TOCN-4100. The salinity of the water samples was also determined by a salinity meter; model ATAGO S/Mill–E. The sediment samples were initially digested in HNO3–HClO4 (Merck Co.) and then the concentrations of the heavy metals (Cu, Cd, Pb and Ni) were determined by an atomic absorption spectrophotometer; model PG-AA500 (Moyel et al., 2015). Portable pumps and grab were used for sampling, washed out carefully with distilled water before use. The plastic and glass utensils used for storing and testing the heavy metals had been rinsed in advance in diluted nitric acid and then washed using distilled water. All glassware was acid washed by soaking in dilute nitric acid and rinsed with deionized water before use (Safari et al., 2018). The experiments were repeated two times with the mean values. The statistical analyses including the correlation matrix were conducted using the SPSS 20.0 software.

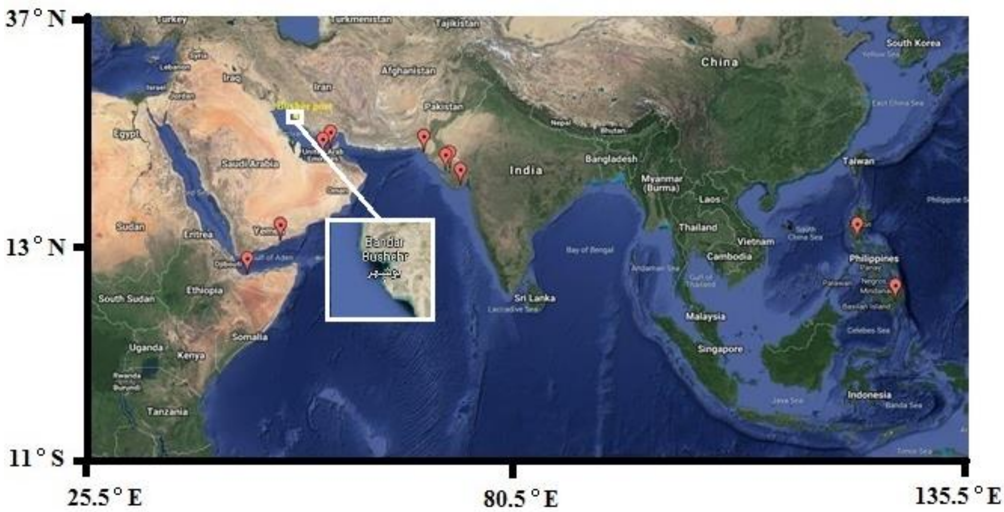

Fig. 1. Geographical map of all original ports of ships entering Bushehr port (Adapted from maps.google.com)

Table 1. Specification of 10 Ships sampled in Bushehr port

No.	Last port of call	Ship type	Total ballast capacity (m3)	Season of sampling
1	Kandla, India	Tanker	1950	Winter
2	Mina Zayed, Emirates	Bulk Career	12000	Winter
3	AL-Hamriye, Emirates	Tanker	2750	Winter
4	Berbera, Somalia	General cargo	4135	Winter
5	Davao, Philippines	Reefer	3530	winter
6	Manila, Philippines	Reefer	1690	Summer
7	Karachi, Pakistan	Tanker	2920	Summer
8	Mukalla, Yemen	Tanker	6010	Summer
9	Mundra, India	General cargo	3980	Summer
10	Pipavav, India	Container	20500	Summer

Fig. 2. Sediment sampling using grab

Fig. 3. Ballast water tank

RESULTS AND DISCUSSION

In this study, we compare the temperature, salinity, pH and the concentration of Ni, Cd, Pb and Cu in the water and sediment of the ballast tanks of the ships that entered the Bushehr port.

As can be observed in Table 2, the average of pH in ballast water samples was 8.17. This range of pH because of acidity of the oceans cannot be dangerous for the marine environment of the Persian Gulf and close to previous study results in this Gulf (Sheppard et al., 1993; Kuffner et al., 2008; Sale et al., 2011). The samples taken from the ships contained a high value of TOC where the highest value was seen in Vessel No. 7 from the Karachi Port, Pakistan, with 58.12 ppm. Organic carbon sources in the ballast tanks can arise from suspended organic compounds and degradation of dead creatures inside the tanks. As seen in Table 2, the mean concentration of the total organic carbon for all water samples in summer is significantly greater than in winter ($P < 0.05$). This can be due to better degradation of marine creatures in summer than winter and presence of more organic compounds in the water (Hori et al., 2008). Maglic et al. (2016) reported that corrosion of protective coatings of the ballast tanks can be a source of organic carbon in the water and sediment of the ballast tanks. During sampling from the ships' ballast tanks, it was observed that the tank of Vessel No. 7 from Karachi, Pakistan, was very old and highly corroded on the inside coatings of its tank. Another reason for higher TOC in tanks, as seen in Vessel No. 7, was the use of ballast tanks as storage to keep petroleum compounds, an act which occurs in the absence of proper supervision of port authorities and increases the organic and oil compounds and other pollutants in the ballast tanks. Table 2 indicates that the mean water temperature in the ballast tanks is 26.2°C. Results in this study were close to previous studies (Hume et al., 2013, 1999; Nosrati-Ghods et al., 2017). The temperature difference in the samples can be attributed to the difference in the sampling season, tank capacities and duration of travel (Nosrati-Ghods et al., 2017).

According to the results in Table 2, the mean salinity of the water samples was 37.9 ppt. Some studies have reported a mean salinity of 37.5 ppt for the Persian Gulf waters near the Bushehr port which is consistent with our study (Nosrati-Ghods et al., 2017). Increased salinity in summer is due to the increase in temperature followed by increased water evaporation in summer.

Table 2. Physicochemical properties of ballast water

No. vessels	pH	Temperature (°C)	Salinity (ppt)	TOC (ppm)
1	8.1	23	36	32.8
2	8.3	24	37	25.15
3	8.6	22	36	28.1
4	8	23	37	27.8
5	8.5	24	35	21.01
6	8	28	38	26.73
7	8.1	28	40	58.12
8	7.9	29	38	28.84
9	8	30	40	52.68
10	8.2	31	42	46.11
Mean	8.17	26.2	37.9	34.73

As shown in Table 3 and 4, all heavy metals (Ni, Cd, Pb, and Cu) were found in all water and sediment samples taken from the ships' ballast tanks. It should be noted though that all the concentrations of the heavy metals obtained in this research were lower than the previous studies (Feng et al., 2016; Tjahjono et al., 2017). The highest content of metal in the water and sediment samples was related to Ni with a mean of 740.46 ppb in the water samples and with a mean of 1485 ppb in the sediment samples. Conversely, Cd had the lowest content with a mean of 110.60 ppb and 28.92 ppb in the sediment and water, respectively. The mean concentrations of the heavy metals in a descending order are as follows: Ni > Cu > Pb > Cd. The results of this study were consistent with other studies (Murphy et al., 2008; Dobaradaran et al., 2018). Karbassi et al. (2005) reported the mean concentration of Ni, Pb and Cu in coastal sediments of Bushehr port 105700, 44600 and 21000 ppb respectively that were more compared with this study. They also reported, the origins of heavy metals in sediments were anthropogenic activities (Karbassi et al., 2005). Biati et al. (2012) were reported the mean concentration of Pb in sediments of Bushehr coastal area was 30560 ppb. This concentration was higher compare with this study. They were reported, origin of Pb in coastal area was anthropogenic such as: industries activity along the coast of Bushehr, agriculture wastewaters (Biati et al., 2012). Noroozi et al., (2015) reported 25, 2 and 0 ppb as the concentration levels of Pb, Cd and Cu in coastal waters of the Bushehr port respectively, which are lower compared to the present study (Noroozi et al., 2015). Dobaradaran et al. (2018) were reported that ballast water of ships entering to Bushehr port contain 8 heavy metals (Ni, Cu, Pb, Cd, Fe, Cr, Mn and Hg). They also reported that ballast waters discharged by ships in Bushehr port are main sources of heavy metal contamination (Dobaradaran et al., 2018). Nosrati-Ghods et al (2017) also were reported the mean concentrations of Co, Cr, Ni, and Pb in sea sediment in Kharg Island-Persian Gulf, 13.95, 8.65, 23.55, and 27.15 mg/l, respectively that was close to this study (Nosrati-Ghods et al., 2017). High levels of Ni in some tanks may be due to exchange of ballast water in the Persian Gulf. Therefore the high levels of oil pollution in the Persian Gulf (Hayes et al., 1993; Naser, 2013) and the Ni index could explain the high levels of Ni and other metals in ballast tanks (AL-Saraw et al., 1998; Massoud et al., 1998; wang et al., 2010).

In general, concentrations of heavy metals in the water and sediment samples were significantly different ($P < 0.05$) and concentrations of metals in the sediment samples were significantly greater than the water samples. Low concentrations of heavy metals in the water can be attributed to their inability to remain insoluble, whereas they can bind to the sediment (Vink, 2002). It is noteworthy that the sediment accumulated in the bottom of ballast tanks was several years old or even as old as the ships themselves. However, the water inside the ballast tanks is exchanged several times a year. Therefore, in addition to the ballast water exchanging and discharging practice, the present study suggests the same practice with sediments, and this proposed practice could be followed in all the seas, especially in the Persian Gulf.

Table 3. Heavy metal contents (ppb) in water samples and quality guidelines

samples	Ni	Cd	Pb	Cu
1	1300	20	7.25	45.25
2	1100	51.25	32	286.25
3	1000	22.5	36.75	104.5
4	710	22	44.25	250
5	692.27	35	51.25	154.5
6	634.62	17.5	44	268
7	865.37	41.25	29.4	33.82
8	365.37	21.25	7.95	168
9	423	39	29	227
10	414	19.5	39	286
Mean	750.46	28.92	32.08	182.33
NOAA QGL*	74	40	210	4.8

*National Oceanic and Atmospheric Administration Quality Guideline

Table 4. Heavy metal contents (ppb) in sediment samples and quality guidelines

samples	Ni	Cd	Pb	Cu
1	1700	88	320	1400
2	1150	205	430	1350
3	1300	72	120	610
4	900	68	1600	2200
5	1400	99	430	550
6	1750	58	250	750
7	2050	185	270	610
8	1000	70	190	470
9	1950	156	370	610
10	1650	105	150	380
Mean	1485	110.6	413	893
NOAA QGL*	20900	1200	46700	34000

*National Oceanic and Atmospheric Administration Quality Guideline

In this study, to evaluate the pollution of heavy metals in the water and sediment samples, we used the American Standard for water and sediment developed by the National Oceanic and Atmospheric Administration (NOAA) (Serrano & DeLorenzo, 2008; Zhang et al., 2017; Feng et al., 2017).

As observed in Table 3, the concentrations of Ni and Cu in all the ballast water samples and Cd in the water samples from Vessels No. 2 and 7 were greater than the NOAA quality standard. It was also determined that Pb in all the water samples and all the metals in the sediment samples did not exceed the NOAA quality standard.

Therefore, if the polluted water and sediment of the ships are discharged into the sea, there will be a risk potential for pollution of regional waters. Hence, it is essential to pay more attention to the quality of the ballast water in the ships entering the Bushehr port, especially with regard to the heavy metals in the water and sediment of their ballast tanks.

With the statistical analyses, it was shown that there is no significant difference between the concentrations of the heavy metals in the water and sediment samples in cold and hot seasons, except for Ni in the water which was significantly different in the cold season compared to the hot season ($P < 0.05$). Based on the results, if the ballast water is not thoroughly and properly exchanged, then pollution with heavy metals will be likely during both hot and cold seasons.

High pollution in ship No. 2 from Mina Zayed port can be due to exchanging ballast water near jetty. Before the implementation of the Ballast Water Management Convention, all ships discharged their ballast waters near the jetties with no treatment and exchange in deep waters. So this led to increasing the pollution in semi–closed jetties area. In Karachi port in Pakistan, untreated wastewater and sewage from factories, industrial zones and urban area are discharged into the sea near the port facility (Hameed et al., 2012). This could explain the high concentrations of metals in Vessel No. 7 Ni, Cd, Cu and Pb are used as alloys in steel production and it is possible that they are found in the ballast tanks due to degradation and decay of steel in the body of the tanks. Many of the ships studied in this paper were very old and decay in body of tanks and contaminated sediment was observed inside them. Another reason for the ballast tank pollution is changing the ballast water in the pollution areas of the Persian Gulf. At present, water and sediment of this Gulf is polluted owing to the presence of such things as numerous oil platforms and oil spills, discharge of untreated urban sewage, discharge of vessels' sewage, discharge of desalination plants' sewage which contain a lot of pollutants. (Elshorbagy, 2005; Lattemann & Höpner, 2008; Nasr, 2013).

Unfortunately, due to lack of appropriate monitoring and supervision programs to ensure the implementation of the Ballast Water Management Convention for ships entering the Bushehr port, ships have exchanged their ballast water incompletely and in some cases have not done it altogether. In addition, some ship officers provide inaccurate information about the location and time of their ship's ballast water exchange to the port authorities. Unfortunately in Bushehr port, port complex and jetties are closed to public beach. This way, the pollution in the water and sediment of ballast tanks are released into the marine environment, thus threatening the human health and coastal ecosystem. Therefore, to properly implement this Convention and prevent contamination, more serious supervision programs and continuous monitoring should be applied.

The correlation analysis is one of the statistical methods used to evaluate the strength of relationship between two quantitative variables. The high relationship between heavy metals may indicate that these metals have the same pollution sources (Haiyan & Stuanes, 2003; lin et al., 2013). The results of the Pearson correlation coefficients and their level of significance are given in Tables 5 and 6. No significant correlation was observed among the metals in the ballast water tanks. This is likely due to the fact that sources of heavy metals in the ballast water are different and have complicated mechanisms. As it is seen in Table 6, there is a positively significant relationship between Pb and Cu in the sediment of ballast tanks ($P < 0.01$). This is also likely due to the fact that both metals come from a common source in terms of geochemical features or because an equal amount of pollution from a common source has entered the environment thus showing the same behaviour and interdependence as do metals (Mir Mohammad et al., 2016). However, no significant relationship was observed among other metals in the sediment which is could be attributed to their complicated sources ($P > 0.05$). Sources of heavy metals in the water and sediment of ballast tanks may include: corrosion in the body of tanks, organic materials and wastewater (the ballast water polluted with wastewater loaded in ports), polluted soil and sand entering the tanks during the water exchange operations (Maglic et al., 2016). For more details on sources of pollution in tanks, it is proposed to use the principal component analysis (PCA) (Lin et al., 2013). By identifying the connection between heavy metals and environmental factors, it would be possible to develop control programs for such metals. As it is shown in Table 5, there is a significant negative relationship between Ni and temperature ($P < 0.01$). Although there was a relationship between temperature and other metals, none of them were significant ($P > 0.05$); pH and heavy metals (except for Cu) were all positively correlated. Salinity was also positively related to all the metals, except for Ni, though none of these two relationships were significant. Based on the results given in Table 5, there was a relationship between all the heavy metals in the water samples and TOC, none significant. This indicates that change in the TOC of the ballast water does not lead to change in concentrations of the heavy metals and, in other words, they are not affected.

Table 5. Correlation matrix of physicochemical parameters and heavy metal contents in ballast water

	Pb	Ni	Cd	Cu	TOC	pH	Temp	Salinity
Pb	1							
Ni	-0.19	1						
Cd	0.09	0.20	1					
Cu	0.44	-0.48	0.01	1				
TOC	-0.19	-0.24	0.22	-0.21	1			
pH	0.43	0.40	0.20	-0.17	-0.32	1		
Temp	-0.11	-0.77**	-0.03	0.31	0.63	-0.54	1	
Salinity	-0.04	-0.56	0.01	0.29	0.80**	-0.44	0.87**	1

TOC (total organic carbon), Temp (temperature)
** Correlation is significant at the level of 0.01

Table 6. Correlation matrix of heavy metal contents in ballast water sediment

	Pb	Ni	Cd	Cu
Pb	1			
Ni	-0.48	1		
Cd	-0.14	0.34	1	
Cu	0.84**	-0.45	-0.05	1

** Correlation is significant at the level of 0.01

The International Maritime Organization (IMO) has no requirement for ship owners to use treatment technologies in their ships to remove heavy metals in their ballast tank, and its purpose is mainly to eliminate or reduce dangerous invasive organisms or species transmitted through ballast tanks. According to the results of the research, unfortunately the studied vessels did not use any ballast water heavy metal treatment equipment or technology, and what is more, the Bushehr Port lacks the necessary equipment for water ballast treatment at its jetties, but given that presence of heavy metal in aquatic ecosystems can cause bio-accumulation in the marine biomass and pose major hazards to the food chain, it is better to employ various mechanical and chemical treatment technologies and techniques available to remove or reduce suspended matter and heavy metals. Below are some of the methods for treating heavy metals and their advantages:

Chemical precipitation which has low capital cost and simple operation (Kurniawan et al. 2006).

Adsorption with new adsorbents that has low-cost, easy operating conditions, with a wide pH range and high metal-binding capacities (Babel & Kurniawan, 2003; Aklil et al., 2004). Membrane filtration that has small space requirements, low pressure, and high separation selectivity (Kurniawan et al., 2006). Electrodialysis that has high separation selectivity (Mohammadi et al., 2005). Photocatalysis that involves removal of metals and organic pollutant simultaneously, with less harmful by-products (Barakat et al. 2004; Kajitvichyanukula et al., 2005). It should be noted that in choosing and applying the type of ballast water treatment, several factors are important including the laws and standards of a country, the cost of installing the filtration equipment as well as its efficiency.

CONCLUSIONS

The results of this study showed that the water and sediment of the studied ships' ballast tanks contain a great amount of heavy metals and their mean concentrations were in the following descending order: Ni > Cu > Pb > Cd. In this research, it was revealed that the ballast water exchange cannot by itself be effective in removing pollutants like heavy metals and it should be combined with other physiochemical treatment techniques. Since the jetties are close to the public swimming location and risks of discharging polluted ballast water are increasing, the authors propose complete implementation of ballast water exchange together with continuous monitoring of tanks and development of an effective regional strategy to remove pollution from ballast tanks in ships entering the Bushehr port.

ACKNOWLEDGEMENT

This paper published with financial and spiritual support of Iranian Ports and Maritime Organization.

GRANT SUPPORT DETAILS

The present research has been financially supported by IMO (grant No. TI351).

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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