Shell Plate Metal Dissolution Time of the Sunken M/V Joe-2 Ship and Its Effects on the Marine Ecosystem

Burhan Taşlı

The assumption that a ship only pollutes the marine environment when it sinks is a misconception. In reality, the environmental impact of a shipwreck can persist for decades. One of the primary factors contributing to this long-term pollution is the corrosive effect of dissolved oxygen in seawater, which gradually thins the steel hull of the sunken vessel. As the structural integrity of the hull weakens, pollutants such as fuel, cargo, or other hazardous substances may eventually leak into the marine environment.

This study investigates the potential timeline of hull corrosion for the M/V Joe-2, which sank off the coast of Kumluca, Turkey, while carrying 3,000 tons of bauxite—a mineral that poses ecological risks due to its aluminium oxide and hydroxide content. Although the ship did not release pollutants during the sinking process, its cargo remains a potential threat. Using known corrosion rates for steel in submerged zones (~0.10 mm/year) and accounting for the standard hull plate thickness of 8.10 mm (as per SOLAS regulations), it is estimated that complete dissolution of the ship's outer hull could take up to 80 years. However, localised weaknesses, particularly at weld joints, may cause structural failures earlier, potentially leading to the release of pollutants before full corrosion is reached. These findings underscore the long-term environmental risks posed by sunken vessels, even when immediate pollution is not observed.

KEY WORDS

~ M/V Joe-2
~ Dissolving of ship plates
~ Pollution
~ Bauxite
~ Corrosion rate

Çanakkale Onsekiz Mart University, Gallipoli Maritime Vocational School, Department of Deck, Çanakkale, Türkiye
e-mail: burhan.tasli@comu.edu.tr
doi: 10.7225/toms.v14.n03.007
Received: 3 Apr 2024 / Revised: 8 Mar 2025 / Accepted: 5 Jul 2025 / Published: 21 Oct 2025

1. INTRODUCTION

Maritime transportation is defined as the most ecologically acceptable transportation method (Michaelowa and Krause, 2000). It is seen as more advantageous than other types of transportation due to its low costs and high amount of cargo carried, and therefore forms the backbone of global trade. Maritime transportation, which is the most preferred type of transportation, contains many dangers as human injuries, ship's capsizing, fire etc., both during the cruise and the time in the port, due to the different structure of the working environment. The complex structure of ship operations makes ship accidents and dangerous events inevitable and can cause great damage. According to the data for 2021 reported around the world, 2,637 accidents (all types of accident) occurred and 2,854 ships were involved in these accidents. Fourteen of these ships sank and 58 marine pollution events occurred. There were 621 injuries and 36 deaths in all accidents (EMSA, 2022). According to EMSA (European Maritime Safety Agency) report of 2022, 2,510 casualties and incidents occurred. Six ships were lost, 38 pollution events occurred, 597 injuries and 38 fatalities happened (EMSA, 2023).

Maritime accidents occur frequently in maritime history. Some of these have caused huge losses and require regulations in the maritime sector. For example, the *Titanic*, which hit an iceberg and sank in the Atlantic Ocean in 1912. The fact that the *Titanic* carried only 20 lifeboats made the consequences of the accident all the more severe. As a result, 1,501 people lost their lives (Frey et al., 2011). Thereupon, the SOLAS (Safety of Life at Sea) convention was published in 1914 and precautions were taken to prevent a similar casualty. SOLAS has 12 parts and all the parts regulate important topics. For example, standards of life saving equipment are regulated with part III of SOLAS (IMO, 1974).

If it is thought that a ship will only create pollution when it sinks is erroneous. The effects of a shipwreck in the water may continue for years after. The best example of this is the container ship M/V Rena, which sank in 2011 on the Astrolabe Reef off the coast of New Zealand. 1,368 containers and 1,733 tonnes of heavy fuel oil (HFO) were carried by the Rena at the time of grounding. Although the oil spill from the M/V Rena shipwreck was relatively minor, the reef continues to be severely damaged by the ship's cargo today. Research studies carried out in this region in the years after the shipwreck occurred have detected toxic chemicals, petroleum products, and heavy metals in marine life in the sediments of the reef. While most oil was cleaned or degraded in the environment, contaminants stored in the ship cargo remained in the environment much longer. For example, when the ship's hull broke apart, one of the containers on the Rena contained more than 20 tonnes of granulated copper pieces, which were scattered across Astrolabe Reef. The oil spill reached the shore after five days (Schiel et al., 2016). Copper is known to be toxic to marine life and it is impossible to completely remove fine particles. Also copper ions kill fish, algae, protozoa and bacteria at doses below 1 mg/liter (Brown and Rattigan, 1979). The best example is the Batuhan A ship. M/V Batuhan A sunk on 15 February 2024. Although she carried marble powder which presents no hazard, there was approximately 200 cubic metre fuel oil is in ship fuel tanks. However, this important issue is not discussed in public (Taşlı, 2024).

M/V Joe-2 also started flooding off the coast of Kumluca, Antalya province of Turkey, on 5 April 2023, and subsequently sent an emergency message requesting assistance at 0422 via EPIRB. It was determined that there were fourteen crew members aboard the ship and three of them lost their lives. M/V Joe-2 was carrying 3,000 tonnes of bauxite mine from Iskenderun to Ukraine (Çeviren, 2023). The cause of accident has not been determined by maritime authorities. Some reasons can be given with known details of the accident. Weather condition, flooding of cargo hold, and dynamic separation could have been contributing factors that caused the ship to sink.

Bauxite is a mixture of aluminium oxides and hydroxides used in the manufacture of aluminium. It is the second most important global metal that comes after iron in industry due to its high thermal and electrical conductivity, high corrosion resistance, low density and mechanical properties (Gülfen, 1996).

In the process from bauxite mineral in the soil to aluminium metal products, it is one of the substances that can cause environmental pollution since the iron impurities often end up in alkaline lakes of iron corrosion products, known as “red mud”. Contact of bauxite with the sea will cause serious damage to the ecosystem, as will be discussed later in the article. In addition, ship borne pollutants like, paint, bilge, ballast water, fuel oil, toxic substances, etc. on the sinking ship spread into the marine environment, which can reduce the oxygen level of the water (EriK, 2015) and may cause sudden and mass deaths by having a toxic effect on fish and many aquatic creatures. The season of March to May is the breeding and development period of fish, and there are hunting bans in the region. Fish productivity will decrease as a result of pollution (Antalya Körfez, 2023). Also, Turkish National Risk Shield Model Board Member and Turkish Nature Conservation Association Scientific Advisor Dr. Erol Kesici stated that the cost of not retrieving the sunken ship would be greater than its removal and management costs (Karar, 2023).

This study has been carried out to estimate how long it will take for the sinking ship named *Joe-2* to break into the sea water due to corrosion and release its bauxite cargo into the sea, and to investigate what extent of pollution this may cause.

2. MATERIAL AND METHOD

In order to access the information of the sunken Joe-2 ship, marinetraffic.com and vesselfinder.com websites, were called ship traffic tracking systems, were used. Marine traffic application has 6,600 AIS (Automatic Identification System) receivers and give the real time position of ships. Traffic tracking systems, which work with navigation device data called AIS (Automatic Identification System), provide the current positions of ships by receiving AIS data at certain periods (Kpler, 2024). Its accuracy was confirmed by comparing the information published by the General Directorate of Maritime Affairs with the information obtained from the system.

In SOLAS regulation II-1/3-6, criteria for the thickness of the coating plate of ships are determined. In accordance with these criteria, the plate thicknesses to be used for the bottom, side and deck coatings of ships are determined. By examining the relevant regulation, the plate thickness of the ship named JOE-2 has been estimated. The calculation of plate thickness formula is:

For bottom plates $t_{min} = 5.5 + 0.03_{LCSR\text{-}B}$

The annual rate at which the plates thinned in the sea was analysed with Byron's corrosion rate table (Byron, 2020) and Kuroda’s table (Kuroda et al., 2008). Byron’s corrosion rate table gives value which is related to initial corrosion stage. Initial or early stage was defined for the first year following the contact with seawater. The process then continues with a constant corrosion value. (Zhao and Jin, 2016). Kurodo's table gives this constant value.

3. RESULT AND DISCUSSION

3.1. General Information of M/V Joe-2

IMO: 9070515	Name: JOE 2	Vessel Type - Generic: Cargo

Vessel Type - Detailed: General Cargo	Navigational Status: Decommissioned or Lost	Call Sign: J5AD9
Flag: Guinea-Bissau [GW]	Gross Tonnage: 2608	Summer DWT: 3426 t
Length Overall x Breadth Extreme: 86.04 x 14.5 m	Year Built: 1993	

Table 1. General information of the M/V Joe-2 (Source: Marinetraffic, 2023)

The sinking of a ship can be due to many reasons. For example, the MV Batuhan A sank in the Sea of Marmara due to seawater flooding the holds (Taşlı, 2024). As another example, OBO ship Derbyshire sunk due to huge typhoon (Faulkner, 2002). The MV Joe 2, for which detailed information is provided in Table 1, sank and was destroyed while transporting 3,000 tonnes of bauxite. Since there is no accident report made public yet, there is no clear information about the cause. However, the circular published by the IMO warned the ships carrying bauxite. The IMO Sub-Committee located the positive styles of bauxite with a big share of smaller debris, which may be a problem related to a newly-diagnosed phenomenon of “dynamic separation”, while there may be extra moisture inside the cargo. In such conditions, a liquid slurry (water and high-quality solids) can form stable material, in step with the file of a worldwide Global Bauxite Working Group on Research into the Behaviour of Bauxite in the course of Shipping. The unfastened floor impact, resulting from spillage of liquid, can notably have an effect on the stability of the vessel and result in danger to the ship (IMO, 2017). The same situation occurred with M/V Bulk Jupiter in 2015. The Bulk Jupiter sunk off the coast of Vietnam due to dynamic separation. A crew member of the Bulk Jupiter described the events after the accident. He stated that the bauxite cargo in the hold became fluid like gel and disrupted the stability of the ship (Ferauge et al., 2019).

3.2. General Information of Bauxite

Bauxite was first discovered near the town of Les Baux in France, from which it took its name. It is the main ore for producing alumina (Al_2O_3), which is a direct precursor in the making of aluminium metal. (IAI, 2015). Bauxite has a color mixture of red and brown. It is a naturally occurring heterogeneous material and consists of one or more aluminium hydroxide minerals, primarily gibbsite [$Al(OH)_3$], boehmite [γ-AlO(OH)] and diaspora [α-AlO(OH)]4. Additionally, bauxite contains other compounds containing small amounts of impurities, such as hematite [Fe_2O_3], goethite [FeO(OH)], quartz [SiO_2], rutile/anatase [TiO_2], kaolinite [$Al_2Si_2O_5(OH)_4$] with impurities in traces (Mitchell et al., 1961). Trace elements contained in bauxite include arsenic, beryllium, cadmium, chromium, lead, manganese, mercury, nickel, and naturally occurring radioactive substances, such as uranium and thorium. These elements often remain bound to the bauxite residue, even after alumina extraction (IAI, 2015). The impact of bauxite on the vessel is summarised in Table 2.

Air Pollution	Dust emissions (large particles ranging 1-10μm, fine particles ranging 0.1-1 μm) leading to cardiovascular and respiratory problems. Reduced FEV1 after dust exposure (≥100 mg/m3) of 20 years among non-smokers
Water Pollution	Leaching of iron, aluminum, arsenic, cadmium, lead, nickel, manganese and mercury into drinking water sources. High concentration of heavy metals in sediments, which are deposited in the water, which further dissolves and deposits into fish and benthic invertebrates, in which levels are 10-1000 higher than in

	normal water.
Food Contamination	Lead, cadmium, arsenic accumulation in vegetables. High levels of lead found in sweet potato, exceeding CODEX. Safety limit of 0.1 mg/kg.

Table 2. Types of environmental pollution in bauxite mining (Source: Ky et al., 2017)

The best example of bauxite's effects on ecosystem was found on Batata Lake. Batata Lake, located in the municipality of Oriximiná in Pará State, Brazil, experienced significant environmental degradation due to bauxite mining activities conducted by Mineração Rio do Norte (MRN) between 1979 and 1989. During this period, approximately 24 million tonnes of bauxite tailings were discharged directly into the lake, covering about 30% of its area with a thick layer of red sludge (Scarano, n.d., 2023). Moreover, according to the study of pollution on Batata Lake, bauxite residue effected Amazonian crystalline system and one metre decrease in the production of phytoplankton was observed, reduced by 60% (Roland and de Assis Esteves, 1998).

The minerals contained in red mud are hibsite quartz, calcite, hematite, sodalite, anhydrite, dolomite, cancrinite, and gibbsite. The chemical compounds that make up the structure of red mud are Fe, Al, Ca, Si, Ti and hydroxides. A red mud seep due to its constituents is hyperalkaline (pH > 12), which can be toxic to aquatic life (Sun et al., 2019). In October 2010, the biggest leakage of bauxite residue occurred at Ajkai in Hungary. Approximately 1 million m^3 red mud (bauxite residue), released accidently, the spill causing serious injured and killed ten people. The world attention was focused on this situation and red mud harms (Lockwood et al., 2015).

The red mud is produced during aluminium production process as a result of leaching of the aluminium minerals out of bauxite to create a concentrated aluminium solution.. Because of the absence of the chemical treatment steps, this means that bauxite cargo of M/V Joe-2 may not pollute like red mud at and around the accident area of the sea. However, especially alumina will not dissolve on the at seabed, therefore a mineral layer is available for chemical and microbiological leaching. The marine organisms in the immediate area of the mineral deposit may well be affected by the by-products of oxygeneated salt water leaching the impurities into the bauxite.

Although no direct environmental measurements were conducted along the Kumluca coast in this study, relevant literature provides insight into the potential ecological risks associated with bauxite cargo and its by-products, particularly red mud. Red mud, a highly alkaline residue generated during alumina production from bauxite, typically has a pH value of 10–13 and contains elevated levels of trace metals, such as aluminium, iron, titanium, and rare earth elements (Feigl, Anton and Uzinger, 2015; Coutrakon, Lach and Korf, 2021). If released into the marine environment, these components can significantly alter sediment chemistry, increase turbidity, and pose toxicity risks to both benthic and pelagic organisms (Ruyters et al., 2011). The accumulation of red mud in coastal zones has also been shown to impair photosynthesis in seagrasses and corals (Renforth et al., 2012). Given the depth and oceanographic conditions of the wreck site near Kumluca, similar long-term environmental consequences may arise if the cargo is eventually exposed. Further site-specific assessments, including geochemical and biological monitoring, are essential to evaluate the actual risk and inform potential mitigation strategies.

3.3. Corrosion Rate of Plates

Although ships may not cause pollution while they are sinking, corrosion will begin on ships that come into contact with sea water. In the following years, all substances that can harm the marine ecology, such as the cargo they carry, fuel, and insulation materials will release toxic materials and cause pollution. As the shell plates corrode, cracks occur and cargo and fuel leak into the sea. However, this requires a process. Some of the main factors affecting corrosion in seawater are:

- Seawater pH
- Conductivity (as a measure of salinity)
- Water Temperature
- Current velocity
- Dissolved Oxygen (Kuroda et al., 2008).

In addition to this, the position of the ship on the seabed directly affects the rate of shear formation. According to ship stability booklets and calculations, shifting cargoes cause pressure and force to ship hull (Yangfang, 2003). Since the bauxite cargo carried by the M/V Joe-2 ship is shifting, it will slide towards where the ship lies and create extra pressure on her hull. According to this condition, it can be said that this will cause the plate, weakened by corrosion, to shear faster.

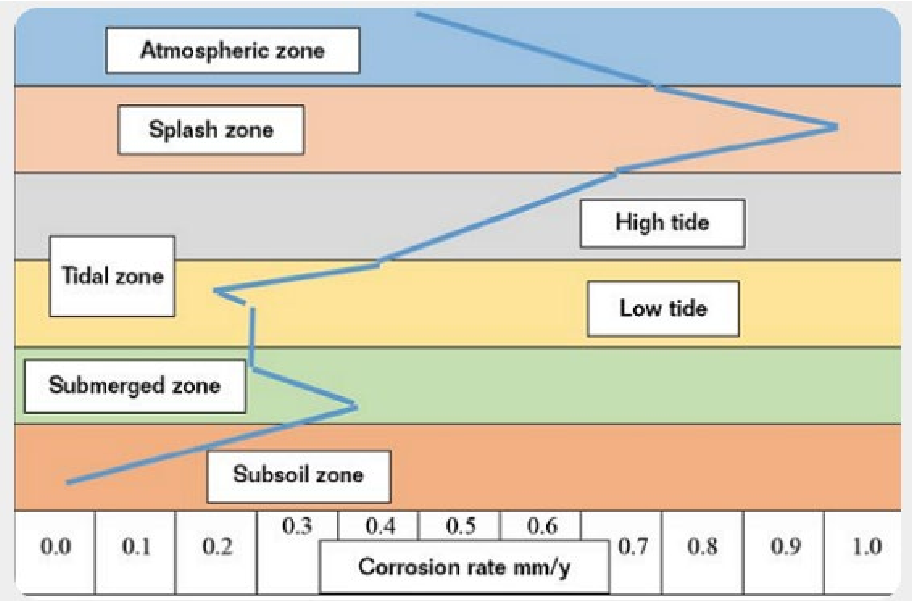

Figure 1. Byron's corrosion rate (Source: Byron, 2020).

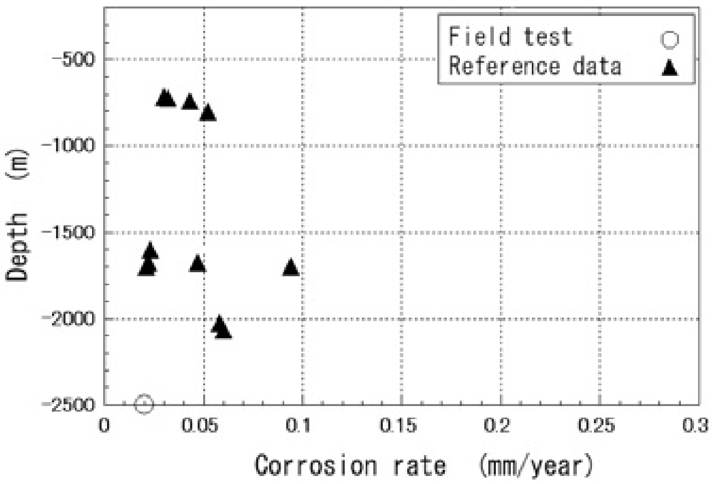

Figure 2. Kuroda's corrosion rate table (Source: Kuroda et al., 2008)

According to Figure 1, Average corrosion rate is ~0.35 mm/y in the semi-submerged splash zone. However, it shows the early stage of corrosion. As stated in the materials and methods section, the early stage lasts one year. However, after one year, the corrosion rate remains at constant value. Kuroda’s table shows the average rate for all periods. According to Figure 2, considering that the M/V Joe-2 ship sank to a depth of approximately 1,500 meters, it can be seen from the graph that an annual corrosion rate of between 0.02 and 0.10 mm/yr will occur.

Generally vessel’s shipyard period or last dimension measurement documents are not publicly available. Therefore the minimum thickness calculation had been carried out according to minimum standard values. The bottom of the ships is protected with antifouling paint. Special Surveys are to be carried out at five year intervals to renew the Classification Certificate (ClassNK, 2017). The special survey is carried out in a dry dock. One of the processes in dry dock is renewing antifouling. The protection period of antifouling paint is expected to last at least for five years. Every year after these initial five years, the vessel will begin experiencing structural loss. The protection period may last longer than five years. However, it may be seen from the early stage rate, as given by Byron, that antifouling painting duration will not exceed five years. Also, the antifoul coating was designed for active water flow at depths of up to 5-10 metres (the draught of the ship) so it may last longer than expected. However, at greater depths, alternative decay mechanisms may compromise the integrity of the antifouling layer. For this reason, Byron's early-stage rate was used at the completion of the five-year protection period and Kuroda's corrosion rate was used from the 6th year onwards. Furthermore, the corrosion rate for year was calculated with 0,10 mm/y (real value 0,1016 mm/y). Further down the steel surface, corrosion is governed by marine organisms that attach to the metal and the rate at which oxygen diffuses through the water.

According to SOLAS Chapter XII Regulation, 4 and 6 vessels have a minimum thickness of shell plate.

Plating	**Minimum thickness, in mm**
Keel	$7.5 + 0.03L_{CSR\text{-}B}$
Bottom, inner bottom	$5.5 + 0.03L_{CSR\text{-}B}$
Weather strength, deck and trunk deck, if any	$4.5 + 0.02L_{CSR\text{-}B}$
Side shell, bilge	$0.85\, L_{CSR\text{-}B}{}^{1/2}$
Inner side, hopper sloping plate and topside sloping plate	$0.7\, L_{CSR\text{-}B}{}^{1/2}$
Transverse and longitudinal watertight bulkheads	$0.6\, L_{CSR\text{-}B}{}^{1/2}$
Accommodation deck	5.0

Table 3. Minimum thickness of plating (Source: ClassNK, 2017.)

According to Table 3,, the thickest shell plates of ships are at the ships’ bottom, so calculations were completed with bottom plates values. Thickness calculation formula is shown below:

For bottom plates $t_{min} = 5.5 + 0.03L_{CSR\text{-}B}$

$$t_{min} = 5.5 + 0.03x86.04 = 8.0812 \text{ mm} \equiv 8.10 \text{ mm}$$

According to the above information, the dissolution of plates has been given in Table 4.

Year	**Slimming Quantity**	**Last Thickness**

6	0.10 mm	8.00 mm
10	0.50 mm	7.60 mm
20	1.50 mm	6.60 mm
50	5.00 mm	3.10 mm
75	7.50 mm	0.60 mm
80	8.00 mm	0.10 mm

Table 4. Thickness of bottom plates over the years

4. CONCLUSIONS

According to the above data, it has been determined that the vessel will be weakened to a point of near certain collapse due to corrosive factors, takeing up to 80 years (including the antifouling protection period). However, after the shell plate reaches a certain thinness, it is likely to shear due to internal and external factors. In addition, the position of the ship on the seabed may expedite the possibility of a collapse. The most optimistic estimate is that within 80 years, the bottom plating sheet of M/V Joe-2 will be punctured and its bauxite cargo will be released into the sea. However, before this situation arises, the sea water and marine microorganisms will have been interacting with the cargo and, consequently, leaching of heavy metal impurities will be taking place. When a structural collapse occurs, heavy metals will accumulate on the seabed and cause serious damage to the sea environment. Since such water is not suitable for sea creatures, fish migrations will occur, resulting in the creation of uninhabitable areas. Batata Lake was effected by bauxite residue, thereby reducing phytoplankton by 60% (Roland and de Assis Esteves, 1998). The same situation may occur in the Joe-2's accident area.

Waiting for the shell plate to collapse will be extremely ill-advised, since the physical structure of bauxite may change to a slurry. This physical structure will occur bauxite releasing from cargo vent or the other open spaces, which is why precautions must be urgently taken.

Today's ship accident investigation studies generally focus on pollution occurring during sinking. However, with this study conducted on the Joe-2 ship, it can be concluded that the danger has not ended for ships, even if they did not cause pollution during the sinking. On the contrary, an effect extending over years can be observed.

CONFLICT OF INTEREST: The author declared no potential conflicts of interest with respect to the research, authorship, and publication of this article..

REFERENCES

Antalya Körfez, 2023. 'Batan gemi çevreye büyük zarar veriyor'. *Antalya Körfez*, 23 April. Available at: https://www.antalyakorfez.com/batan-gemi-cevreye-buyuk-zarar-veriyor. (Accessed: 04 March 2024).

Brown, B.T., Rattigan, B.M., 1979. Toxicity of soluble copper and other metal ions to Elodea canadensis. Environ. Pollut. 1970 20, 303–314. https://doi.org/10.1016/0013-9327(79)90153-8

Byron, F., 2020. Corrosion Impact of Offshore Platforms, Structures, and Vessels. Available at: https://www.materialsperformance.com/articles/corrosion-basics/2020/12/corrosion-impact-of-offshore-platforms-structures-and-vessels (Accessed: 13 October 2024).

ClassNK, 2017. *Rules for the survey and construction of steel ship*. Available at: https://www.classnk.or.jp/hp/pdf/activities/csrh/393_erstl_csr-bt_2017.pdf (Accessed: 18 March 2024).

Coutrakon, G.C., Lach, L.M. and Korf, R.P., 2021. Environmental behavior of red mud under marine conditions. Marine Pollution Bulletin, 173, p.113010.

Çeviren, M., 2023. 'Antalya açıklarında ticari gemi battı! 5 personel kurtarıldı, 9'u aranıyor.', *Milliyet*, 5 April. Available at: https://www.milliyet.com.tr/gundem/antalya-aciklarinda-ticari-gemi-batti-5-personel-kurtarildi-9u-araniyor-6927237 (Accessed: 10 March 2024).

EMSA, 2022. *Annual Overview of Marine Casualties and Incidents 2022*. Available at: https://safety4sea.com/emsa-annual-overview-of-marine-casualties-and-incidents-2022// (Accessed: 5 March 2024).

EMSA, 2023. *Annual Overview of Marine Casualties and Incidents 2023*. Available at: https://emsa.europa.eu/publications/item/5052-annual-overview-of-marine-casualties-and-incidents.html. (Accessed: 20 August 2024).

EriK, N.Y., 2015. Petrol tankeri kazaları ve neden olduğu çevre kirliliği. Mavi Gezegen; TMMOB.

Faulkner, D., 2002. AN ANALYTICAL ASSESSMENT OF THE SINKING OP THE M.V. DERBYSHIRE. J. Ship Ocean Technol. 6, 19–76.

Feigl, V., Anton, A. and Uzinger, N., 2015. Red mud as a component for artificial soil mixtures: A review of its potential and risks. Journal of Soils and Sediments, 15(3), pp.453–470.

Ferauge, S., Jacobs, W., Baere, K.D., 2019. "LIQUEFACTION" AND "DYNAMIC SEPARATION" DIFFERENT ASPECTS OF THE SAME PROBLEM. Int. J. Marit. Eng. 161. https://doi.org/10.5750/ijme.v161iA4.1109

Frey, B.S., Savage, D.A., Torgler, B., 2011. Behavior under Extreme Conditions: The Titanic Disaster. J. Econ. Perspect. 25, 209–222. https://doi.org/10.1257/jep.25.1.209

Gülfen, M., 1996. Solubility of Milas Bauxite Ore in Sulfuric Acid Solution. PhD Thesis. University of Sakarya.

IAI, 2015. *Bauxite residue management: best practice.* Available at: https://bauxite.world-aluminium.org/fileadmin/user_upload/Bauxite_Residue_Management_-_Best_Practice__English__Compressed.pdf.

IMO, 2017. *Bauxite may become unstable when carried in bulk on a ship, potentially causing the vessel to capsize*. Available at: https://www.imo.org/en/MediaCentre/PressBriefings/Pages/22-bauxite-CCC.aspx (Accessed: 04 March 2024).

Kpler (2024) Marine Traffic Data Service. Available at: https://www.kpler.com/product/maritime/data-services (Accessed: 10 October 2024).

Kuroda, T., Takai, R., Kobayashi, Y., Tanaka, Y., Hara, S., 2008. Corrosion Rate of Shipwreck Structural Steels under the Sea. https://doi.org/10.1109/OCEANSKOBE.2008.4531052

Ky, L., Ly, H., Kh, T., Yy, T., Sp, L., Am, Q., T, P., R, N., 2017. Environmental and Occupational Health Impact of Bauxite Mining in Malaysia: A Review. IIUM Med. J. Malays. 16. https://doi.org/10.31436/imjm.v16i2.346

Lockwood, C.L., Stewart, D.I., Mortimer, R.J.G., Mayes, W.M., Jarvis, A.P., Gruiz, K., Burke, I.T., 2015. Leaching of copper and nickel in soil-water systems contaminated by bauxite residue (red mud) from Ajka, Hungary: the importance of soil organic matter. Environ. Sci. Pollut. Res. 22, 10800–10810. https://doi.org/10.1007/s11356-015-4282-4

MarineTraffic (2023) Joe-2 ship's details. Available at: https://www.marinetraffic.com/tr/ais/details/ships/shipid:419747/mmsi:-9070515 /imo:9070515/vessel:JOE_2 (Accessed: 11 December 2023).

Michaelowa, A. & Krause, K., 2000. 'International maritime transport and climate policy', *Intereconomics*, 35(3), pp: 127-136. doi: https://doi.org/10.1007/BF02927198

Mitchell, J., Manning, G.B., Molyneux, M., Lane, R.E., 1961. Pulmonary fibrosis in workers exposed to finely powdered aluminium. Br. J. Ind. Med. 18, 10–23. https://doi.org/10.1136/oem.18.1.10

Renforth, P., Mayes, W.M., Jarvis, A.P., Burke, I.T., Manning, D.A.C. and Gruiz, K., 2012. Contaminant mobility and carbon sequestration downstream of the Ajka red mud spill: The effects of calcium carbonate addition. Environmental Science: Processes & Impacts, 14(5), pp.738–746.

Roland, F., de Assis Esteves, F., 1998. Effects of bauxite tailing on PAR attenuation in an Amazonian crystalline water lake. Hydrobiologia 377, 1–7. https://doi.org/10.1023/A:1003252805671

Ruyters, S., Mertens, J., Vassilieva, E., Dehandschutter, B. and Smolders, E., 2011. The red mud accident in Ajka (Hungary): Plant toxicity and trace metal bioavailability in red mud contaminated soil. Environmental Science & Technology, 45(4), pp.1616–1622. https://doi.org/ 10.1021/es104000m.

Scarano, F., n.d. 2023. From virus to igapó forest: a systematic review of 35 years monitoring of an Amazonian Lake impacted by bauxite tailings (Batata Lake). Acta Limnol. Bras. https://doi.org/10.1590/S2179-975X5922

Schiel, D., Ross, P., Battershill, C., 2016. Environmental effects of the MV Rena shipwreck: cross-disciplinary investigations of oil and debris impacts on a coastal ecosystem. N. Z. J. Mar. Freshw. Res. 50, 1–9. https://doi.org/10.1080/00288330.2015.1133665

Sun, C., Chen, J., Tian, K., Peng, D., Liao, X., Wu, X., 2019. Geochemical Characteristics and Toxic Elements in Alumina Refining Wastes and Leachates from Management Facilities. Int. J. Environ. Res. Public. Health 16, 1297. https://doi.org/10.3390/ijerph16071297

TAŞLI, B., 2024. Analysis of the causes of loss of life as a result of the sinking of the M/V Batuhan-A, using the fishbone method. Mar. Rep. 3, 56–62. https://doi.org/10.5281/zenodo.12378881

Zhao, Y., Jin, W., 2016. Chapter 10 - Steel Corrosion-Induced Concrete Cracking Model, in: Zhao, Y., Jin, W. (Eds.), Steel Corrosion-Induced Concrete Cracking. Butterworth-Heinemann, pp. 159–170. https://doi.org/10.1016/B978-0-12-809197-5.00010-4