Innovations

Reef at Risk: A Rapid Evaluation of Copper Pollution in Cebu City's Coral Ecosystem

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Abstract: *Coral reefs are vital ecosystems supporting marine biodiversity, providing significant ecological and economic benefits. This study evaluated copper levels in Cebu City's SRP reef ecosystem. Situated near river mouths, the reef is highly vulnerable to pollution. The study analyzed copper concentrations in sediments from three sites with varying proximity to urban runoff sources, examined the relationship between copper levels and site proximity, and conducted a rapid visual assessment of the reef and its associated fauna. Sediment samples were analyzed revealing interesting patterns of copper concentrations. Surprisingly, the highest levels were observed at the site farthest from urban runoff sources (Site2). ANOVA test showed no statistically significant differences in mean copper concentrations among the sites (p=0.282), and the distribution of values demonstrated substantial variability. Copper concentrations were generally lower in sandy sediments compared to silt, consistent with the latter's higher capacity for heavy metal adsorption. Findings highlight dynamics influencing copper distribution in reef sediments, including sediment characteristics. While copper levels were below the threshold for acute toxicity, potential for bioaccumulation and long-term impacts on coral health cannot be ignored. Reef biodiversityindicated 30 fish species (9 Pomacentridae), 6 algae species, and 4 echinoderms. Despite 23% dead coral and 39.84% rubble, 31.83% live coral indicates resilience, yet urgent sustainable management is needed due to fishing, sedimentation, and pollution.Further testing, increased sampling, and environmental factor analysis are needed to understand copper sources and impacts on reef health. Continuous monitoring, pollution control, and community engagement are recommended to be conducted.*

Keywords*: urban pollution, copper concentration, coral reefs, reef-associated fauna, conservation efforts*

Introduction

Coral reefs, often referred to as the rainforests of the sea, are critical ecosystems that support marine biodiversity, providing habitats for approximately 25% of all marine species, including fish and invertebrates (Hoegh-Guldberg et al., 2007). However, urban coral reefs, which are located near densely populated areas, are increasingly threatened by anthropogenic pressures such as pollution, overfishing, and habitat destruction. Among these threats, pollution from heavy metals like copper has emerged as a particularly insidious factor, disrupting the ecological balance of these sensitive habitats.This study then tried to explore the levels of copper contamination in selected sites in the urban coral reef ecosystem located in Cebu City, Philippines. Cebu City, one of the most rapidly urbanizing coastal cities in the country, hosts a recently rediscovered coral reef adjacent to the South Road Properties (SRP) area. This reef, though located near multiple river mouths that carry urban runoff, remains largely understudied in terms of its pollution levels, particularly concerning copper contamination. Given the crucial role reefs play in marine ecosystems and the vulnerability of this reef to urbanization pressures, this study seeks to evaluate the impact of copper pollution and provide baseline data for future conservation efforts.

Coral reefs are globally recognized for their ecological, economic, and cultural importance. However, urban coral reefs, especially those located in proximity to large cities, face unique challenges due to the influx of pollutants, sedimentation, and habitat degradation. Cebu City's coral reef, situated near the SRP area, is particularly vulnerable due to its proximity to several river mouths, such as the Guadalupe, Arrabal, and Bulacao Rivers, which are conduits for urban runoff and industrial waste (Jones et al., 1997). Copper, a prevalent pollutant in these waters, is especially harmful to corals, causing physiological stress at concentrations as low as 10 μg/L and fatal effects at concentrations above 30 μg/L (Negri & Hoogenboom, 2011). Given these threats, it is imperative to assess the current levels of copper pollution in Cebu City's reef and its potential impact on coral health.

The increasing urbanization of coastal areas has led to a surge in pollution, particularly from heavy metals such as copper, which is widely used in industrial processes and antifouling paints for ships (Jones et al., 2019). Copper is highly toxic to coral reefs, even at low concentrations, and can disrupt critical biological processes like photosynthesis and respiration by damaging the coral's symbiotic algae, zooxanthellae (Fabricius, 2005). Furthermore, copper impairs larval settlement and growth in corals, which can severely limit reef regeneration and resilience (Vandermeulen & Bamba, 2020). Despite these significant impacts, there is a lack of comprehensive data on the extent of copper contamination in urban coral reefs, particularly in Southeast Asia, hence the call for studies focusing on coral reef health and heavy metals concentrations, specifically copper.

Research objectives

This study aims to address this gap by conducting a rapid evaluation of copper pollution in Cebu City's coral reef ecosystem, which is possibly the last remaining reef in the area. With these, the study sought to provide the current status of Cebu City SRP's coral reef ecosystem and copper concentrations by looking at the copper levels among its reef-associated fauna- with the following target objectives:

1. measure concentrations of copper in the sedimentsof from Cebu City's coral reef;
2. analyze the relationship between the reef's proximity to urban runoff sources and the levels of copper contamination;
3. provide a qualitative connection between the findings of the biodiversity assessment in the reef and the measured copper levels in the sediments

Related Studies

Several studies were keen to note on the feasibility of sediment copper to correlate with the reef health and that they reported some interesting insights. To note, Jafarabadi et al. (2017) investigated heavy metal distribution, ecological risk, and human health risks in marine surface sediments and coastal waters of fringing coral reefs in the Persian Gulf. The study then found significant spatial variations in heavy metal concentrations, with higher levels near urban areas and industrial activities revealing potential adverse effects on marine organisms, particularly in areas with elevated heavy metal levels. More so, Gopinath et al. (2010) conducted a baseline study of trace metal concentrations in coral reef sediments of the Lakshadweep Archipelago, finding that concentrations varied spatially across different reef sites after observing enrichment of certain metals compared to global average shale values. They then emphasized the importance of establishing baseline data for future monitoring and assessment of trace metal pollution in this relatively pristine environment.

Marques et al. (2020) investigated the ecotoxicological effects of combined copper exposure, ocean acidification, and warming on a reef calcifying organism using a multiple biomarker approach, in which they found that copper exposure caused significant physiological stress, even at environmentally relevant concentrations. These combined stressors were deemed to result in greater detrimental impacts on the calcifying organism than any single stressor alone, highlighting the synergistic effects of multiple environmental changes on marine organisms.Pait and his team (2014) assessed chemical contaminants in sediments from the St. Thomas East End Reserves in the US Virgin Islands identifying various contaminants, including heavy metals and polycyclic aromatic hydrocarbons (PAHs), exceeding effect levels in some areas. Sediment contamination was then linked to historical and ongoing anthropogenic activities, such as industrial discharges and boat traffic.

Copper pollution in Cebu City's coral ecosystem presents a significant environmental threat, particularly due to the harmful effects of heavy metals on coral reefs. Coral ecosystems, known for their sensitivity to changes in water quality, are vulnerable to bioaccumulation of heavy metals such as copper, leading to severe ecological consequences- with literature shows that coral reefs can absorb and accumulate copper from surrounding marine environment. For instance, Mokhtar et al. (2012) indicated that corals can act as bioindicators of trace metal pollution, including copper, by incorporating these metals into their skeletons. This bioaccumulation can disrupt coral physiology, increase susceptibility to diseases, and diminish their resilience to other environmental stressors such as climate change and ocean acidification.

Locally, the sources of copper pollution in Cebu City's marine environments can be traced back to a combination of anthropogenic activities, including industrial discharges, agricultural runoff, and urbanization. According to the findings of Ramos et al. (2004), urbanization has been directly linked to the increase of heavy metal concentrations in coral reef sediments, which poses a significant risk to marine biodiversity. Industrial activities, particularly in regions undergoing rapid development, contribute substantial amounts of copper and other trace metals to coastal waters(reference). This mirrors findings from similar studies conducted in other regions, such as Chabahar Bay, where industrial and urban waste was found to cause heavy metal contamination in coral reefs. The impacts of copper pollution on coral reefs have been studied extensively in the Philippines and other regions with urbanized coasts. For example, David (2002) studied the effects of a mine-tailings spill in Marinduque Island, Philippines, where copper and other metals significantly affected marine sediments. This research underscores the need for more stringent environmental regulations and industrial waste management practices to mitigate the impacts of such pollution

Del Fierro et al. (2021) reported on the state of marine protected areas (MPAs) in Tuburan, Cebu, noting that coral cover and fish populations have been maintained through conservation efforts. However, ongoing copper pollution could undermine these conservation initiatives if not addressed(reference). The combination of pollution and ineffective waste management strategies poses a long-term threat to the sustainability of Cebu's coral ecosystems. One solution for this ss the implementation of stricter pollution control regulations and enhanced monitoring systems to track the health of coral ecosystems over time. However, implementing such measures may require significant financial investment, collaboration between government agencies, and engagement with industrial stakeholders.

Methodology

The study assessed the levels of copper contamination in sediments in multiple sampling sites with varying proximity to urban runoff sources. This approach not only focuses on the quantitative analysis of copper concentrations but also incorporates spatial dimensions to investigate the relationship between urbanization and environmental contamination. By employing standardized sampling and analytical techniques, the study aimed to provide robust data that will enhance our understanding of how urban runoff contributes to copper pollution in marine ecosystems. Furthermore, the study performed a visual assessment of the reef to conduct a rapid assessment of the reef in relation to measured copper toxicity levels.

Figure 1.

Map of the study area in Cebu Straight adjacent to the South Road Properties

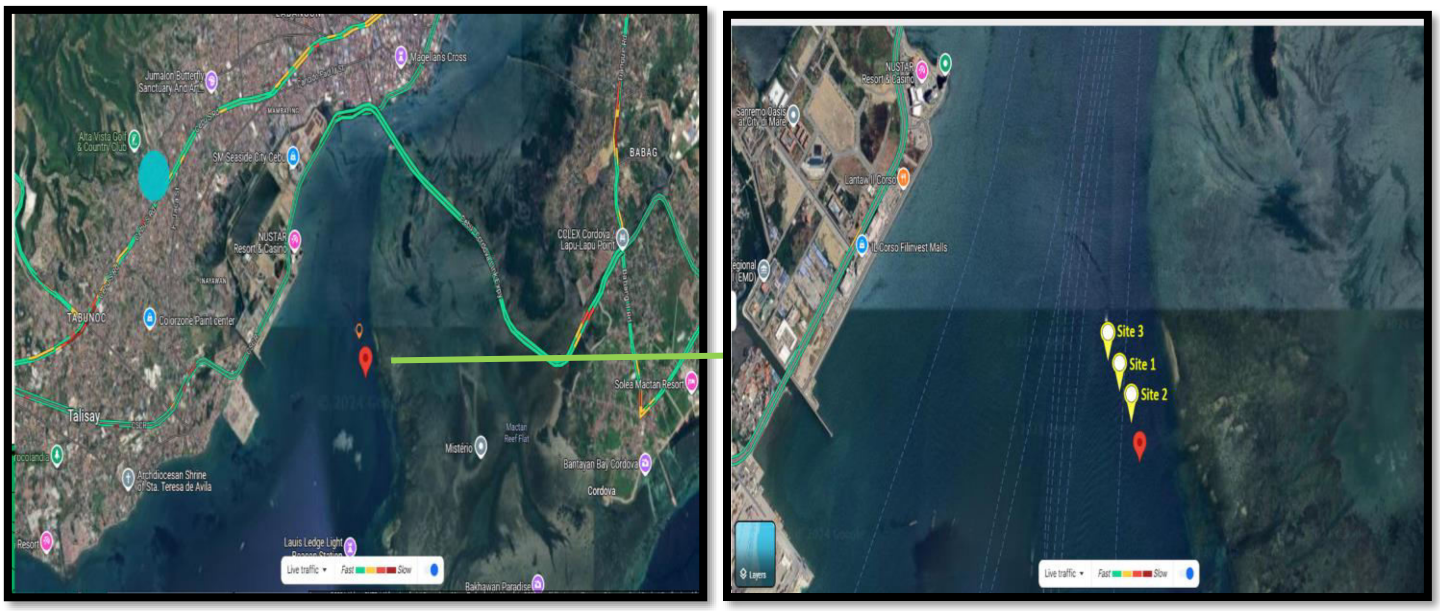


Figure 1 shows the study area which is located in the Cebu Strait, particularly in the waters adjacent to Cebu South Road Properties (SRP), facing NuStar Resort & Casino and the IL Corso Filinvest MallCebu City reef was selected as a site for a potential marine protected area, located 10°15.44' North and 123°53.7' East. The Cebu South Coastal Road runs parallel to the shoreline, creating a boundary between the inland urban development and the coastal marine environment. This section of the Cebu Strait is influenced by urban runoff from surrounding residential, commercial, and industrial zones. Additionally, the Cebu South Road Properties (SRP) is a reclaimed area with significant ongoing urban and industrial activity, which makes the surrounding waters vulnerable to pollution, including copper contamination from runoff and waste dischargefacing potential environmental stress due to the heavy traffic, construction activities, and potential discharge from industries, all of which can introduce pollutants, including copper, into the marine ecosystem. It is also subject to currents that may spread pollutants, affecting coral reefs and marine biodiversity. The 2021 annual Report from DENR-Environmental Management Bureau (EMB) revealed that Butuanonand Guadalupe Rivers in Metro Cebu were continuously monitored due to their proximity to heavily industrialized and densely populated areas, resulting in extremely high pollution levels with elevated BOD concentrations and low oxygen levels. Major development issues in Metro Cebu, such as poor sewage and solid waste management, are exacerbated by rapid population growth and informal settlements (DENR, 2022).

Site selection

Three sampling sites were chosen based on their proximity to potential copper contamination sources, including urban runoff outlets, industrial discharge areas, and major shipping lanes. The selection is geared to represent a gradient of exposure, with some sites situated near high-exposure areas and others positioned farther away to serve as control or baseline comparison points. To ensure precise site selection, a Geographic Information System (GIS) was employed, allowing for accurate georeferencing of each site using GPS coordinates (Harvey et al., 2007).

B. Sampling

Sediment Collection

Sediment samples were collected from each site last November 2024, to assess copper accumulation in the reef substrate. Sediments act as reservoirs for heavy metals, which can be remobilized into the water column under certain environmental conditions, thus contributing to ongoing contamination. Using PVC pipe corers, sediment cores were collected at a depth of 10 cm to capture the upper layer, where the highest concentration of pollutants typically accumulates (Bastidas & García, 2000). To enhance representativity, three replicate cores were taken from each site. These samples were stored in sterilized bottles, immediately after collection, were transported to the laboratory for analysis.

Copper Concentration Analysis

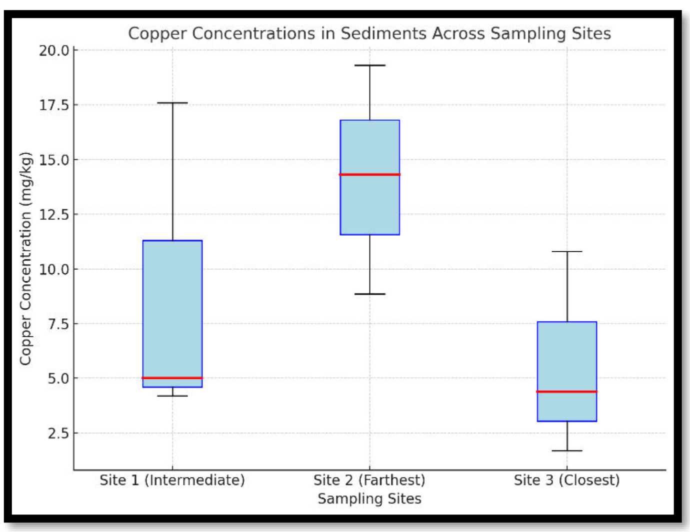
Copper concentrations in sediments was also determined using Atomic Adsorption Spectrometer (AAS) a highly sensitive technique capable of detecting trace levels of metals (Ellwood & Van den Berg, 2000) at the USC Water Laboratory. Prior to analysis, all samples underwent standardized digestion procedures to ensure that copper is fully extracted from the sample matrices.

Results and Discussions

The data collected from the site were then subjected to analysis in the lab. Further, data from a recent terminal report of the reef and reef-associated fauna were recorded and included in the study.

Figure 2

Results of copper levels per site collection



The boxplot presented in Figure 2 highlights the distribution of copper concentrations across the three sampling sites:Site 2 (Farthest) has the highest median concentration and the widest range, suggesting greater variability in copper levels.Site 3 (Closest) has the lowest median copper concentration and a smaller range, contradicting the expectation that proximity to urban runoff would result in higher contamination.Site 1 (Intermediate) shows moderate copper levels but with a notable outlier (17.6 mg/kg).

Boxplot Analysis

At Site 1 (Intermediate), copper concentrations exhibit relatively low levels, with a median of approximately 5 mg/kg. The interquartile range (IQR) reveals moderate variability, with the majority of values falling between roughly 4 and 10 mg/kg. The whiskers extend slightly beyond this range, indicating a narrow spread of concentrations and the absence of significant outliers.Site 2 (Farthest) demonstrates the highest copper concentrations among the three sites (14 mg/kg). The IQR highlights significant variability, as most data points are distributed between approximately 9 and 19 mg/kg. The whiskers are relatively short, suggesting that the majority of the measurements are tightly clustered around the IQR and that no extreme outliers are present.In contrast, Site 3 (Closest) shows the lowest copper concentrations of 4 mg/kg. The IQR indicates limited variability, as most data points range between 1.5 and 6 mg/kg. The whiskers show a minimal spread beyond the IQR, reflecting the consistency of the data and a lack of extreme values at this site. indicating a non-localized source of pollution (e.g., atmospheric deposition or long-range water transport).

Table 1

Samples with their sediment classification, copper levels per site with the threshold and probable effect level per site

Sample code	Copper levels (in mg Cu/Kg)	Sediment type	Threshold/Effect level
1A	5.01	1A - Sandy	Threshold Effect Level (TEL): **18.7 mg/kg** Probable Effect Level (PEL): **108 mg/kg**
1B	17.6	1B - Silt	
1C	4.20	1C - Sandy	
2A	8.85	2A - Sandy	
2B	14.3	2B - Silt	
2C	19.3	2C - Silt	
3A	10.8	3A - Silt	
3B	1.69	3B - Silt	
3C	4.39	3C- Sandy	

Above is the list of samples with their sediment classification, copper levels per site with the threshold and probable effect levels. For the Threshold Effect Level (TEL), the level is 8.7 mg/kg, below this, adverse effects on marine organisms are unlikely. In addition, Probable Effect Level (PEL) sets into a 108 mg/kg level, above this, adverse effects on marine organisms are more likely.

Implications of copper levels reef's proximity to pollution source

The data analyzed from this studywith respect to copper concentrations in sediment samples across three reef sites revealed important trends in contamination levels and their potential implications for coral health. While the one-way ANOVA indicated no statistically significant differences among the three sites, the distribution of copper concentrations, as visualized in the boxplot, suggests that factors other than proximity to runoff sources play a crucial role in sediment copper contamination.

For Site 1 located at an intermediate distance from urban runoff sources, exhibited moderate copper concentrations with a median of approximately 5 mg/kg and an interquartile range (IQR) of 4–10 mg/kg. This suggests that dispersal mechanisms or limited pollution inputs may influence copper levels at this site. Site 2, the farthest from urban runoff sources, displayed the highest copper levels, (14 mg/kg and an IQR of 9–19 mg/kg). The elevated copper concentrations at this site may be attributed to sediment characteristics, such as finer grains or higher organic matter content, which are known to bind heavy metals effectively. These findings are consistent with Gupta and Singh (2011), who reported that fine-grained sediments and organic matter serve as reservoirs for heavy metals. Surprisingly, Site 3, the closest to urban runoff sources, had the lowest copper concentrations, with a median of ~4 mg/kg and minimal variability (IQR ~1.5–6 mg/kg). This somehow counterintuitive result may be due to strong water currents or sediment flushing processes that limit copper accumulation near runoff sources, a phenomenon supported by Salomons and Förstner (1984), who emphasized the role of hydrodynamic conditions in contaminant transport.

Table 2

ANOVA results Copper level and distance of each sites

Cases	Sum of Squares	df	Mean Square	F	p
Distance	110.782	2	55.391	1.573	0.282
Residuals	211.333	6	35.222		

Note. Type III Sum of Squares

From the data, p-value of 0.282 was recorded, which is greater than the significance level (0.05). This indicates that there is no statistically significant difference in copper concentrations among the three sampling sites.The lack of significant differences may suggest that other factors (e.g., ocean currents, sediment characteristics, or copper retention in sediments) influence the distribution of copper concentrations more than proximity to urban runoff sources.

Copper concentrations in all three sites were below the threshold of 50 mg/kg, a commonly cited value for copper toxicity in marine sediments. However, even at sub-lethal concentrations, copper can adversely impact coral health, with data that copper interferes with coral reproduction, larval settlement, and photosynthesis by damaging the symbiotic algae (zooxanthellae) within coral tissues, as with Jones (1997) who demonstrated that copper concentrations as low as 10 µg/L in water can impair photosynthetic efficiency in corals, while Weber et al. (2012) noted that chronic exposure to low levels of copper can disrupt coral calcification and growth. Although sediment-bound copper is less bioavailable than dissolved copper, disturbances such as storms or dredging could release bound copper into the water column, posing a direct threat to reef ecosystems.The elevated copper levels at Site 2 raise concerns about potential bioaccumulation and long-term impacts on reef health. Sediments in this area could act as a chronic source of copper exposure for benthic organismsand other reef-associated fauna. Bioaccumulation of copper through trophic transfer may further impact the broader reef ecosystem, potentially leading to declines in biodiversity and ecosystem functionality (Rainbow, 2002).These highlighted the complexity of copper distribution in reef sediments and its implications for the said coral reef health. While proximity to urban runoff sources is a critical factor, other environmental variables, such as sediment composition, water circulation, and pollution transport mechanisms, must also be considered- strengtheningthe importance of holistic monitoring approaches that integrate sedimentological and hydrodynamic analyses with assessments of bioavailable copper and its ecological impacts. Mores so, the copper concentrations observed in reef sediments, while below acute toxicity thresholds, may still pose risks to coral health, particularly under conditions that enhance copper bioavailability. This poses a dire need for targeted pollution management and conservation strategies that address both point and non-point sources of contamination. In addition, further research on the bioavailability of copper and its sub-lethal effects on coral physiology is essential for mitigating long-term risks to coral reef ecosystems.

Reef and Reef-associated Fauna

The following data were cited from the study ofRosales (n.d.) as part of the terminal report of the assessment of marine biodiversity resources conducted last October 2024 through the Integrated Coastal Resources Management Center of the Cebu Technological University-Main Campus. The said report was also conducted in the site of the current study site. Similar observations were noted as for the marine organisms from the latter to the previous and as per confirmation of the Bantay Dagat.

In this area, no seagrass was found. Six species of algae were identified namely, Caulerpa racemosa, Caulerpa lentillifera, Padina Sp., Halymenia Sp., Turbinaria Sp. And Halimeda Sp. and belongs to five families. For the ichthyofauna, a total of 30 species were identified and recorded comprising of 15 fish families. Of these, family Pomacentridae (Damselfishes) has the highest number of species found in the area with nine (9) species, followed by Apogonidae with two species, Labridae, Chaetodontidae, Mullidae, Scaridae and Caesionidae with two species and Pinguipedidae, Tetraodontidae, Pomacathidae, Serranidae, Scianidae, Lutjanidae, Nemipteridae and Monacanthidae having one species. For the macro-invertebrate composition of the reef, data reported that there arefour species belonging to Phylum Echinodermata with three families, namely Oreasteridae (Seastar), Comatulidae (Feather Star), and Diadematidae (Sea Urchin).The reef ecosystemexhibits a mix of resilience and signs of environmental stress. A significant portion, 39.84%, consists of sand, silt, and rubble, indicating a notable presence of degraded or non-living substrates. Dead coral accounts for 23% of the reef, reflecting the effects of environmental stressors or human activities such as overfishing, sedimentation, and coral bleaching. Despite these, live coral still covers 31.83% of the area, playing a vital role in supporting the reef's biodiversity and health. This proportion of live coral provides hope for recovery if the stressors impacting the reef are effectively managed. As for algae (5.33% of the reef), they form a relatively small component, possibly highlighting the competition for space between algae and live coral- indicating shifts in water quality or nutrient availability within the ecosystem.

As per data reported as well by Rosales(n.d.), the reef's composition highlights an ecosystem under stress, as indicated by the significant presence of dead coral and loose sediments. Nevertheless, the considerable live coral cover and minimal algae presence demonstrate resilience and potential for recovery with appropriate conservation measures. The coral cover in the area is classified as fair, with 31.83% live coral cover, 22.33% of which consists of soft corals. Studies show that coral reefs often experience phase shifts when hard coral dominance gives way to macroalgae, sponges, corallimorpharians, zoantharians, and soft corals(Hughes et al., 2007). The reef also serves as a key fishing ground for Cebu City and nearby municipalities. However, unregulated fishing practices have caused extensive damage, accelerating the decline in coral cover. Additional stressors, such as land reclamation projects and industrial runoff, have further degraded the reef. Sediments from reclamation materials and industrial discharge settle on the reef, smothering corals, impeding their feeding and reproduction, and diminishing the light necessary for photosynthesis. This sedimentation process not only harms corals but also affects filter-feeding organisms reliant on a healthy reef environment.Currently, the reef comprises 23% dead coral cover, 5.33% algae, and 39.84% non-living substrate, including sand, silt, and rubble. These indicators underscore the urgent need for sustainable management practices to protect and restore the reef's ecological balance.

Conclusion

This study investigated copper concentrations in sediments from three reef sites, revealing significant spatial variability despite no statistically significant overall difference (p=0.282). Site 2, furthest from urban runoff, exhibited the highest median copper level (14 mg/kg) and lowest relative variability (CV=0.369), suggesting a consistent, likely non-point source of contamination. This contrasts with Sites 1 and 3, closer to urban runoffs, which showed moderate mean concentrations but high relative variability (CVs of 0.841 and 0.832, respectively). Site 1's variability points to fluctuating pollution inputs, whereas Site 3's low levels, despite proximity to potential runoff, may indicate effective dispersal mechanisms or sediment flushing processes.

These highlights the complexity of copper distribution in reef sediments, influenced by factors beyond proximity to urban runoff (sediment characteristics and hydrodynamic conditions). While all sites had copper levels below the 50 mg/kg threshold for toxicity, the variability and higher mean concentrations in Sites 1 and 2 raise concerns regarding potential sub-lethal impacts on coral health. The observed variability highlights the need for ongoing monitoring and tailored management strategies.

The accompanying reef assessment (Rosales, n.d.) reveals an ecosystem under stress, with significant dead coral (23%) and sediment (39.84%), yet demonstrating resilience with substantial live coral cover (31.83%). This highlights the intertwined nature of water quality and reef health. The high copper levels in Site 2, combined with the prevalence of dead coral and sediment in the broader reef ecosystem, underscore the potential for synergistic effects, impacting coral health and biodiversity. This necessitates integrated management strategies that address both point and non-point pollution sources, while also focusing on sediment characteristics and hydrodynamic conditions to mitigate further risks to coral reef ecosystems. Further research on copper bioavailability and its sub-lethal effects on coral physiology is noted to be critical for effective conservation efforts.

Recommendations

From the data presented, some important key points have been taken into considerations of the researchers and can be used as benchmark areas:

It is suggested to perform additional tests like sediment transport modeling or chemical fingerprinting, copper bioavailability testslike porewater copper concentrations and complete heavy metal pollution panel to trace the sources of copper.Increase sampling replicates to reduce variability within sites and strengthen statistical power. More so, analysis of other environmental factors (e.g., sediment grain size, organic matter) that might affect copper adsorption and distribution is recommended. Toxicology assessment, mapping and pollution source identification, which were not part of the study is highly recommended as this will also justify how environmental key drivers affect fauna in the reef as well as the overall coral reef health. It is deemed important as well to implement continuous monitoring of heavy metal levels and other pollutants, particularly in silt sediment areas, to mitigate contamination hotspots and address sources of pollution. While information dissemination is crucial, it is also equally essential to enforce stricter controls on land reclamation projects, industrial discharges, and the use of destructive fishing gear to minimize further degradation of reef habitats.More engagement to local communities in sustainable fishing practices and marine conservation efforts to balance livelihood needs with ecological preservation is also suggested.As assessment studies play a vital role in successful biodiversity and conservation efforts, it is also imperative to conduct longitudinalstudies and long-term monitoring on biodiversity, sediment dynamics, and coral health to evaluate the effectiveness of implemented interventions and guide future policy-making.

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