Journal of
Environmental
Nanotechnology

Review Article

Environmental Assessment in Panguil and Iligan Bay, Philippines: Review and Future Perspectives

Joemar S. Macalisang[1,2*], Jeffrey Ken B. Balangao[3] and Ferlyn V. Logronio[4]
[1]College of Engineering and Technology, Northwestern Mindanao State College of Science and Technology, Tangub City, Philippines
[2]School of Graduate Studies, J.H. Cerilles State College Pagadian-Annex, Pagadian City, Philippines
[3]Department of Manufacturing Engineering Technology, College of Technology, University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines
[4]College of Agriculture and Environmental Studies, Northwestern Mindanao State College of Science and Technology, Tangub City, Philippines
Received: 13.07.2024 Accepted: 28.09.2024 Published: 30.09.2024
*joemar.macalisang@nmsc.edu.ph

ABSTRACT

Northern Mindanao, in the southern Philippines, is known for its rich biodiversity and vital coastal ecosystems. Rapid economic growth in the region, marked by industrialization and urban expansion, raises concerns about pollution and its impact on water quality and marine life. This review deals with environmental assessments conducted in Panguil and Iligan Bay, focusing on pollutant levels and their effects on marine life. By analyzing data from sediments, phytoplankton, benthic foraminifera, seagrasses and macroinvertebrates, key contaminants affecting the region's environmental health and biodiversity were identified. Findings across various studies were integrated to provide a comprehensive understanding of contamination trends and biodiversity responses. This work emphasizes the interconnected environmental challenges in Iligan and Panguil Bay, along with the surrounding areas, urging a multifaceted approach that promotes sustainability, fills research gaps, and informs effective conservation and management strategies.

Keywords: Environmental assessments; Pollutants; Marine life; Panguil bay; Iligan bay.

1. INTRODUCTION

Northern Mindanao, located in the southern part of the Philippines, is a region renowned for its rich biodiversity and vital coastal and marine ecosystems (Jimenez *et al.* 2009; Orbita and Gumban, 2013; Boco *et al.* 2014; Metillo *et al.* 2015; Keith *et al.* 2018; Jimenez *et al.* 2020; Lagud *et al.* 2020; Sienes *et al.* 2022). The region, shown in Fig. 1, is currently experiencing a phase of significant economic transformation, driven by major infrastructure projects and increased industrial activity. Among these developments is the construction of a new bridge across Panguil Bay, which aims to enhance connectivity, promote economic growth, and facilitate transportation and trade across the municipalities and cities in the area. While these advancements promise substantial economic benefits, they also raise concerns about potential environmental impacts, particularly on the region's coastal and marine ecosystems.

Panguil Bay, a critical component of Northern Mindanao's coastal environment, is especially susceptible to the effects of intensified human activity and industrialization. Historically, the bay and even neighboring areas have been challenged by pollution, notably from heavy metals and other contaminants resulting from industrial discharges, and urban waste (Enguito *et al.* 2018; Jimenez *et al.* 2018; Cabili and Orbita, 2024; Enguito and Matunog, 2017; Roa, 1998). The anticipated increase in regional development and industrial activities due to the new bridge and other economic initiatives could aggravate these environmental issues, making it imperative to assess and monitor the status of the bay's ecosystem.

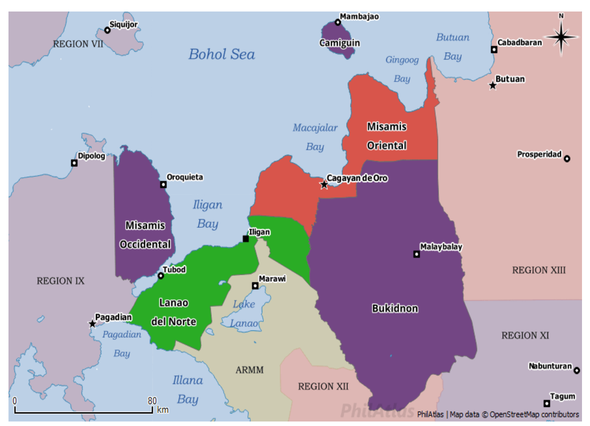

Fig. 1: Northern Mindanao region or Region 10 boundary map (source: PhilAtlas)

In addition to Panguil Bay, Iligan Bay is also of significant concern due to its proximity to various industrial operations. This bay has been identified as potentially vulnerable to pollution associated with industrialization. Previous studies have documented issues related to water quality and heavy metal contamination in Iligan Bay, raising alarms about the potential impact of continued industrial activities on the bay's ecological health (Teves, 1994; Demotica *et al.* 2012; Balala and Oclarit, 2007; Lacuna and Alviro, 2014; Unsing and Lacuna, 2014).

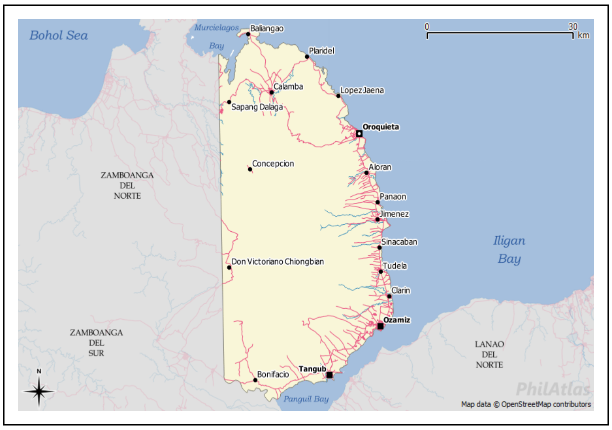

Fig. 2: Misamis Occidental boundary map (source: PhilAtlas)

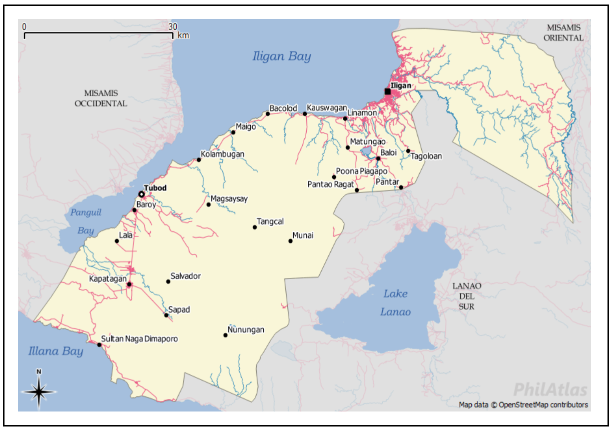

Fig. 3: Lanao Del Norte boundary map (source: PhilAtlas)

Figs. 2 and 3 provide boundary maps of Misamis Occidental and Lanao del Norte provinces, respectively, illustrating the interconnected bays of Panguil Bay and Iligan Bay. These maps highlight the geographic focus of the study, showing the spatial relationship between these two critical water bodies and emphasizing their importance within the broader context of Northern Mindanao's coastal and marine ecosystems.

The rapid economic progress in Northern Mindanao, characterized by increased industrialization, urban expansion, and enhanced trade and tourism activities, necessitates a comprehensive evaluation of the region's coastal and marine environments. As industrial activities and infrastructure projects expand, the risk of further pollution and its impact on water quality and marine biodiversity increases. The construction of the new bridge over Panguil Bay, in particular, is expected to heighten local and regional economic activities, potentially leading to further environmental pressures.

This review aims to address these concerns by consolidating research on pollution and ecological assessments in Northern Mindanao's coastal areas, with a specific focus on Panguil Bay and Iligan Bay. This review will provide a comprehensive understanding of the current environmental status, identify emerging trends, and highlight areas that need further investigation. It is significant because it addresses the dual challenges of balancing economic development with environmental preservation. As Northern Mindanao continues to grow, it is essential to assess the potential impacts of infrastructural and industrial activities on coastal ecosystems and implement effective measures to mitigate adverse effects. It also provides valuable insights into the condition of Northern Mindanao's coastal and marine environments, aiding policymakers and stakeholders in making informed decisions that promote sustainable development while safeguarding natural resources and marine biodiversity. The integration of economic progress with environmental management is essential for the sustainable development of Northern Mindanao.

2. METHODOLOGY

Research papers published between 2002 and 2024 were collected for this review. The studies were chosen based on their relevance to environmental pollution, marine biodiversity, and ecological indicators in Panguil and Iligan Bay, Northern Mindanao, Philippines. Key inclusion criteria included studies on seawater quality, heavy metal and microplastics accumulation, biodiversity assessments, and pollution impacts. Data were extracted from peer-reviewed journal papers. Published review articles were also considered (Wang *et al.* 2013; Tian *et al.* 2020; Karaouzas *et al.* 2021; Poikane *et al.* 2020; Adyasari *et al.* 2021; Yan *et al.* 2021; Pinna *et al.* 2023). This review focused on collecting various findings related to heavy metal concentrations, microplastics, species diversity, and the health of marine ecosystems.

3. DISCUSSION

Previous studies conducted in Panguil and Iligan Bays consistently reported alarming presence of heavy metals in various environmental samples. These findings are supported by the presence of metals like lead, cadmium, and mercury in sediments, water, and biota. Moreover, several studies are also conducted and confirmed the presence of microplastics. The various studies linked the pollutants from diverse sources, including industrial discharges, agricultural runoff, and domestic wastewater, contributing to the degradation of these coastal ecosystems.

The ecological implications of heavy metal contamination in these bays are significant, since they can bioaccumulate in organisms, leading to adverse health effects and disruption to the food webs. These pollutants can also impair water quality, reducing the availability of oxygen and affecting aquatic biodiversity. Furthermore, the presence of heavy metals in these coastal areas poses risks to human health, particularly for communities relying on marine resources for livelihood.

3.1 Panguil Bay

Recent studies conducted in the Panguil Bay and nearby areas have highlighted significant environmental concern related to pollutants and ecological health as shown in Table 1.

Table 1. Summary of key findings and indicators from studies in Panguil Bay and nearby areas

Reference	Key Findings	Pollutants	Ecological Indicators	Location
Enguito *et al.* (2018)	High heavy metal levels in seawater	Various metals	Impact on water quality	Port of Ozamiz
Jimenez *et al.* (2018)	Lead contamination in waters	Lead	Health risks	Port of Mukas
Cabili and Orbita, (2024)	Heavy metal accumulation in mangroves	Various metals	Mangrove health	Kauswagan, Lanao del Norte
Nabua *et al.* (2023)	Status of mangroves	Not specified	Mangrove condition	Panguil Bay
Lacuna *et al.* (2012)	Phytoplankton diversity and abundance	Not specified	Changes in diversity and abundance	Panguil Bay
Osing *et al.* (2019)	Mangrove species composition	Not specified	Mangrove species diversity	Panguil Bay
Fabiosa *et al.* (2021)	Invasive mussel Mytella strigata	Not specified	Invasive species impact	Panguil Bay
Villanueva *et al.* (2021)	Diversity of mangrove species	Not specified	Mangrove species diversity	Panguil Bay
Jumawan *et al.* (2021)	Assessment of mud crab fishery	Not specified	Mud crab fishery status	Panguil Bay
Dejarme *et al.* (2015)	Bacterial contamination in bivalves and farmed seaweed	Not specified	Fecal coliform contamination, health risks	Panguil Bay
Gamolo and Besagas, (2018)	Microbiological profile of cultured seaweeds Kappaphycus alvarezii	Not specified	Safe microbiological profile for consumption	Kolambugan, Lanao del Norte
Bonifacio *et al.* (2022)	Presence of Microplastics in sediments and in marine biota	Microplastics	Impact on water quality Impact on the sediments Health impacts	4 areas within Panguil Bay

Enguito *et al*. (2018) and Jimenez *et al*. (2018) found alarming levels of heavy metals, including lead, cadmium, and mercury, in seawater from the Port of Ozamiz and Port of Mukas, respectively, attributing this pollution primarily to industrial discharges and stressing the need for urgent pollution control. Cabili and Orbita, (2024) documented heavy metal accumulation in mangrove sediments. Moreover, Bonifacio *et al*. (2022) detected in their study conducted in 2022 microplastics in sediment samples and in the clam tissues sampled along different sites in Panguil Bay coming from fishing nets, rope materials, and food and drink wrappers/packages. Nabua *et al*. (2023) noted a decline in mangrove health and biodiversity due to pollution and land conversion. Lacuna *et al*. (2012) linked phytoplankton community changes to water quality variations, suggesting their use as indicators of environmental shifts. Osing *et al*. (2019) highlighted that while reforested mangroves had lower biodiversity, they were essential for ecosystem restoration. Villanueva *et al*. (2021) and Jumawan *et al*. (2021) emphasized the importance of mangrove conservation and sustainable fisheries management. Additionally, Dejarme *et al*. (2015) and Gamolo and Besagas, (2019) raised concerns about bacterial contamination in bivalves and seaweeds, pointing to the need for improved food safety and aquaculture management.

3.2. Iligan Bay

Research studies in Iligan Bay have highlighted several critical issues related to different pollutants like heavy metals and macro and microplastics and to ecological health. This is shown in Table 2. Ganaway and Lacuna (2014) observed that pollution in Iligan city's coasts led to reduced diversity and altered community structures of benthic foraminifera, illustrating broader ecological impacts. Vicente *et al*. (2002) linked harmful algal blooms (HABs) in the bay to nutrient pollution from agricultural and industrial sources, emphasizing the need for effective nutrient management. Tampus *et al*. (2014) identified areas with severe pollution in seawater and recommended enhanced monitoring and control measures. In a related study, Tampus *et al*. (2013) found significant degradation of riparian vegetation due to pollution, underscoring the need for restoration efforts.

Castañeto and Lacuna (2015) noted that coastal zooplankton diversity and abundance were negatively impacted by water quality, highlighting the importance of maintaining good water conditions. Superada and Tampus (2015) confirmed that macroinvertebrates are reliable indicators of pollution levels. Balala and Oclarit (2007) found potential for bioremediation using marine bacteria from industrial effluents. Unsing and Lacuna (2014) reported significant negative effects of industrial pollution on foraminifera. Siblos and Tabugo (2024) used bacterial communities as bioindicators for mangrove health, while Recamara *et al*. (2015) showed that Marine Protected Areas (MPAs) improved reef fish diversity. Lacuna and Alviro (2014) documented that pollution significantly impacted the diversity and abundance of benthic foraminifera in Iligan city's nearshore sediments, indicating their potential as bioindicators of marine environmental health. Lacuna *et al*. (2013) found that foraminiferal assemblages along the southeast coast of Iligan Bay reflected water quality and pollution levels, supporting their use as bioindicators for marine environmental monitoring. Overall, the studies emphasize the detrimental effects of pollution and the importance of both monitoring and conservation strategies. Several studies also detected and confirmed the presence of plastic waste specifically mesoplastics and microplastics in several biota and on the different areas within the Iligan Bay (Laput *et al*. 2024; Bacosa *et al*. 2024; Celmar *et al*. 2024) which causes further environmental and health concern.

Table 2. Summary of key findings and indicators from studies in Iligan Bay

Reference	Key Findings	Pollutants	Ecological Indicators	Location
Ganaway and Lacuna, (2014)	Benthic foraminifera diversity in polluted coasts	Not specified	Reduced foraminifera diversity	Iligan City
Vicente *et al.* (2002)	Harmful algal bloom	Not specified	Algal blooms	Iligan Bay
Tampus *et al.* (2014)	Seawater quality in stressed zones	Not specified	Quality status	Iligan Bay
Tampus *et al.* (2013)	Riparian vegetation assessment	Not specified	Vegetation quality	Iligan City
Castañeto and Lacuna, (2015)	Coastal zooplankton composition	Not specified	Zooplankton diversity	Iligan City
Superada and Tampus, (2015)	Macroinvertebrates as indicators of water quality	Not specified	Water quality	Iligan City
Balala and Oclarit, (2007)	Heavy metal biosorption by marine bacteria	Various metals	Biosorption effectiveness	Iligan Bay
Unsing and Lacuna, (2014)	Benthic foraminifera assemblages and environmental parameters	Not specified	Assemblage variation	Iligan City
Siblos and Tabugo, (2024)	Bacterial communities in mangrove species	Not specified	Microbial diversity	Bayug Island, Iligan City
Recamara and De Guzman, (2015)	Reef fish communities in Marine Protected Areas	Not specified	Fish community patterns	Iligan Bay
Lacuna and Alviro, (2014)	Tropical foraminiferans community structure and environmental health	Not specified	Indicators of environmental health	Iligan City
Lacuna *et al.* (2013)	Foraminiferal assemblages and sediment structure in the southeast coast	Not specified	Foraminifera as indicators of environmental health	Southeast coast of Iligan Bay
Laput *et al.* (2024)	Presence of Microplastics in edible bivalve mollusc	Microplastics	Stress to the marine life	Buruun, Iligan City
Bacosa *et al.* (2024)	Mesoplastic evidence in sandy beaches of Iligan City	Mesoplastic	Detrimental effects to the marine organism and to the environment	Beaches in Iligan City
Celmar *et al.* (2024)	Microplastics in seagrass	Microplastics	Health impacts	Iligan Bay

3.3. Environmental Status and Emerging Challenges

Significant levels of heavy metals reported in seawater samples (Enguito *et al*. 2018; Jimenez *et al*. 2018) from the Port of Ozamiz and the Port of Mukas due to industrial discharges, which are primary source of contamination, pose potential health risks to local communities dependent on these bays for their livelihood. Similarly, Cabili and Orbita (2024) found heavy metal accumulation in mangrove sediments in Kauswagan, Lanao del Norte, emphasizing the critical role of mangroves in sequestering contaminants and mitigating pollution. Heavy metals are widely regarded as harmful due to their potential to accumulate in soil, water, and living organisms, leading to toxic effects on ecosystems and human health. Their persistence in the environment makes them particularly dangerous, as even low concentrations could cause long-term contamination and disrupt biological processes (Sardar *et al*. 2013; Yadav *et al*. 2020; Jiang *et al*. 2021; Balangao *et al*. 2023; Tanjung *et al*. 2019; Sany *et al*. 2013; Witkowska *et al*. 2021; Mitra *et al*. 2022).

Nabua *et al*. (2023) revealed a decline in mangrove health and diversity in Panguil Bay due to pollution and land conversion, calling for conservation efforts. Osing *et al*. (2019) compared species composition and diversity of natural and reforested mangrove forests in Panguil Bay, finding that reforested areas had lower biodiversity but were crucial for ecosystem restoration. These studies collectively highlight the importance of conservation efforts to restore and protect mangrove ecosystems, which play a vital role in coastal resilience.

Ecological indicators such as benthic foraminifera and macroinvertebrates were used by Lacuna and Alviro (2014), Ganaway and Lacuna (2014), and Superada and Tampus (2015) to assess the health of coastal environments. Their findings demonstrated that pollution led to reduced species diversity and altered community structures, with benthic foraminifera and macroinvertebrates proving to be reliable indicators of water quality.

Microbial health and phytoplankton communities were significantly impacted by pollution (Gamolo and Besagas, 2018; Dejarme *et al*. 2015; and Lacuna *et al*. 2012). This had a cascading effect on the health of commercially important species and overall ecosystem productivity. The presence of bacterial contaminants in cultured seaweeds and commercially important bivalve species in Panguil Bay raised concerns about food safety and the need for improved management practices.

Harmful algal blooms (HABs) were another area of concern, as reported by Vicente *et al*. (2002), who linked the occurrence of HABs in Iligan Bay to nutrient pollution from agricultural runoff and industrial effluents. Tampus *et al*. (2014) and Unsing and Lacuna (2014) provided further evidence of the significant impact of industrial activities on coastal water quality and marine biodiversity, with industrial pollution leading to critical pollution levels in certain areas. Balala and Oclarit (2007) explored the potential for bioremediation using marine bacteria isolated from industrial effluents, offering a possible solution to mitigate the effects of heavy metal contamination.

Reef fish communities in Marine Protected Areas (MPAs) in Iligan Bay showed positive outcomes, as reported by Recamara and De Guzman (2015). Their study indicated that protection efforts improved fish diversity and abundance over time, demonstrating the effectiveness of conservation measures. However, the introduction of invasive species like the mussel Mytella strigata, as documented by Fabiosa *et al*. (2021), poses additional challenges to local biodiversity and ecosystem stability.

Jumawan *et al*. (2021) emphasized the need for sustainable fisheries practices to protect valuable sea animals such as mud crabs from overfishing and habitat destruction. The findings underscore the urgent need for stringent environmental regulations, enhanced pollution monitoring, and community involvement in conservation efforts. This comprehensive assessment highlights the critical importance of balancing economic development with environmental sustainability to protect the coastal and marine ecosystems of Northern Mindanao amidst rapid industrialization and infrastructure development.

The methodologies employed by literature studies vary, with some focusing on direct measurement of heavy metal concentrations in water and sediments (Enguito *et al*. 2018; Cabili and Orbita, (2024), while others used ecological indicators like benthic foraminifera and macroinvertebrates (Lacuna and Alviro, 2014; Superada and Tampus, 2015). The results generally align in indicating significant pollution levels and their adverse effects on marine biodiversity, though the specific sources and impacts of pollutants differ. For instance, Vicente *et al*. (2002) focused on nutrient pollution and HABs, while Gamolo and Besagas (2018) examined microbial contamination in aquaculture.

A consistent trend across these studies is the significant impact of industrial and agricultural activities on coastal pollution and marine biodiversity. There is a clear need for improved pollution control and conservation measures. However, gaps remain in long-term monitoring data and the understanding of complex interactions between pollutants and marine ecosystems. Some studies, like those by Recamara and De Guzman (2015) and Fabiosa *et al*. (2021) highlight the effectiveness of MPAs and the threats posed by invasive species, suggesting areas for future research and action.

Plastic pollution in Northern Mindanao's coastal areas has become a growing concern, with research revealing significant contamination from both microplastics and mesoplastics. Bonifacio *et al.* (2022) found high levels of microplastics in sediments and marine species, such as edible bivalves in Panguil Bay, while Laput *et al*. (2022) observed microplastic accumulation in gastropods from intertidal zones, highlighting the widespread nature of plastic debris. Celmar *et al*. (2023) further demonstrated how microplastics enter the marine food web through seagrass ecosystems, threatening species dependent on these habitats. Additionally, Bacosa *et al.* (2023) provided the first comprehensive evidence of mesoplastics—plastic particles between 5 mm and 25 mm—in the sandy beaches of Iligan City, with higher concentrations found near the city center and polyethylene mesoplastics being the most common. The long-term effects of these pollutants on marine ecosystems and human health remain unclear, underscoring the need for enhanced waste management, stronger regulations, and public awareness to address the escalating issue of plastic pollution.

The practical implications of these findings include the urgent need for stringent environmental regulations, enhanced pollution monitoring, and active conservation efforts to protect critical ecosystems like mangroves and coral reefs. Theoretically, these studies contribute to our understanding of the use of ecological indicators in monitoring marine health and the potential for bioremediation strategies. Effective management and sustainable practices are essential to mitigate the adverse effects of pollution and ensure the long-term health and productivity of Northern Mindanao's coastal and marine environments.

4. CONCLUSION

This review provided a comprehensive understanding of the current environmental status in both Panguil and Iligan Bay. It highlighted the critical need for effective environmental management strategies to address the intricate relationship between industrial activities, pollution, and ecosystem health, emphasizing the urgency to protect human health and biodiversity.

Long-term monitoring programs are essential to track changes in heavy metal contamination and other pollutants in the coastal waters of Northern Mindanao, helping to understand temporal trends and the effectiveness of pollution control measures. Further studies on the effectiveness of mangrove restoration projects, focusing on biodiversity and ecological functions of reforested areas compared to natural mangroves, are also crucial. Expanding research on the use of bioindicators such as benthic foraminifera and bacterial communities will refine their application in environmental monitoring. Investigating the socio-economic impacts of environmental degradation on local communities, particularly those dependent on fisheries and aquaculture, will aid in developing targeted and sustainable livelihood interventions.

Detailed source allotment studies to identify specific industrial and agricultural activities contributing to pollution will enable more precise regulatory actions. Exploring the interactions between local environmental stressors and broader climate change impacts, particularly how rising sea levels and changing weather patterns may exacerbate existing issues, is another critical area. In-depth studies on the impacts of invasive species on local ecosystems and developing management strategies to control their spread are necessary. Investigating innovative bioremediation techniques, such as the use of marine bacteria for heavy metal biosorption, can lead to practical solutions for cleaning up contaminated marine environments. By addressing these areas, future research can lead to more effective and sustainable management of coastal and marine ecosystems in Northern Mindanao and beyond.

Future studies could also focus on tracking the sources and pathways of microplastics and mesoplastics in Panguil and Iligan Bays, particularly from fishing gear and packaging, to understand their distribution. Research could also assess the physiological and ecological impacts of microplastic ingestion on marine species and investigate the toxic chemicals associated with plastic debris and their effects on marine life and human health. Additionally, studies on the degradation rates of plastics in both sediment and water environments, along with long-term monitoring of plastic pollution levels, are essential for evaluating environmental persistence and the effectiveness of mitigation efforts.

Lastly, this work underlines the complex and interrelated nature of environmental challenges in the coastal regions of Northern Mindanao. Addressing these challenges requires a multifaceted approach that promotes environmental sustainability, fills existing research gaps, and considers both global and local contexts. Policymakers and stakeholders must leverage these insights to develop effective conservation and management strategies that safeguard the region's rich biodiversity and support the well-being of its communities. The forthcoming operation of the new Panguil Bay bridge and the ongoing economic progress further highlight the urgency of these efforts, ensuring that development proceeds in harmony with environmental management.

REFERENCES

Adyasari, D., Pratama, M. A., Teguh, N. A., Sabdaningsih, A., Kusumaningtyas, M. A. and Dimova, N., Anthropogenic impact on Indonesian coastal water and ecosystems: Current status and future opportunities, *Mar. Pollut. Bull.*, 171, 112689 (2021). https://doi.org/10.1016/j.marpolbul.2021.112689

Bacosa, H. P., Perpetua, Z. D., Aron, J. B., Bondaug, J. C. S., Cui, V. T., Imperial, J. E., Monera, C. M. M., Villariaz, J., Gabriel, A. D., Mayol, A. P. and Shiu, R. F., First documented evidence of mesoplastic pollution in the Philippines: The case of the sandy beaches in Iligan City, *Reg. Stud. Mar. Sci.*, 75, 103574 (2024). https://doi.org/10.1016/j.rsma.2024.103574

Balala, A. C., and Oclarit, J. M., Toxic heavy metal biosorption by some marine bacteria isolated from the sediments of industrial effluents of Iligan Bay, *Annals of Tropical Research*, 29(2), 1-13 (2007). https://doi.org/10.32945/atr2922.2007

Balangao, J. K. B., Caingles, V. K. S. and Baguhin, I. A., Morphological and environmental characterization of lime sludge/fly ash stabilized sub-base materials, *Sci. Int. (Lahore)*, 35(3), 283-290 (2023).

Boco, S. R., Metillo, E. B. and Papa, R. D., Abundance, size and symbionts of Catostylus sp. medusae (scyphozoa, rhizostomeae) in Panguil Bay, Northern Mindanao, Philippines, *Phil. J. Syst. Biol.*, 8, 63-81 (2014).

Bonifacio, P. S. P., Metillo, E. B. and Romano Jr., E. F., Microplastic in sediments and ingestion rates in three edible bivalve mollusc species in a southern Philippine estuary, *Water Air Soil Pollut., 233,455* (2022). https://doi.org/10.1007/s11270-022-05926-w

Cabili, J. R. and Orbita, M. L., Assessment of Heavy Metal Accumulation in Mangroves of Kauswagan, Lanao del Norte, Philippines, *IMCC J. Sci.*, 4(1), 22-25 (2024).

Castañeto, A. M. and Lacuna, M. L., Coastal zooplankton in the waters of Iligan City, Northern Mindanao, Philippines, *Aquaculture, Aquarium, Conservation and Legislation*, *8*(4), 588-601 (2015).

Celmar, J. M., Gabriel, A. D., Hung, C. C. and Bacosa, H. P., Microplastic pollution on seagrass blades in two coastal bays in Northern Mindanao, Philippines, *Reg. Stud. Mar. Sci.*, 77(1), 103636 (2024). https://doi.org/10.1016/j.rsma.2024.103636

Dejarme, S. M., Tubio, E. G. and Quiñones, M. B., Bacterial contamination in selected commercially important bivalve species and farmed seaweed in the Panguil Bay, Northern Mindanao, *J. Environ. Aquat. Resour.*, 3, 42-53 (2015).

Demotica, J. S., Amparado, R. J., Malaluan, R. M. and Demayo, C. G., Characterization and leaching assessment of ferronickel slag from a smelting plant in Iligan City, Philippines, *Int. J. Environ. Sci. Dev.*, 3(5), 470-474 (2012). http://dx.doi.org/10.7763/IJESD.2012.V3.269

Enguito, M. R. C., Dispo, A. J., Jumawan, K., Mahinay, C., Garvan, E. J., Unsang, D. K., ... and Permano, A., Analysis of heavy metals in seawater samples collected from the Port of Ozamiz, Philippines, *Journal of Multidisciplinary Studies*, 32(7), 82-107 (2018). http://dx.doi.org/10.7828/jmds.v7i2.1225

Enguito, M. R. C., and Matunog, V. E., Solid Waste Generation Rate in the Port of Ozamiz, Philippines, *J. Multi-Discip. Stud.*, 6(2), 76-90 (2017). http://dx.doi.org/10.7828/jmds.v6i2.1046

Fabiosa, M. P., Abao, C. A. A., Fabiosa, N. P. and Uba, K. I. N., First record of the invasive mussel Mytella strigata (Mollusca: Bivalvia: Mytilidae) in Panguil Bay, southern Philippines, *J. Environ. Aquat. Resour.*, 6, 35-46 (2021). http://dx.doi.org/10.48031/msunjear.2021.06.03

Gamolo, L. and Besagas, R. L., Microbiological profile of cultured seaweeds kappaphycus alvarezii, *Int. J. Biosci.*, 13, 140-145 (2018). http://dx.doi.org/10.12692/ijb/13.6.140-145

Ganaway, S. M. and Lacuna, M. L., Benthic foraminifera in moderately polluted coasts of Iligan City, Philippines: Diversity and abundance, *Anim. Biol. and Anim. Husb.*, 6(1) (2014).

Jiang, Z., Guo, Z., Peng, C., Liu, X., Zhou, Z. and Xiao, X., Heavy metals in soils around non-ferrous smelteries in China: Status, health risks and control measures, *Environ. Pollut.*, 282, 117038 (2021). https://doi.org/10.1016/j.envpol.2021.117038

Jimenez, J. U., De Guzman, A. B., Jimenez, C. R. and Acuña, R. E., Panguil Bay fisheries over the decades: Status and management challenges, *J. Environ. Aquat. Resour.*, 1(1), 15-31 (2009). http://dx.doi.org/10.48031/msunjear.2009.01.02

Jimenez, C. R., Molina, D. L., Garcia, J. P., Quiñones, M. B., de la Rosa, H. K. T., Samson, J. J. and Paghasian, M. C., Species Composition, Abundance, and Catch Trends of Roundscads Decapterus spp. in Iligan Bay, Northern Mindanao, Philippines, *J. Environ. Aquat. Resour.*, *5*, 28-42 (2020). http://dx.doi.org/10.48031/msunjear.2020.05.03

Jimenez, J. M., Tagaro, S. J., Tabotabo, J. E., Catingub, J. L., and Dacayana-Alvarez, C. M., Lead Contamination in the Waters of the Port of Mukas, Kolambugan, Philippines, *J. Multi-Discip. Stud.*, 7(1), 159-170 (2018). http://dx.doi.org/10.7828/jmds.v7i1.1250

Jumawan, C. Q., Metillo, E. B. and Polistico, J. P., Assessment of mud crab fishery in Panguil Bay, *The Philippine Journal of Fisheries*, 28(1), 17-32 (2021). http://dx.doi.org/10.31398/tpjf/28.1.2020A0002

Karaouzas, I., Kapetanaki, N., Mentzafou, A., Kanellopoulos, T. D. and Skoulikidis, N., Heavy metal contamination status in Greek surface waters: A review with application and evaluation of pollution indices, *Chemosphere*, 263, 128192 (2021). https://doi.org/10.1016/j.chemosphere.2020.128192

Keith, R., Juranes, R. S. and Metillo, E. B., Lunar periodicity in reproduction of two venerid clams Meretrix meretrix and Katelysia hiantina in Panguil Bay, Northern Mindanao, Philippines, *Int. J. Biosci.*, 13(6), 70-81 (2018). http://dx.doi.org/10.12692/ijb/13.6.70-81

Lacuna, M. L. and Alviro, M. P., Diversity and abundance of benthic foraminifera in nearshore sediments of Iligan City, Northern Mindanao, Philippines, *Anim. Biol. and Anim. Husb.*, 6(1) (2014).

Lacuna, M. L. D., Esperanza, M. R. R., Torres, M. A. J. and Orbita, M. L. S., Phytoplankton diversity and abundance in Panguil Bay, Northwestern Mindanao, Philippines in relation to some physical and chemical characteristics of the water, *Adv. Environ. Sci.*, 4(3), 122-133 (2012).

Lacuna, M. L., Masangcay, S. I., Orbita, M. L. and Torres, M. A., Foraminiferal assemblage in southeast coast of Iligan Bay, Mindanao, Philippines, *Aquaculture, Aquarium, Conservation and Legislation*, *6*(4), 303-319 (2013).

Lagud, Y. L., Logronio, F. V., Sakilan, J. M. and Yagos, R. M., Assessment on the seagrass cover in Cabucan Island Hadji Panglima Tahil, Sulu Philippines, *Journal of Biodiversity and Environmental Sciences (JBES)*, 17(3), 93-100 (2020).

Laput, J. R. L., Adamat, L. A., Tumang, V. M. C. and Moneva, C. S. O., Bioaccumulation of microplastics in *Echinolittorina* sp. along intertidal areas of Barangay Buru-un, Iligan City, Philippines, *AACL Bioflux*, 17(1), 499-507 (2024).

Metillo, E. B., Cadelinia, E. E., Hayashizaki, K. I., Tsunoda, T. and Nishida, S., Feeding ecology of two sympatric species of Acetes (Decapoda: Sergestidae) in Panguil Bay, the Philippines, *Mar. Freshwater Res.*, 67(10), 1420-1433 (2015). http://dx.doi.org/10.1071/MF15001

Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., Abubakr M. I., Mayeen, U. K., Hamid, O., Fahad A. A. and Simal-Gandara, J., Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity, *J. King Saud Univ. Sci.*, 34(3), 101865 (2022). https://doi.org/10.1016/j.jksus.2022.101865

Nabua, W. C., Roxas, A. T. and Uy, W. H., The status of mangroves in Panguil Bay, Philippines, *AACL Bioflux*, 16(6), 3079- 3092 (2023).

Orbita, M. L. and Gumban, N. B., Investigation of the community structure of seagrasses in the coastal areas of Iligan City, Mindanao, Philippines, *Adv. Agric. Botanics*, *5*(3), 140-151 (2013).

Osing, P. K. A. S., Jondonero, M. A. P., Suson, P. D., Guihawan, J. Q. and Amparado Jr, R. F., Species composition and diversity in a natural and reforested mangrove forests in Panguil Bay, Mindanao, Philippines, *J. Biodivers. Environ. Sci.*, 15, 88-102 (2019).

Pinna, M., Zangaro, F., Saccomanno, B., Scalone, C., Bozzeda, F., Fanini, L. and Specchia, V., An overview of ecological indicators of fish to evaluate the anthropogenic pressures in aquatic ecosystems: from traditional to innovative DNA-based approaches, *Water*, 15(5), 949 (2023). https://doi.org/10.3390/w15050949

Poikane, S., Herrero, F. S., Kelly, M. G., Borja, A., Birk, S. and Van, D. B. W., European aquatic ecological assessment methods: A critical review of their sensitivity to key pressures, *Sci. Total Environ.*, 740, 140075 (2020). https://doi.org/10.1016%2Fj.scitotenv.2020.140075

Recamara, D. B. and De Guzman, A. B., Spatio-Temporal Patterns of Reef Fish Communities in Selected Marine Protected Areas in Iligan Bay, Northern Mindanao, *J. Environ. Aquat. Resour.*, 3, 84-95 (2015). http://dx.doi.org/10.48031/msunjear.2015.03.08

Roa, E. C., Nutrients and heavy metals of plankton in mussel growing areas: Panguil Bay, Lanao del Norte and Binoni Lagoon, Camiguin Province [Philippines] (1998).

Sany, S. B. T., Salleh, A., Sulaiman, A. H., Sasekumar, A., Rezayi, M. and Tehrani, G. M., Heavy metal contamination in water and sediment of the Port Klang coastal area, Selangor, Malaysia, *Environ. Earth Sci.*, 69(6), 2013-2025 (2013). https://doi.org/10.1007/s12665-012-2038-8

Sardar, K., Ali, S., Hameed, S., Afzal, S., Fatima, S., Shakoor, M. B., Saima, A. B. and Tauqeer, H. M., Heavy metals contamination and what are the impacts on living organisms, *Greener Journal of Environmental management and public safety*, 2(4), 172-179 (2013). https://doi.org/10.15580/GJEMPS.2013.4.060413652

Siblos, S. K. V. and Tabugo, S. R., High-throughput analysis using 16S rRNA sequencing of bacterial communities associated in selected mangrove species from Bayug Island, Iligan City, Philippines, *Biodiversitas Journal of Biological Diversity*, 25(1) (2014). https://doi.org/10.13057/biodiv/d250107

Sienes, R. K. A., Lucaser, M. A. O. and Metillo, E. B., Population Parameters of Asiatic Hard Clam, Meretrix meretrix (Bivalvia: Veneridae), in Panguil Bay, Philippines, *Mindanao Journal of Science and Technology*, 20(2) (2022). http://dx.doi.org/10.61310/mndjstecbe.0989.22

Superada, J. L. and Tampus, A. D., Macroinvertebrates as indicators of water quality in three estuary sites in Iligan City, Philippines, *J. Multi-Discip. Stud.*, 4(1), 50-85 (2015). http://dx.doi.org/10.7828/jmds.v4i1.859

Tampus, A. D., Apuan, D. A., Jabbar, M. M. and Salapuddin, F. B., Characterization of seawater quality in stressed coastal zone of Iligan Bay, *Adv. Environ. Sci.*, 6(1), 7-16 (2014).

Tampus, A. D., Tobias, E. G., Amparado, R. F., Bajo, L. M. and Sinco, A. L., Assessment of the riparian vegetation along the riverine systems in Iligan City, Philippines, *Adv. Agricult. Botanics*, *5*(2), 102-114 (2013).

Tanjung, R. H. R., Hamuna, B., and Yonas, M. N., Assessing heavy metal contamination in marine sediments around the coastal waters of Mimika Regency, Indonesia, *J. Ecol. Eng.*, *20*(11) (2019). https://doi.org/10.12911/22998993/113411

Teves, F., Mercury-Resistant Bacteria Isolated from an Industrial Effluent Outlet in Iligan City, Philippines, *Asia Pacific Journal of Social Innovation*, 9(2), (1994).

Tian, K., Wu, Q., Liu, P., Hu, W., Huang, B., Shi, B., Yunqiao, Z., Bong-Oh, K., Kyungsik, C., Jongseong, R., Jong, S. K. and Wang, T., Ecological risk assessment of heavy metals in sediments and water from the coastal areas of the Bohai Sea and the Yellow Sea, *Environ. Int.*, 136, 105512 (2020). https://doi.org/10.1016/j.envint.2020.105512

Unsing, H. M., and Lacuna, M. L., Assemblages of benthic foraminifera in front of three industries along the coast of Iligan City, Southern Philippines and its relation to some environmental parameters, *Adv. Environ. Sci.*, *6*(2), 168-182 (2014).

Vicente, H. J., Gaid, R. D., Dejarme, H. E., Roa, E. C. and Azanza, R. V., Harmful algal bloom in Iligan bay, southern Philippines, *Sci. Diliman*, 14(2) (2002).

Villanueva, G. V., Alaman, B. B., Calago, J. C., Genon, A. M. and Pangilinan, P., Diversity of mangrove species along Panguil Bay, Ozamiz City, Mindanao Island, Philippines. *Int. J. Bot. Stud.*, *6*(3), 580-586 (2021). https://dx.doi.org/10.22271/botany

Wang, S. L., Xu, X. R., Sun, Y. X., Liu, J. L. and Li, H. B., Heavy metal pollution in coastal areas of South China: a review, *Mar. Pollut. Bull*, 76(1-2), 7-15 (2013). https://doi.org/10.1016/j.marpolbul.2013.08.025

Witkowska, D., Słowik, J. and Chilicka, K., Heavy metals and human health: Possible exposure pathways and the competition for protein binding sites, *Mol.*, 26(19), 6060 (2021). https://doi.org/10.3390/molecules26196060

Yadav, H., Kumar, R. & Sankhla, M. S., Residues of pesticides and heavy metals in crops resulting in toxic effects on living organism, *J. Seybold Rep.*, *1533*, 9211 (2020). http://dx.doi.org/10.13140/RG.2.2.24806.65609

Yan, M., Wang, L., Dai, Y., Sun, H. & Liu, C., Behavior of microplastics in inland waters: aggregation, settlement, and transport, *Bull. Environ. Contam. Toxicol.*, 107(4), 1-10 (2021). https://doi.org/10.1007/s00128-020-03087-2