

# Physicochemical and Heavy Metal Assessment of Seawater Adjacent to the Shipbuilding and Repair Maintenance, Incorporated (SRMI) Shipyard, Tubay, Agusan Del Norte

MARLON NAIVE<sup>1</sup>, ABEL V. CONDE<sup>1</sup>, EUTROPIO N. GANANCIAS JR<sup>1</sup>., GERALD ANTHONY G. NOVAL<sup>1</sup>, IAN RICH G. PASTER<sup>1</sup>, KENNETH M. REFAMA<sup>1</sup>

<sup>1</sup>Merchant Marine Academy of Caraga, Inc., Butuan City, Philippines

ORCID NO.

Marlon Naive: <http://orcid.org/0009-0002-3626-1475>

Abel V. Conde: <http://orcid.org/0009-0000-1676-4767>

Eutropio N. Ganancias Jr.: <http://orcid.org/0009-0000-6775-1938>

Gerald Anthony G. Noval: <http://orcid.org/0009-0002-6919-6366>

Ian Rich G. Paster: <http://orcid.org/0009-0005-0651-1068>

Kenneth M. Refama: <http://orcid.org/0009-0006-3862-4435>

Corresponding Author Email: [condeabelvargas@gmail.com](mailto:condeabelvargas@gmail.com)

Originality: 99%

Grammar Check: 97%

Plagiarism: 1%

## ABSTRACT

### *Article History:*

Received: 03 Nov 2025

Revised: 29 Dec 2025

Accepted: 12 Mar 2026

Published: 17 Aug 2026

**Keywords:** *Environmental science, physicochemical parameters, oil and grease pollution, descriptive-evaluative design, Tubay, Agusan del Norte, Philippines*

Shipyard operations worldwide are recognized as a significant source of marine environmental contamination, yet no published assessment has evaluated seawater quality specifically at the Shipbuilding and Repair Maintenance, Incorporated (SRMI) Shipyard in Tubay, Agusan del Norte, Philippines, against the Department of Environment and Natural Resources (DENR) Class SC marine water standards. This study determined the physicochemical parameters (pH, total alkalinity, total suspended solids, oil and grease concentration, and dissolved oxygen) and heavy metal concentrations (copper, nickel, manganese, and iron) of seawater adjacent to the SRMI Shipyard relative to DENR Class SC standards. The study employed a quantitative, non-experimental descriptive-evaluative design. One composite seawater sample was collected within approximately 100 meters of the shipyard dock in January 2025 and analyzed at the Department of Science and Technology laboratory in Ampayon, Butuan City. pH (8.4), total alkalinity (165 mg/L), total suspended solids (36 mg/L), and dissolved oxygen (8.18 mg/L) all fell within DENR limits, as did iron (0.2882 mg/L); copper,

nickel, and manganese were not detected. Oil and grease measured 1.6 mg/L, exceeding the 1.0 mg/L DENR standard by 60%, the sole non-compliant parameter identified. This narrow, parameter-specific contamination profile indicates that SRMI Shipyard's environmental impact on adjacent seawater is currently concentrated in petroleum-based discharge rather than heavy metal contamination, supporting a correspondingly narrow and well-targeted corrective intervention focused on oil containment and waste-oil management rather than a broad-spectrum pollution control overhaul.

## INTRODUCTION

Shipyard operations worldwide are recognized as a significant source of marine environmental contamination. Budiyanto, Kusnoputranto, Didjaja, and Lestari (2016) identified environmental contamination as a persistent concern in shipbuilding, particularly during repair activities, and Ashari, Soesilo, and Herdiansyah (2021) found that shipyards generate hazardous industrial waste, including heavy metals, especially when repair materials are disposed of improperly. Once released, heavy metals are persistent and non-degradable: they eventually settle onto the seabed and accumulate in bottom sediments, which can act as both long-term sinks and secondary sources of contamination for the surrounding water column (El-Sharkawy, Abdel-Aziz, & Salem, 2025). Comprehensive water quality assessment, therefore, requires evaluating physicochemical parameters such as pH, conductivity, total dissolved solids, temperature, dissolved oxygen, salinity, and turbidity, since variations in these properties provide direct evidence of contamination (Escatron, Villamor, Eviota, & Escatron, 2022), and multi-stressor risk assessment approaches that jointly evaluate water quantity and quality pressures have been shown to better capture cumulative impacts on vulnerable water resources than single-parameter assessments alone (Wade, O'Brien, Wepener, & Jewitt, 2021).

Globally, shipyard-adjacent and marina water quality has drawn sustained research attention across continents. In France, Chouba and colleagues (2022) diagnosed chemical and microbiological contamination across four marinas in the Gulf of Aigues-Mortes and found that marinas, situated at the land-sea interface, are vulnerable to both local discharges and upstream terrigenous inputs, leading to measurable water quality degradation. In Croatia, Obhodaš and colleagues (2021) tracked seasonal physicochemical and microbiological trends in Marina Punat, in the northern Adriatic Sea, from 2009 to 2018, and used the resulting time series to evaluate the effectiveness of implemented environmental protection measures. In Bangladesh, ship-breaking, which the International Labour Organization has identified as among the most hazardous occupations in the world, exposes coastal waters to asbestos, oil residues, lead-based paints, and heavy metals such as cadmium and arsenic (International Labour Organization, n.d.), and toxic metal contamination at Bay of Bengal ship-breaking sites has been directly linked to both environmental degradation and occupational hazard (Ali, Wahid, Rahman, & Anwar,

2022). Turkish shipyard research similarly distinguishes construction from dismantling operations, noting that both processes cause substantial environmental damage, and that international bodies such as the European Union and the International Maritime Organization have commissioned studies aimed at reducing, managing, or recycling shipyard waste without further endangering the environment (Şahin & Bilgili, 2024); comparable calls for coordinated shipyard, shipping-company, and port-level environmental reform have also emerged from green-shipping policy research in East Asia and Europe (Lee & Nam, 2017).

Within the Association of Southeast Asian Nations (ASEAN) region, water quality indices have become a standard tool for evaluating industrial and coastal contamination. Indonesia, Malaysia, Thailand, and Vietnam have each applied water quality indices to characterize different aspects of their surface water conditions (Wong, Shimizu, He, & Nik Sulaiman, 2020), and a multi-decade review of Indonesian coastal water research found that 54%, 82%, and 50% of studies exceeded national standards for heavy metals, nutrients, and organic pollutants, respectively, with elevated levels concentrated near shipping lanes, ports, and industrialized bays (Adyasari, Pratama, Teguh, Sabdaningsih, Kusumaningtyas, & Dimova, 2021).

In the Philippines, local water quality assessments applying standard physicochemical and statistical methods have been conducted in rivers such as the Surigao River in Surigao City (Escatron et al., 2022) and the Mananga River in Metro Cebu, where principal component analysis of dissolved oxygen, biological oxygen demand, and total suspended solids explained roughly 84% of total variance in water quality, reflecting the influence of nearby commercial and industrial discharges (Mercado, Cai, Futralan, Ligaray, & Sy Choi, 2024).

The SRMI Shipyard is a small harbor located in Tubay, Agusan del Norte, on the northeastern coast of Mindanao facing Butuan Bay, and it plays an important role in the local economy by supporting maritime industry and employment. However, the industrial activities within and surrounding the shipyard, including oil handling, metal work, and vessel repair, pose risks to adjacent water quality through industrial discharge, oil spills, and other pollutants, consistent with the broader pattern of shipyard-related waste management challenges documented in comparable ship repair facilities (Ashari et al., 2021), and maintaining good water quality is essential both for the shipyard's operational sustainability and for the health of the surrounding community and marine ecosystem. Despite the extensive global and regional literature on shipyard and marina water contamination, no published assessment has evaluated seawater quality specifically at the SRMI Shipyard against the Philippines' DENR Class SC marine water standards. This gap justifies the present study, which the researchers undertook to determine whether SRMI Shipyard's adjacent seawater complies with national physicochemical and chemical water quality standards, and to identify which specific parameters, if any, indicate localized contamination requiring corrective action.

## **FRAMEWORK**

This study is anchored on the Driver-Pressure-State-Impact-Response (DPSIR) framework, originally developed by the Organisation for Economic Co-operation and Development as the Pressure-State-Response model and later extended and adopted by the European Environment Agency for integrated environmental assessment and reporting (European Environment Agency, 1999). The framework explains environmental conditions as the outcome of a causal chain: societal or economic Drivers generate Pressures on the environment, these Pressures alter the environmental State, the altered State produces Impacts on ecosystems and human well-being, and these Impacts, in turn, prompt societal or regulatory Responses intended to manage the Drivers or Pressures.

Applied to this study, the Driver is the continued construction, repair, and maintenance operations of the SRMI Shipyard, including oil handling, metal work, and vessel repair. The Pressure is the discharge of oil, grease, and metal-containing residues into adjacent coastal waters that such operations are known to generate. The State is represented by the study's measured variables: the physicochemical parameters (pH, total alkalinity, total suspended solids, oil and grease, and dissolved oxygen) and heavy metal concentrations (copper, nickel, manganese, and iron) of the seawater sampled adjacent to the shipyard. The potential Impact is the risk that any parameter found outside acceptable limits poses to marine ecosystem health and to the shipyard workers and surrounding community that depend on these waters. The Response is embodied in the DENR Class SC marine water quality standards against which the measured State is benchmarked, and in the parameter-specific corrective action recommended once a non-compliant reading is identified.

This framework directly informed the study's variables and analytic structure: it justifies measuring State indicators across both physicochemical and heavy metal domains as the empirical link between an unmonitored Pressure (shipyard discharge) and a regulatory Response (DENR Class SC compliance), rather than requiring the study to establish direct causal attribution in advance. A textual synthesis, rather than a schematic diagram, is presented here, consistent with the descriptive-evaluative scope of the study.

## **OBJECTIVES**

This study evaluated the marine water quality adjacent to the Shipbuilding and Repair Maintenance, Incorporated (SRMI) Shipyard in Tubay, Agusan del Norte, relative to DENR Class SC standards through the following specific objectives: (1) determined the physicochemical parameters of seawater samples adjacent to the SRMI Shipyard in terms of pH, total alkalinity, total suspended solids (TSS), oil and grease concentration, and dissolved oxygen (DO); and (2) determined the heavy metal concentrations of seawater samples adjacent to the SRMI Shipyard in terms of copper (Cu), nickel (Ni), manganese (Mn), and iron (Fe).

## METHODOLOGY

### Research Design

This study employed a quantitative, non-experimental descriptive-evaluative research design to assess the seawater quality adjacent to the SRMI Shipyard in Tubay, Agusan del Norte. The design integrated targeted field sampling within receiving coastal waters with standardized laboratory analyses, comparing empirical findings against DENR Administrative Order No. 2016-08 Class SC marine water quality standards (Department of Environment and Natural Resources, 2016).

### Research Site

The study was conducted at the Shipbuilding and Repair Maintenance, Incorporated (SRMI) Shipyard in Tubay, a municipality in Agusan del Norte within the Caraga Region, Philippines. Tubay is situated on the northeastern coast of Mindanao, facing Butuan Bay. The sampling point was located within approximately 100 meters of the shipyard dock, closest to the point of direct shipyard influence, in accordance with standard localized-impact monitoring practice.

### Participants

This study did not involve human participants. The unit of analysis was a single composite seawater sample collected at the designated sampling point described above; no human respondents, biological specimens, or protected fauna/flora were sampled.

### Instrumentation

Sample collection equipment included acid-washed polyethylene or glass sample bottles, a cooler with ice packs to maintain samples at 4 °C during transport, nitrile gloves, a grab sampler for hard-to-reach areas, waterproof labeling materials, a smartphone for recording sampling coordinates, personal protective equipment (lab coat, gloves, and safety goggles), distilled water for equipment rinsing, and field notebooks. Laboratory instrumentation included a calibrated pH meter, a LaMotte Multi-Parameter Meter for total alkalinity and dissolved oxygen, and a Flame Atomic Absorption Spectrophotometer (Flame AAS) for heavy metal quantification. All instruments and testing protocols followed the Standard Methods for the Examination of Water and Wastewater (SMEWW, 24th ed., 2023): Method 4500- $\text{H}^+$  B for pH, Method 5520 B for oil and grease, Method 2540 D for total suspended solids, and Method 3111 B for copper, nickel, manganese, and iron via Flame AAS. Materials were prepared with the assistance of personnel from the Department of Science and Technology (DOST) Laboratory Standards office in Ampayon, Butuan City.

## Research Ethics Protocol

The researchers secured written communication and permission from SRMI Shipyard management before sampling, disclosing the study's purpose, methodology, and potential outcomes. Sampling methods were planned to minimize environmental disturbance, and the researchers followed sustainable field practices to protect local ecosystems and biodiversity during collection. All findings were reported accurately regardless of outcome, and any information related to proprietary shipyard operations was treated as confidential. The researchers adhered to relevant local regulations governing environmental research and water quality sampling.

## Data Collection

The sample gathering process was executed through a systematic and methodical approach. Formal permits and clearances were first secured for sampling at the SRMI Shipyard, which included confirming site coordinates and obtaining permission from shipyard authorities. Subsequently, the researchers prepared sterile sample containers and materials, coordinated with on-site shipyard personnel, and confirmed access to the designated sampling coordinates. In January 2025, one composite seawater sample was collected near the shipyard entrance, closest to the dock area, with the assistance of shipyard safety officers. Immediately following collection, the containers were labeled, sealed, and stored under parameter-appropriate conditions to preserve sample integrity. The samples were then transported within the required holding time to the DOST laboratory in Ampayon, Butuan City, using temperature-controlled containers. Upon arrival, the DOST laboratory conducted standardized analyses for each physical and chemical parameter. Finally, the researchers retrieved the laboratory results and evaluated them against DENR standards, supported by relevant literature.

## Data Analysis

Laboratory results for each physicochemical parameter and heavy metal were tabulated and compared directly against the corresponding DENR Administrative Order No. 2016-08 Class SC marine water quality standard (Department of Environment and Natural Resources, 2016) to determine regulatory compliance. No inferential statistical formulas were applied, consistent with the single-composite-sample descriptive-evaluative design.

# RESULTS AND DISCUSSION

## Physicochemical Parameters

**Table 1**

*Physicochemical Analysis of Seawater Samples Adjacent to the SRMI Shipyard Relative to DENR Class SC Standards*

| Physicochemical parameter | DENR standard         | Result       | Interpretation                    |
|---------------------------|-----------------------|--------------|-----------------------------------|
| pH                        | 7.0–8.5               | 8.4          | Within acceptable range           |
| Total alkalinity          | 200 mg/L<br>(maximum) | 165<br>mg/L  | Within normal level               |
| Total suspended solids    | 110 mg/L<br>(maximum) | 36 mg/L      | Within normal level               |
| Oil and grease            | 1.0 mg/L<br>(maximum) | 1.6 mg/L     | Above the DENR standard           |
| Dissolved oxygen          | 2 mg/L (minimum)      | 8.18<br>mg/L | Exceptionally high oxygen content |

*Note. DENR standards per Department of Environment and Natural Resources (2016) Administrative Order No. 2016-08, Class SC marine water criteria.*

The seawater sample's pH measured 8.4, within the DENR-permitted range of 7.0 to 8.5, indicating that the water is neither excessively acidic nor alkaline and that marine life is not placed at pH-related risk. This finding is consistent with research showing that coastal marine environments typically maintain pH between 7.5 and 8.5 under stable conditions (Marion, Millero, Camões, Spitzer, Feistel, & Chen, 2011). Total alkalinity (165 mg/L) remained below the 200 mg/L upper limit, indicating that the water's acid-buffering capacity is neither excessively high nor low, and total suspended solids (36 mg/L) fell well below the 110 mg/L standard, indicating relatively clear water not heavily burdened by particulate matter. These findings align with the broader observation that water pollution, driven primarily by human activity, remains among the most significant global environmental threats of the twenty-first century, alongside deforestation, soil degradation, and climate change (Steffen et al., 2015), underscoring the value of routine physical parameter monitoring even where results indicate compliance.

However, oil and grease concentration measured 1.6 mg/L, exceeding the DENR standard of 1.0 mg/L by 60%. This result indicates that the water contains more oil and grease than the permissible level, which can harm marine life and reduce overall water quality. This finding is consistent with the principle that water quality reflects the combined physical, chemical, biological, and aesthetic elements that determine water's potential utility (Dickens & O'Brien, 2021), and it reinforces the importance of well-formulated, rigorously enforced environmental protection standards for guiding effective environmental management and law enforcement (Wu, 2020). Because heavy metal and related contaminant exposure through drinking water and coastal resources poses a well-documented public health risk in developing-country contexts, as demonstrated by health risk assessments of arsenic and toxic heavy metal exposure in Iran (Alidadi, Tavakoly Sany, Zarif Garaati Oftadeh, Mohamad, Shamszade, & Fakhari, 2019), the elevated oil and grease reading at SRMI Shipyard warrants immediate corrective attention despite the otherwise favorable physical parameter profile. Dissolved oxygen measured 8.18 mg/L, well above the 2 mg/L minimum standard, indicating an oxygen-rich environment generally favorable to marine life; however, unusually high dissolved

oxygen concentrations can, under certain conditions, promote the release of bed-sediment-bound compounds such as phosphate, iron, and manganese into the water column, which can in turn harm aquatic biota (Hermans, Astudillo Pascual, Behrends, Lenstra, Conley, & Slomp, 2021).

## Heavy Metal Concentrations

**Table 2**

*Heavy Metal Analysis of Seawater Samples Adjacent to the SRMI Shipyard Relative to DENR Class SC Standards*

| Heavy Metal Concentrations | DENR standard          | Result       | Interpretation            |
|----------------------------|------------------------|--------------|---------------------------|
| Copper                     | 0.02 mg/L<br>(maximum) | Not detected | Not detected              |
| Nickel                     | 0.02 mg/L<br>(maximum) | Not detected | Not detected              |
| Manganese                  | 2–5 mg/L<br>(maximum)  | Not detected | Not detected              |
| Iron                       | 0.3 mg/L<br>(maximum)  | 0.2882 mg/L  | Detected, within standard |

*Note.* DENR standards per Department of Environment and Natural Resources (2016) Administrative Order No. 2016-08, Class SC marine water criteria. Non-detection reflects concentrations below the Flame Atomic Absorption Spectroscopy method detection limit.

Copper, nickel, and manganese were not detected, but iron was measured at 0.2882 mg/L, just below the 0.3 mg/L allowable maximum. This result is directly relevant to the dissolved oxygen mechanism noted above: while compliant, the narrow margin, combined with the high dissolved oxygen level's potential to mobilize sediment-bound iron, indicates that continuous monitoring is warranted to ensure the concentration does not exceed the standard over time. The general pattern of non-detectable copper, nickel, and manganese alongside a compliant iron level is broadly consistent with marina and shipyard water quality research showing that although these facilities are vulnerable to both local and upstream pollutant inputs (Chouba et al., 2022), not all shipyards exhibit heavy metal contamination at any given sampling point in time. Nonetheless, heavy metals entering aquatic ecosystems from shipping and harbor activities, geological erosion, and industrial runoff are persistent and non-biodegradable, and they carry the potential for long-term bioaccumulation up the marine food chain (Emon, Rahman, Hasan, Chowdhury, & Rahman, 2023), a concern that supports the shipyard's continued vigilance even where current metal readings are within standard limits. Effective monitoring and management, including standardized laboratory analysis such as the Flame AAS method used here, remain essential tools for mitigating these risks and safeguarding both human health and aquatic biodiversity in shipyard-adjacent waters (Adjovu, Stephen, James, & Ahmad, 2023).

## CONCLUSIONS

The seawater surrounding the SRMI Shipyard in Tubay, Agusan del Norte, is generally compliant with DENR Class SC marine water quality standards, with pH, total alkalinity, total suspended solids, dissolved oxygen, and the heavy metals copper, nickel, manganese, and iron all falling within permissible limits. The principal exception, oil and grease concentration at 1.6 mg/L against a 1.0 mg/L standard, indicates localized contamination attributable to shipyard operations and represents this study's key contribution to the local environmental record, since no prior published assessment has established DENR-benchmarked water quality data specific to this facility. This finding neither confirms a broad environmental crisis at the site nor permits complacency: it demonstrates that shipyard water contamination, where it occurs, can be highly parameter-specific rather than uniformly distributed across all pollutant classes, a pattern that refines rather than contradicts the general literature associating shipyard operations with environmental risk. Read against the DPSIR framework, the findings support the model's premise that a Driver-Pressure chain can manifest narrowly in a single State indicator rather than broadly across all measured parameters; as a descriptive-evaluative assessment, this study does not test or generate new formal theory beyond this confirmatory application. Sustained, parameter-specific monitoring, rather than periodic broad-spectrum testing alone, is therefore indicated as the more efficient long-term strategy for safeguarding both marine ecosystem health and SRMI's regulatory compliance.

## TRANSLATIONAL RESEARCH

These findings could be translated into practical tools for shipyard operations and future researchers. Operationally, regular seawater monitoring, with a focus on oil and grease at multiple sampling points, could serve as an early-warning system for pollutant escalation. Programmatically, the results support considering the installation of oil-water separators, strengthening waste management protocols, and routinely inspecting spill containment systems to curb oil and chemical leaks, consistent with coordinated shipyard-level environmental reform practices documented in green-shipping policy research (Lee & Nam, 2017).

Institutionally, an upgraded wastewater treatment system paired with periodic environmental audits may help SRMI Shipyard sustain DENR compliance. It is recommended that these findings be translated into a simple, plain-language advisory brief and compliance checklist, in Filipino and English, so that shipyard management and local government partners can track the single flagged parameter, oil and grease, without needing to interpret full laboratory reports.

For future researchers, the findings point to opportunities for further study on contamination sources, expanded sampling, long-term ecological assessment, and stakeholder engagement in water quality stewardship.

## LITERATURE CITED

- Adjovu, G. E., Stephen, H., James, D., & Ahmad, S. (2023). Overview of the application of remote sensing in effective monitoring of water quality parameters. *Remote Sensing*, 15(8), Article 1938. <https://doi.org/10.3390/rs15081938>
- Adyasari, D., Pratama, M. A., Teguh, N. A., Sabdaningsih, A., Kusumaningtyas, M. A., & Dimova, N. (2021). Anthropogenic impact on Indonesian coastal water and ecosystems: Current status and future opportunities. *Marine Pollution Bulletin*, 171, Article 112689. <https://doi.org/10.1016/j.marpolbul.2021.112689>
- Ali, M. M., Wahid, F., Rahman, M. M., & Anwar, N. (2022). Toxic metal pollution in Bay of Bengal ship breaking sites: Assessment of environmental and occupational hazards. *Environmental Monitoring and Assessment*, 194(5), Article 352. <https://doi.org/10.1007/s10661-022-09990-8>
- Alidadi, H., Tavakoly Sany, S. B., Zarif Garaati Oftadeh, B., Mohamad, T., Shamszade, H., & Fakhari, M. (2019). Health risk assessments of arsenic and toxic heavy metal exposure in drinking water in northeast Iran. *Environmental Health and Preventive Medicine*, 24, Article 59. <https://doi.org/10.1186/s12199-019-0812-x>
- Ashari, R., Soesilo, T. E., & Herdiansyah, H. (2021). Strategy for shipyard industrial waste management in controlling water and air pollution in ship repair. *IOP Conference Series: Earth and Environmental Science*, 716(1), Article 012009. <https://doi.org/10.1088/1755-1315/716/1/012009>
- Budiyanto, A., Kusnopranto, H., Didjaja, R. S., & Lestari, F. (2016). Environmental insurance model in the shipyard industry. *Asian Journal of Applied Sciences*, 4(3), 632–639. Retrieved September 2, 2026, from <https://tinyurl.com/budiyanto-shipyard-2016>
- Chouba, L., Delpoux, S., Causse, L., Marie, M., Freydier, R., Toubiana, M., & Montigny, C. (2022, June). Status of water quality and impact of dredging activities in four ports of the Gulf of Aigues Mortes (France). In *9th International Symposium "Monitoring of Mediterranean Coastal Areas: Problems and Measurement Techniques"* (pp. 416–425). Firenze University Press. Retrieved September 2, 2026, from <https://tinyurl.com/chouba-aiguesmortes-2022>
- Department of Environment and Natural Resources. (2016). *DENR Administrative Order No. 2016-08: Water quality guidelines and general effluent standards of 2016*. Republic of the Philippines. Retrieved September 2, 2026, from <https://tinyurl.com/denr-ao-2016-08>

- Dickens, C., & O'Brien, G. (2021). Water quality: Standards and indicators. In W. Leal Filho, A. M. Azul, L. Brandli, A. Lange Salvia, & T. Wall (Eds.), *Clean water and sanitation* (Encyclopedia of the UN Sustainable Development Goals). Springer. [https://doi.org/10.1007/978-3-319-70061-8\\_111-1](https://doi.org/10.1007/978-3-319-70061-8_111-1)
- El-Sharkawy, M., Abdel-Aziz, R., & Salem, A. (2025). Heavy metal pollution in coastal environments: Ecological impacts and management strategies. *Sustainability*, 17(2), Article 701. <https://doi.org/10.3390/su17020701>
- Emon, F. J., Rahman, M. S., Hasan, M. R., Chowdhury, M. Z. R., & Rahman, M. (2023). Bioaccumulation and bioremediation of heavy metals in fishes: A review. *Toxics*, 11(6), Article 510. <https://doi.org/10.3390/toxics11060510>
- Escatron, M. J. E., Villamor, V. F., Eviota, M. P., & Escatron, R. A. (2022). Water quality assessment of Surigao River, Surigao City, Philippines. *Journal of Entomology and Zoology Studies*, 10(5), 1–10. <https://doi.org/10.22271/j.ento.2022.v10.i5a.9038>
- European Environment Agency. (1999). *Environmental indicators: Typology and overview* (Technical Report No. 25/1999). Retrieved September 8, 2026, from <https://www.eea.europa.eu/en/analysis/publications/tec25>
- Hermans, M., Astudillo Pascual, M., Behrends, T., Lenstra, W. K., Conley, D. J., & Slomp, C. P. (2021). Coupled dynamics of iron, manganese, and phosphorus in brackish coastal sediments populated by cable bacteria. *Limnology and Oceanography*, 66(7), 2611–2631. <https://doi.org/10.1002/lno.11779>
- International Labour Organization. (n.d.). *Ship-breaking: A hazardous work*. Retrieved September 2, 2026, from <https://www.ilo.org/resource/other/ship-breaking-hazardous-work>
- Lee, T., & Nam, H. (2017). A study on green shipping in major countries: In the view of shipyards, shipping companies, ports, and policies. *The Asian Journal of Shipping and Logistics*, 33(4), 253–262. <https://doi.org/10.1016/j.ajsl.2017.12.009>
- Marion, G. M., Millero, F. J., Camões, M. F., Spitzer, P., Feistel, R., & Chen, C. T. A. (2011). pH of seawater. *Marine Chemistry*, 126(1–4), 89–96. <https://doi.org/10.1016/j.marchem.2011.04.002>
- Mercado, M. J. N., Cai, W. T., Futralan, C. C. M., Ligaray, M., & Sy Choi, A. E. (2024). Water quality assessment of Mananga River using principal component analysis. *Philippine Journal of Science*, 153(2), 575–584. Retrieved September 2, 2026, from <https://tinyurl.com/mercado-mananga-2024>

- Obhodaš, J., Kutle, M., Kutle, A., Barši, P., Vinković, A., Bužan, T., & Valković, V. (2021). Changes in trends of the seawater column parameters and sediment elements' concentrations from 2009 to 2018 in the marina located in the Northern Adriatic Sea. In *The Montenegrin Adriatic coast: Marine chemistry pollution* (pp. 353–372). Springer. [https://doi.org/10.1007/978-3-030-61615-3\\_18](https://doi.org/10.1007/978-3-030-61615-3_18)
- Şahin, V., & Bilgili, L. (2024). A literature analysis on environmental impacts and relevant international legislation of shipyards. *Naše More*, 71(1), 38–44. <https://doi.org/10.17818/NM/2024/1.3>
- Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Rayers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), Article 1259855. <https://doi.org/10.1126/science.1259855>
- Wade, M., O'Brien, G. C., Wepener, V., & Jewitt, G. (2021). Risk assessment of water quantity and quality stressors to balance the use and protection of vulnerable water resources. *Integrated Environmental Assessment and Management*, 17(1), 110–130. <https://doi.org/10.1002/ieam.4356>
- Wong, Y. J., Shimizu, Y., He, K., & Nik Sulaiman, N. M. (2020). Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor River Basin, Malaysia. *Environmental Monitoring and Assessment*, 192(10), Article 644. <https://doi.org/10.1007/s10661-020-08543-4>
- Wu, H. (2020). Environmental protection standards and policy enforcement: A critical review. *Environmental Policy and Governance*, 30(4), 222–234. <https://doi.org/10.1002/ect.1889>