IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Sustainable Development and Planning
Vol. 21, No. 2, February, 2026, pp. 631-642
Journal homepage: http://iieta.org/journals/ijsdp

Coastal Planning and Water Quality Management Under Industrial Reclamation in the Manyar Estuary, Gresik, Indonesia

Andik Isdianto[1*], Mark Jonathan Manullang[1], Oktiyas Muzaky Luthfi[1], Rudianto[1], Gilang Rusrita Aida[2], Nico Rahman Caesar[2], Desy Arisandi[2], Rhochmad Wahyu Illahi[3], Aulia Lanudia Fathah[4], Alifiulahtin Utaminingsih[5], Mohammad Maskan[6], Berlania Mahardika Putri[7]

[1] Department of Fishery and Marine Resources Utilization, Brawijaya University, Malang 65145, Indonesia
[2] Department of Fisheries Marine Resources Management, Brawijaya University, Malang 65145, Indonesia
[3] Department of Socio-Economy Fisheries and Marine, Brawijaya University, Malang 65145, Indonesia
[4] Master Program of Environmental Management and Development, Brawijaya University, Malang 65145, Indonesia
[5] Doctoral Program in Sociology, Brawijaya University, Malang 65145, Indonesia
[6] Department of Business Administration, State Polytechnic of Malang, Malang 65141, Indonesia
[7] Master of Environmental Sciences, Universitas Gadjah Mada, Yogyakarta 55284, Indonesia

Corresponding Author Email: andik.isdianto@ub.ac.id

https://doi.org/10.18280/ijsdp.210215

Received: 25 August 2025
Revised: 20 February 2026
Accepted: 26 February 2026
Available online: 28 February 2026

Keywords:
coastal environmental management, coastal land reclamation, compliance monitoring, estuarine turbidity, industrial pollution control, reclamation sustainability strategies, salinity variation, sediment transport analysis

ABSTRACT

Industrial land reclamation in the Manyar Estuary, Gresik (Indonesia), is reshaping coastal water quality and management. This study quantifies links between reclamation extent and estuarine water parameters and turns the evidence into practical coastal-planning actions. We analysed a five-year dataset (2020-2024) combining in-situ measurements at 14 stations (depths 0, 1, and 3 metres) with curated secondary records, and tested associations using correlation analysis within an integrated coastal-planning perspective. Turbidity rose from 5.0 to 16.8 nephelometric turbidity units (NTU; standard < 5), salinity from 24.0 to 31.0, and sediment grain size from 0.0180 to 0.0185 millimetres, while dissolved oxygen improved from 4.0 to 6.6; the reclaimed area expanded from 118 to 128 hectares. Exploratory correlation analysis ($n = 5$) indicated positive associations between reclamation extent and salinity (Pearson $r = 0.884$) and sediment grain size ($r = 0.967$), while turbidity increased monotonically with reclamation extent (Spearman $\rho = 1.000$), though the Pearson association was not statistically supported. Sediment grain size changed marginally (0.0180 to 0.0185 mm) and its correlation with reclamation ($r = 0.967$) should be interpreted cautiously because the absolute change is very small and uncertainty estimates are not provided. Given the short time series ($n = 5$) and mixed data sources, these associations should be treated as exploratory and used to prioritize improved monitoring and hypothesis-driven follow-up analyses before detailed management prescriptions are adopted.

1. INTRODUCTION

Gresik, a key industrial center in East Java, Indonesia, has undergone rapid expansion, significantly impacting the coastal environment. The Manyar Estuary, a vital ecological and economic zone, is increasingly affected by industrial reclamation projects, including the Java Integrated Industrial and Port Estate (JIIPE) [1]. These activities have led to notable shifts in turbidity, salinity, and sediment composition, altering hydrodynamic conditions and biodiversity [2]. While industrial development drives economic growth, it also raises serious environmental concerns that require scientific investigation and sustainable management strategies [3].

Manyar Estuary serves as a critical case study beyond its industrial significance due to its rich biodiversity, fisheries productivity, and role in maintaining coastal resilience [1]. Sediment resuspension and increased turbidity caused by reclamation impact photosynthetic organisms, fisheries, and benthic ecosystems, which are essential for coastal food chains [4]. Additionally, salinity fluctuations threaten mangrove habitats and aquatic species, further stressing the estuarine ecosystem [5].

Global comparisons underscore the widespread impact of coastal reclamation. Studies from Jakarta Bay [6] and Bali's Benoa Bay [7] highlight habitat degradation, water quality decline, and socio-economic disruptions resulting from poorly managed reclamation. Similar trends are observed in China and the Mediterranean, where reclamation disrupts natural sediment transport and marine biodiversity [8, 9]. Yet few studies quantitatively link reclamation extent to measured estuarine responses in turbidity, salinity, and sediment characteristics, especially in policy-relevant frames.

This paper addresses that gap by analysing five years of observations (2020-2024) in the Manyar Estuary, relating reclamation area to turbidity, salinity, and sediment grain size using standard correlation analysis, and interpreting the results through integrated coastal-zone planning to inform permitting, monitoring design, and compliance in rapidly industrialising coasts.

2. MATERIALS AND METHODS

2.1 Research location

This research was conducted on the coast of Manyar District, Gresik Regency, East Java, on July 16, 2024, focusing on coastal industrial areas, including PT JIIPE, PT Ecooil, and PT Siam Maspion Terminal. These three industries are involved in port activities and crude oil processing and are part of the JIIPE. Sampling was carried out during the dry season to avoid the influence of seawater mixing with rainwater, which could affect the physicochemical parameters of the water. During this season, tides are lower, resulting in reduced suspended sediments and a more stable arrangement of bottom sediments [10]. The distribution of sampling stations across the river, estuary, and marine zones is shown in Figure 1.

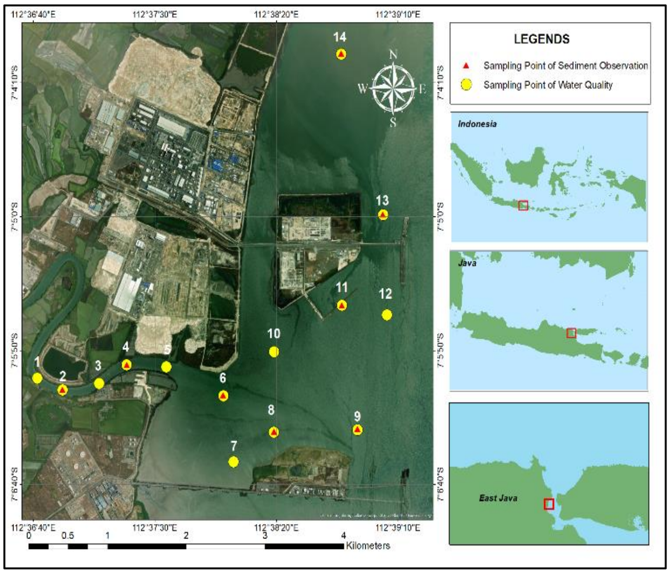

Figure 1. Sampling points for water-column profiling (0, 1, 3 m) and sediment collection, shown at publication-quality resolution with readable labels, scale bar, north arrow, and station IDs

2.2 Data collection

Data collection of water parameters was carried out using AAQ Rinko 1183 (multi-parameter water quality profiler) at depths of 0 m, 1 m, and 3 m. This tool is ISO 9001 JQA 0950 certified and capable of recording data automatically quickly and accurately [11]. Before each survey day, the probe was checked and calibrated following the manufacturer's procedure (sensor check and stabilization). A total of 14 sampling points were determined to cover the river, estuary, and marine areas [12]. Points 1-5 were located downstream of the river to observe the influence of anthropogenic inputs, point 6 at the confluence area of the river and the sea, and points 7-14 around the reclamation island. Sediment samples were then collected using a sediment corer and placed into plastic bags labeled according to depth for further analysis.

Data sources: Primary measurements were collected by the authors during a single-day survey on July 16, 2024 (n = 14 stations). For context, 2020-2021 values were extracted from published literature. Values for 2022-2023 were obtained from Coastal and Marine Resources Management Center (BPSPL) Denpasar, Sidoarjo Working Area as secondary monitoring summaries.

2.3 Laboratory analysis

This study used hydrometer and pycnometer analysis to determine the density and specific gravity of sediments. Hydrometer analysis was carried out by mixing dry sediment samples (50 grams) with sodium hexametaphosphate, precipitated for 24 hours, and measured with a hydrometer at intervals of up to 24 hours to determine the density of the solution [13]. Pycnometer analysis is carried out by putting fine sediment into a pycnometer that has been calibrated according to SNI 2441: 2011, mixed with boiling water, heated, and weighed at temperature intervals of 80 °C, 60 °C, and 40 °C to obtain accurate results [14, 15].

2.4 Statistical analysis

Interpretation rule: Because annual values are assembled from mixed provenance and are not synchronized by season, tide, rainfall, discharge, and station matching, we do not treat the 2020-2024 series as a standardized monitoring record. Therefore, (i) any year-to-year statements are limited to descriptive ranges, (ii) correlation outputs are reported only as illustrative screening, and (iii) management recommendations are framed as provisional priorities for improved monitoring rather than evidence of confirmed temporal impacts. Therefore, the core quantitative evidence is derived from within-campaign spatial patterns (2024), while earlier records are used to contextualize plausible ranges.

This limits strict year-to-year comparability; therefore, the multi-year series is presented as contextual ranges rather than a standardized monitoring record, while interpretation prioritizes verifiable within-campaign spatial variability. To enable valid temporal inference, future monitoring should adopt quarterly synchronized sampling at matched stations, within a fixed tidal window (± 1 h of high tide), with antecedent rainfall and river discharge recorded as covariates and replicated measurements per station-depth.

Annual association estimates between reclamation extent and compiled water-quality metrics (n = 5 years) are reported as an illustrative screening of directionality using Pearson (linear) and Spearman (monotonic) measures, with exact two-sided p-values for Spearman. Given the very small n and mixed data provenance, these estimates are not used to infer temporal trends or causality; significance language is avoided unless strictly supported by p-values, and findings are treated as exploratory indications only. The interpretation of correlation strength followed the coefficient categories presented in Table 1.

Table 1. Coefficient value

Value of r	Description
0.00-0.199	Very low
0.20-0.399	Low
0.40-0.599	Medium
0.60-0.799	Strong
0.80-1.000	Very strong

3. RESULTS AND DISCUSSION

3.1 Inter-annual ranges of aquatic parameters in the last 5 years (2020-2024)

Across 2020-2024, pH and temperature were generally within guideline ranges, but DO in 2020 (4.0 mg/L) was below the > 5.0 mg/L standard and turbidity exceeded the < 5 NTU standard in multiple years; therefore, not all parameters consistently met the quality standards of the Ministry of Environment Decree No. 51 of 2004. The inter-annual summary of reclamation area, water-quality parameters, sediment grain size, and data sources is presented in Table 2.

3.1.1 Degree of acidity (pH)

Figure 2 shows annual pH values in Manyar District (2020-2024) compared with the guideline range (6.5-8.5).

The pH fluctuations in Manyar District from 2021 to 2024, ranging from 6.6 to 8.3, demonstrate the complex interplay between anthropogenic activities and environmental processes. This variation reflects how industrial discharges, particularly from sectors such as sugar and aquaculture, introduce pollutants that significantly affect water chemistry [16, 17]. Similar trends are observed globally, where industrial runoff leads to substantial changes in regional water quality, impacting nutrient cycling and local ecosystems, as seen in Uttarakhand, India [18].

Climate factors like rainfall also influence pH fluctuations, underlining the broad environmental impact of these changes [19]. The improvement in water quality during periods of reduced industrial and mobility activity associated with COVID-19 restrictions illustrates the potential for environmental recovery, although such recovery remains fragile and vulnerable to continued industrial pressure [20, 21].

Studies from East China further show that seasonal nutrient inputs and environmental shifts affect aquatic health, with pH interacting dynamically with other parameters like temperature and dissolved oxygen (DO), impacting diverse ecosystems [22-24]. This emphasizes the need for effective environmental management and regulatory strategies to preserve global aquatic ecosystems, highlighting the critical role of continuous monitoring and adaptive management in mitigating industrial impacts on water quality.

3.1.2 Salinity

Figure 3 shows annual salinity values in Manyar District (2020-2024) compared with the guideline range (30-34 ppt).

The salinity fluctuations in Manyar Subdistrict, highlighted by peaks up to 33.7 ppt in 2022 due to desalination discharges, underscore the significant impacts of industrial activities on local water bodies. This rise in salinity is comparable to global instances where desalination processes notably increase local salinity levels, affecting marine ecosystems [25, 26]. Notably, confined salinity plumes from desalination plants, such as those observed in Spain, show that while localized, these discharges can still amplify salinity and pose risks to nearby marine life [27, 28].

Additionally, urban practices like using seawater for flushing in water-scarce cities further exacerbate salinity levels in wastewater systems, mirroring challenges seen in Manyar [29]. Elevated salinity levels threaten aquatic ecosystems, necessitating stringent regulatory measures to mitigate the adverse effects and ensure ecological integrity [30, 31]. This global challenge underscores the need for effective salinity management strategies that harmonize industrial practices with environmental sustainability.

Table 2. Reclamation area, aquatic parameters and sediment data

Year	Reclamation Area (Ha)	pH	Salinity (ppt)	DO (mg/L)	Temperature (℃)	Turbidity (NTU)	Sediment (mm)	Data Source
2020	118	7.5	24.0	4.0	29	5.0	0.0180	[32]
2021	121	6.6	25.6	5.0	28	6.0	0.0182	[33]
2022	126	7.7	33.7	5.0	30	8.0	0.0183	Institutional monitoring records (secondary data)
2023	127	7.7	30.0	5.0	29	10.0	0.0184	Institutional monitoring records (secondary data)
2024	128	8.3	31.0	6.6	28	16.8	0.0185	Field Data
Quality Standard		6.5-8.5	30.0-34.0	> 5.0	28-32	< 5.0		

Source: Data Processing, 2024
Note: ppt = parts per thousand; NTU = Nephelometric Turbidity Units.

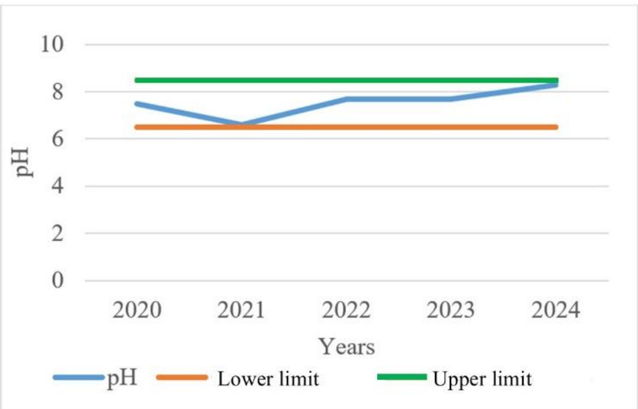

Figure 2. Degree of acidity (pH) profile 2020-2024

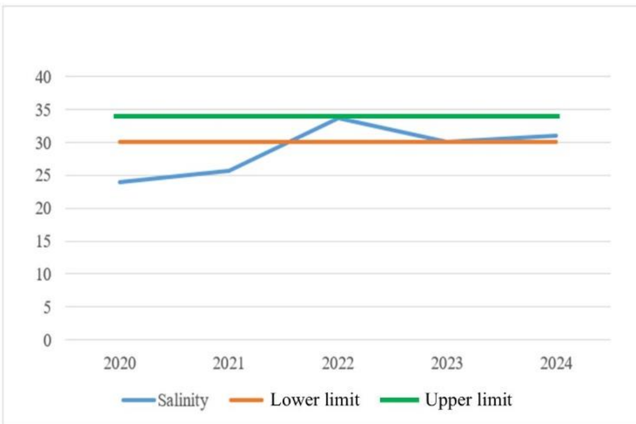

Figure 3. Salinity profile 2020-2024

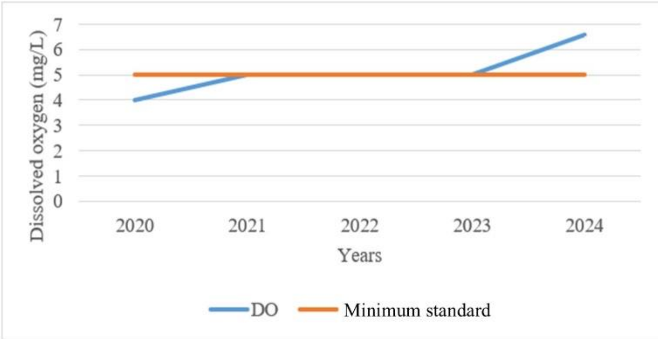

Figure 4. Dissolved oxygen profile 2020-2024

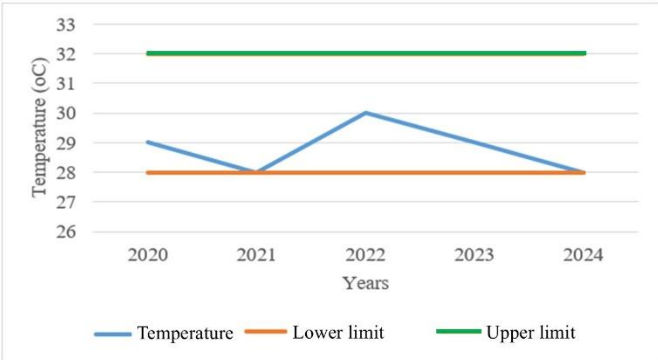

Figure 5. Temperature profile 2020-2024

3.1.3 Dissolved oxygen

Figure 4 shows annual DO values in Manyar District (2020-2024) relative to the minimum quality standard of > 5.0 mg/L.

The consistent levels of DO in Manyar, maintaining at 5 mg/L from 2021 to 2023, highlight the complex interplay between environmental factors. This stability, influenced by average rainfall, supports aquatic health by diluting pollutants and reducing turbidity [34]. However, heavy rainfall can increase turbidity, leading to oxygen depletion as organic waste decomposes [35]. Such fluctuations in DO and turbidity are observed globally, often exacerbated by rainfall and human activities [36].

Studies from around the world, including coastal Sri Lanka, illustrate how stormwater runoff and agricultural contaminants spike turbidity during the southwest monsoon, significantly impacting DO levels [35]. Urban areas similarly report decreased DO due to turbid water from sewage and fertilizers [37]. Industrial discharges, like those in Gwadar, Balochistan, contribute to eutrophication, further depleting oxygen [36].

Temperature also plays a critical role; research in Brazil shows lower water temperatures generally correlate with higher DO levels, underlining the importance of temperature in oxygen solubility [38]. Manyar's stable climatic conditions help sustain DO levels, unlike warmer regions where increased temperatures may lower oxygen levels.

Effective management of aquatic environments requires ongoing monitoring of DO, temperature, and turbidity. By understanding these interactions, proactive strategies can be developed to mitigate pollution impacts and preserve global aquatic ecosystems.

3.1.4 Temperature

Figure 5 shows annual temperature values in Manyar District (2020-2024) compared with the guideline range (28-32 ℃).

In Manyar Subdistrict, water temperature shows remarkable stability, varying only between 1-2 ℃ annually, within established quality standards. This stability highlights the intricate balance between environmental influences like solar intensity, water depth, and movement, and human activities such as reclamation [39]. Reclamation on tidal flats can increase risks from storm impacts by altering sedimentary processes [40], presenting challenges similar to those in Manyar. These observations confirm that the increasing sediment grain size in Manyar is part of a broader global trend where anthropogenic activities significantly alter sediment dynamics. This necessitates the careful management of reclamation practices to preserve ecological balance and water quality in various regions.

3.2 The relationship between each water parameter and reclamation

The correlation results in Table 3 provide an exploratory assessment of how reclamation extent covaries with key aquatic and sediment indicators in Manyar across five annual observations (n = 5). Given the short time series and the estuarine setting, these associations should not be interpreted as causal impacts or definitive trends. To improve robustness under small-sample uncertainty and potential non-linearity, Pearson correlations (linear association) are reported alongside Spearman rank correlations (monotonic association).

Table 3. Correlation test results

Parameter (X)	Pearson r	Pearson p	Spearman ρ	Spearman P (Exact, Two-Sided)	Description
pH	0.6523	0.2328	0.8721	0.0667	Not statistically significant (Pearson p = 0.233; Spearman p = 0.0667); insufficient evidence of association.
Salinity (ppt)	0.8837	0.0468	0.7000	0.2333	Borderline under Pearson (p = 0.0468) but not supported by Spearman (p = 0.2333); association not robust across methods.
DO (mg/L)	0.7718	0.1263	0.8944	0.1000	Not statistically significant (Pearson p = 0.126; Spearman p = 0.100); insufficient evidence of association.
Temperature (℃)	0.0695	0.9116	-0.2108	0.7333	No evidence of association (Pearson p = 0.912; Spearman p = 0.733).
Turbidity (NTU)	0.8093	0.0971	1.0000	0.0167	Monotonic increase supported by Spearman (ρ = 1.000; p = 0.0167), while Pearson is not significant (p = 0.097).
Sediment (mm)	0.9669	0.00718	1.0000	0.0167	Consistent positive association (Pearson p = 0.007; Spearman p = 0.0167); interpret cautiously because the absolute grain-size change is very small.

Turbidity shows a consistent increasing pattern with reclamation area (Spearman $\rho = 1.000$; $p = 0.0167$), while the Pearson test is not significant ($r = 0.809$; $p = 0.097$); therefore, the association is treated as exploratory or early indicators. This result is consistent with the understanding that reclamation activities, by disturbing sediment and enhancing its suspension, contribute to increased turbidity. The greater the reclamation area, the higher the turbidity levels, primarily due to the influx of suspended sediments from construction and land alteration activities. This rise in turbidity can severely limit the penetration of sunlight into water bodies, which is crucial for the photosynthetic activity of phytoplankton, thereby affecting the overall productivity and ecological balance of the aquatic environment [40, 41].

Salinity shows a positive association with reclamation extent under Pearson correlation ($r = 0.884$, $p = 0.047$), but this relationship is not supported by Spearman rank correlation ($\rho = 0.700$, $p = 0.233$), suggesting the pattern is not robust across methods. Therefore, while the pattern is suggestive, the available five-year dataset provides insufficient evidence to conclude that reclamation expansion consistently increases salinity. A plausible mechanism remains that industrial activities associated with reclamation may introduce saline inputs (e.g., brine discharge), which could increase salinity and alter osmotic conditions affecting aquatic biota and their distribution [42].

Sediment grain size exhibits the strongest and most consistent positive association with reclamation area among the tested parameters (Pearson $r = 0.967$, $p = 0.007$; Spearman $\rho = 1.000$, $p = 0.0167$). This indicates a highly consistent increasing pattern in grain-size values as reclamation area increases across 2020-2024. Nevertheless, the compiled records indicate a small but consistently higher grain-size value in later years (0.0180→0.0185mm). This is presented as a qualitative indication of sediment texture change that may accompany coastal modification, so the ecological significance of this shift should be interpreted cautiously even though the statistical association is strong. Areas close to reclamation activities tend to exhibit coarser sediment due to the heavy use of construction materials that alter the natural sediment flow and deposition processes [43].

These associations suggest that reclamation may be linked to changes in key aquatic and sediment indicators in Manyar, particularly for sediment characteristics and potentially turbidity, although inference is constrained by the short annual series ($n = 5$) and mixed temporal data sources. Accordingly, the findings are best used to prioritize monitoring and targeted mitigation rather than to claim definitive impacts. Practical implications include strengthening synchronized, multi-timepoint sampling across years, tracking turbidity and sediment metrics alongside estuarine covariates (e.g., tides and river discharge), and implementing precautionary controls to limit sediment resuspension and manage potential salinity stressors. Placed in a broader context, this study aligns with evidence that coastal modification can pose environmental risks, but stronger empirical support is required before detailed regulatory frameworks are derived from the present correlations.

3.3 Water quality and reclamation impacts

Industrial and reclamation activities can cause significant changes in water parameters. Poorly managed industrial effluent discharge can increase the concentration of organic matter which in turn affects the turbidity of waters [44]. In addition, reclamation that involves backfilling and redirecting water flow can alter the physical parameters of waters such as turbidity, salinity and temperature. Reclamation causes a decrease in water brightness, changes in salinity, and a decrease in biodiversity, indicating degradation of the quality of the aquatic environment [45]. Therefore, proper management and regular monitoring of water quality parameters are essential to minimize the negative impacts of industrial and reclamation activities on aquatic ecosystems.

Continuous monitoring of water quality in Manyar Estuary is essential to identify and address potential negative impacts from industrial pollution. Industrial activities and reclamation activities around the area have the potential to generate effluents that can alter water quality. Without regular monitoring, changes in water quality can go undetected and reach levels that are harmful to the surrounding ecosystem and the health of local communities [46]. Industrial and reclamation activities can cause significant changes in the physical, chemical and biological parameters of water, negatively affecting water quality and aquatic organisms [47]. By conducting continuous monitoring, authorities can promptly identify changes in water quality, determine the source of pollution, and take necessary mitigation measures to prevent further damage to the environment and human health.

Reclamation activities also have the potential to negatively affect the activity of zoobenthos and other biota in the bottom waters. In a case study on Kyushu Island, Japan, bentonite bivalves were found to die in large numbers after reclamation activities. Bivalves, which are commonly used as bioindicators for estimating water quality, died in large numbers, raising concerns about water quality in the Kyushu area [48]. Bivalve mortality in waters in the Kyushu area is due to an increase in sediment size and the amount of sediment suspended in the water that can cover the bivalves and interfere with respiration and filtration processes. In addition, bivalve mortality is also caused by an increase in water parameter values that make the waters not optimal for biota growth.

Changes in water parameters, such as temperature, salinity, pH, and DO content, can have a significant impact on the health of mangrove ecosystems in Manyar District. For example, an increase in water temperature can disrupt the photosynthesis and respiration processes of mangrove plants, while drastic changes in salinity can affect the mangroves' ability to absorb nutrients [5]. Decreased pH (increased acidity) and low DO levels can inhibit root growth and reduce the ability of mangroves to survive. This is reinforced by the low mangrove density value in Manyar Sub-district. When compared to other areas in Gresik, mangroves in Manyar District are considered a poor ecosystem with low density and high ecological disturbance.

Pollutants and changes in aquatic parameters have serious impacts on human health. Industrial effluents containing heavy metals such as mercury, lead and cadmium can contaminate water sources, and through bioaccumulation and biomagnification, these pollutants reach humans through the food chain [49]. Effects include neurological disorders, kidney damage, and cancer. Changes in water parameters, such as decreased DO levels and increased BOD/COD, indicate organic pollution that can lead to the development of pathogenic bacteria in water [50]. This increases the risk of waterborne diseases such as diarrhea, cholera and typhoid. In addition, changes in water pH due to chemical pollutants can cause skin and eye irritation in humans. Effluent management and water quality monitoring are critical steps to protect public health.

3.4 Strategies and solutions to overcome turbidity in Manyar Estuary

These strategies are operationalized within an Integrated Coastal Zone Management (ICZM) and local spatial planning framework, ensuring that sediment control measures (e.g., silt curtains, sediment traps, vegetated buffers) are aligned with designated industrial-estuarine zones and seasonal hydrodynamics.

This study provides compelling evidence of a consistent annual increase in turbidity within Manyar Estuary, which persistently surpasses the environmental quality standards as outlined by the Ministry of Environment No. 51 of 2004. The exacerbation of turbidity levels highlights the immediate necessity for systematic intervention to mitigate these environmental impacts.

3.4.1 Enhanced monitoring and regulation

Within this ICZM framing, enhanced monitoring and regulation are crucial for managing water quality in Manyar Estuary, where industrial reclamation has notably increased turbidity, impacting aquatic ecosystems. Implementing real-time monitoring systems [11] can provide immediate data crucial for regulatory actions. These systems, through continuous turbidity tracking using ISO 9001 JQA 0950 certified tools like the AAQ Rinko 1183, enable quick responses during high turbidity events. These actions are crucial for protecting sensitive aquatic life stages. Instrument calibration/verification followed the manufacturer's SOP prior to field deployment. At each station and depth, measurements were repeated (field replicates) to assess short-term variability and to reduce single-read bias. The 2024 snapshot recorded turbidity up to 16.8 NTU, exceeding the < 5 NTU reference threshold; earlier-year records suggest elevated turbidity can occur. Stricter regulations on activities like dredging and construction, which exacerbate turbidity, are necessary to mitigate these impacts [51]. Such measures will ensure healthier aquatic ecosystems by maintaining water quality within environmentally safe limits, fostering sustainable development in the Manyar area.

3.4.2 Sediment control measures

Consistent with the spatial planning approach, implementing effective sediment control measures is critical for mitigating the impacts of reclamation activities on the Manyar Estuary. The study highlights significant increases in sedimentation rates associated with these activities, which directly correlate with heightened turbidity and changes in sediment grain size. This underscores the importance of integrating sediment traps and vegetative buffers, which not only act as physical barriers to sediment entry but also enhance soil structure, thereby reducing runoff and improving water clarity [52, 53].

Additionally, the use of silt curtains is essential during active reclamation phases. These barriers effectively minimize sediment dispersion into adjacent water bodies, crucial for maintaining the ecological integrity of the estuary. The deployment and maintenance of silt curtains must be carefully managed to adapt to local hydrodynamic conditions, ensuring maximum effectiveness [54]. Collectively, these measures—sediment traps, vegetative buffers, and silt curtains—form an integrated approach to managing sediment runoff. This approach is crucial for protecting Manyar Estuary from the detrimental impacts of increased sediment loads due to industrial activities and land reclamation, thus supporting sustainable coastal management practices.

3.4.3 Water treatment and remediation techniques

In support of the ICZM framework, the integration of advanced water treatment technologies and natural remediation strategies is imperative. Observational data from the area highlights turbidity levels frequently surpassing environmental safety standards, underscoring the urgent need for effective treatment solutions. Advanced water treatment facilities, equipped with modern technologies such as membrane filtration systems, are crucial. These systems are known for their efficiency in removing fine particulate matter, thereby substantially lowering water turbidity [55].

Additionally, the adoption of natural remediation techniques, such as constructed wetlands, offers a sustainable approach to water quality management. These systems utilize biological and physical processes to filter out sediments and pollutants from runoff, effectively reducing turbidity while enhancing the ecological health of the water bodies [56]. Combining these engineered solutions with natural treatment methods not only addresses the immediate issues of water clarity but also supports long-term sustainability by fostering biodiversity and ecological resilience. This dual approach ensures a comprehensive strategy for maintaining water quality within the Manyar Estuary, aligning with environmental standards and sustainable management practices.

3.4.4 Public awareness and stakeholder engagement

Stakeholder engagement is a core pillar of ICZM; raising public awareness and engaging stakeholders is therefore crucial for addressing the environmental and health impacts of turbidity in the Manyar Estuary. Data from the region illustrate the pressing need for community involvement in maintaining water quality and ecological balance. Educational programs play a vital role in informing local populations about the adverse effects of turbidity on aquatic ecosystems and public health. Research underscores the effectiveness of such initiatives in fostering environmental stewardship and promoting sustainable practices [57].

Moreover, stakeholder engagement is essential for incorporating diverse perspectives [58], especially in water management strategies. This inclusive approach ensures that conservation efforts are well-rounded and effectively address the specific needs and challenges of the local environment. Engaging community members, policymakers, and industry representatives in dialogue and decision-making processes enhances the implementation of practical and sustainable water management solutions. Collaborative platforms such as workshops, stakeholder meetings, and community forums facilitate mutual understanding and cooperative action [59], leading to more effective management of natural resources and greater community commitment [60], to reducing turbidity and its impacts. By fostering an informed and involved community, we can enhance the ecological and public health resilience of the Manyar Estuary.

3.5 Specific policy recommendations for water quality management in Manyar Estuary

To translate the findings into practice, we propose an illustrative set of draft KPIs (Key Performance Indicators) as a starting point for monitoring design. However, these targets should be finalized only after a harmonized multi-season dataset is collected and validated against regulatory compliance requirements:

1) Turbidity: < 5 NTU at compliance points (95th percentile during dry season); response trigger at > 8 NTU sustained for > 24 h.
2) Core physicochemical bounds: DO > 5 mg/L; pH 7.0-8.5; temperature within ± 2 °C of seasonal baseline.
3) Monitoring cadence: Monthly baseline sampling +event-based sampling during reclamation/dredging; at least one real-time turbidity logger per critical outfall, calibrated per SOP.
4) Roles & assurance: Operators collect/report; district environmental agency aggregates/validates; third-party audit semi-annual with publicly available summaries.
5) Transparency & enforcement: Quarterly public dashboard; staged enforcement (warning→corrective action plan→fines/suspension) for repeated exceedances.

3.5.1 Policy framework enhancement

Enhancing the policy framework for water quality management in the Manyar Estuary is crucial to mitigating the impacts of industrial reclamation. This study indicates strong associations between reclamation extent and turbidity/salinity/sediment metrics in a short annual dataset (Table 3). These results motivate stricter monitoring and impact-control planning, but do not establish causality [61, 62].

A comprehensive regulatory approach should integrate territorial (spatial) planning principles to balance industrial growth with environmental sustainability, strengthen marine resource protection through stricter reclamation controls [63], and mandate rigorous environmental impact assessments (EIAs) to prevent unchecked ecological degradation [64].

Moreover, Okorigba et al. [65] argued for stronger compliance enforcement to ensure industrial activities align with sustainable water-management practices, while Permana et al. [66] emphasized integrating urban planning to prioritize long-term water-quality preservation. Broad stakeholder engagement—from policymakers to local communities—will further foster participatory governance and regulatory adherence.

A multi-disciplinary policy framework combining scientific monitoring, regulatory enforcement, and stakeholder collaboration is essential to balancing economic development with coastal ecosystem conservation in Gresik and beyond.

3.5.2 Integrated Coastal Zone Management

Adopting an ICZM is crucial for addressing the multifaceted impacts of industrial activities, urban development, and reclamation projects on the Manyar Estuary's water quality. This holistic strategy ensures the balance of environmental, economic, and social objectives, as highlighted by Rudianto et al. [67], who underscore its efficacy in enhancing coastal management awareness and resolving conflicts arising from diverse developmental activities.

The significance of ICZM is also evident in its successful application in regions like China, demonstrating its potential adaptability and effectiveness in similar coastal settings [68]. Furthermore, research by Cantasano et al. [9] emphasizes the necessity of such integrated approaches in the Mediterranean to combat environmental pressures like biodiversity loss and pollution, advocating for robust collaboration among scientific, managerial, and policymaking sectors.

This comprehensive approach is not only about managing the immediate impacts on water quality but also involves long-term strategies to ensure the sustainability of coastal ecosystems, necessitating continued research, stakeholder engagement, and adaptive management practices to respond effectively to evolving environmental challenges.

3.5.3 Collaboration with industrial sectors

Establishing partnerships with industrial sectors is crucial for effective waste management and pollution control. Building on this, Thongkong et al. [69] emphasized integrating planning, monitoring, and evaluation into industrial waste-management strategies to enhance resource efficiency and minimize environmental impacts, while Farzadkia et al. [70] highlighted the necessity of robust waste-management systems to mitigate environmental and health risks associated with industrial waste disposal. Strengthening collaboration between industries and regulatory bodies ensures regulatory compliance and facilitates the adoption of best practices in hazardous-waste management.

Industrial symbiosis is a modern industrial strategy that encourages inter-industry collaboration to enhance resource efficiency, minimize waste, and promote sustainability. By facilitating shared use of materials and coordinated efforts across sectors, it supports cleaner production and more effective waste management [71]. Complementarily, ecological forecasting has been proposed to assess industrial effects on water quality; by integrating data-driven decision tools, firms can proactively manage their pollution footprint [72].

Ultimately, strengthened industry collaboration via optimized waste-management practices, resource sharing, and deployment of advanced monitoring technologies is pivotal to lowering environmental impacts and supporting sustainable industrial growth.

3.5.4 Research and development support

Supporting research and development is essential for understanding the long-term impacts of reclamation and industrial activities on the Manyar Estuary. Findings from this study indicate a consistent rise in turbidity, salinity, and sedimentation rates, emphasizing the need for further investigation into these environmental changes. Increased funding for research can help assess these alterations and develop innovative water management strategies.

Evidence shows that industrial expansion can markedly disrupt aquatic ecosystems, underscoring the need for targeted research to inform mitigation. Complementarily, characterizing the spatiotemporal variability of key water-quality parameters and their relationship with landscape factors is essential to design effective interventions [73, 74]. On the technology side, advanced treatment options—such as oxidation processes—can enhance water quality [75], while numerical simulations provide predictive capacity for managing fluctuations and supporting adaptive planning [76].

Investing in research to develop sustainable water treatment and monitoring technologies is crucial to preserving aquatic ecosystems in reclamation-affected areas like the Manyar Estuary.

3.5.5 Enforcement of regulations

Strengthening the enforcement of environmental regulations is pivotal to mitigating the adverse effects of reclamation and industrial activities in the Manyar Estuary. Documented increases in turbidity and shifts in sedimentation linked to industrial expansion underscore the need for tighter compliance mechanisms. Evidence shows that rigorous enforcement steers firms toward preventive, sustainable pollution-control strategies, whereas weak regulation is associated with poor compliance and inferior outcomes [77]. Complementary measures include credible penalties for non-compliance [78] and addressing Indonesia-specific enforcement gaps by requiring rigorous impact assessments prior to project approval [79].

Implementing strict regulations, enforcing penalties, and conducting thorough environmental assessments are essential to safeguarding water quality in reclamation-affected areas. A strong regulatory framework will ensure compliance, promote sustainable industrial practices, and enhance environmental resilience in the Manyar Estuary.

4. CONCLUSION

This assessment combines a primary field survey with contextual historical records. Across 2020-2024 ($n = 5$), reclamation area shows an exploratory positive association with turbidity and sediment grain size, with the monotonic pattern strongest for turbidity (Spearman $\rho = 1.000$, exact $p = 0.0167$) and consistent positive association for sediment (Pearson $r = 0.9669$, $p = 0.00718$; Spearman $\rho = 1.000$, $p = 0.0167$), while salinity is borderline under Pearson ($r = 0.8837$, $p = 0.0468$) but not supported by Spearman ($p = 0.2333$). pH, temperature, and DO do not show statistically supported associations ($p > 0.05$). Importantly, DO in 2020 (4.0 mg/L) is below the > 5.0 mg/L quality standard, and turbidity in 2024 (16.8 NTU) exceeds the < 5.0 NTU standard, indicating periods of non-compliance that warrant management attention.

Based on these indicative associations, we propose a provisional management direction emphasizing: (i) operational KPIs for compliance (e.g., turbidity < 5 NTU at compliance points, routine and event-based monitoring, third-party audits, and public dashboards), (ii) adoption of an ICZM- and spatial-planning frame to guide siting and operations, and (iii) a suite of interventions—real-time monitoring, sediment-control measures (silt curtains, sediment traps, vegetated buffers), engineered and nature-based treatment, stakeholder engagement, and strengthened enforcement. Together, these measures provide a coherent pathway to curb turbidity exceedances and maintain water quality while accommodating industrial activity.

This study has limitations typical of early-stage, management-oriented assessments: a short time series ($n = 5$) with partially mixed data sources; potential trending/seasonal confounding (e.g., river discharge, rainfall, tides) not fully controlled; reliance on a single sediment metric rather than full particle-size distributions; and indicative rather than source-confirmed attribution for salinity increases near industrial operations. These constraints do not negate the results but call for cautious interpretation and adaptive implementation. To reduce over-interpretation under small n, we report both Pearson and Spearman (with exact p-values for Spearman) and restrict conclusions to exploratory associations rather than causal claims.

A minimum design to enable year-to-year comparability is synchronized repeated sampling at matched stations at least quarterly (wet season, dry season, and transition periods), conducted within a fixed tidal window (e.g., ± 1 h of high tide) and accompanied by antecedent rainfall (48-72 h) and river discharge records as covariates. Replicated measurements per station-depth should be collected to quantify uncertainty and allow trend-robust or multivariate models.

Future work should prioritize year-round, high-frequency sensing and harmonized protocols; hydrodynamic–sediment transport and plume modeling coupled with remote sensing to resolve hotspots; full PSD and geochemical characterization to clarify sediment sources; and causal/statistical designs (e.g., trend-robust estimators, multivariate controls). Parallel ecological monitoring (biota and habitat condition) and policy performance evaluation against the proposed KPIs will be essential to track effectiveness and recalibrate management under the ICZM framework.

ACKNOWLEDGEMENTS

We express our gratitude to those who contributed to this independent research project, which was supported by internal resources. Special thanks to our colleagues for their valuable insights and the local community in Manyar for their cooperation.

REFERENCES

[1] Widodo, A., Utama, W., Purwanto, M.S., Fajar, M.H.M. (2020). Analysis of clay physical parameters in determining soil bearing capacity (Case study: Manyar District, Gresik Regency). Jurnal Geosaintek, 6(2): 61-70. https://doi.org/10.12962/j25023659.v6i2.5445

[2] Saadah, K., Anggraini, R., Medida, V.A., Wiradimadja, A. (2020). Industrialization: The transition of the community of agrarists toward the gresik wringinanom industry. In International Conference on Social Studies and Environmental Issues (ICOSSEI 2019), pp. 305-308. https://doi.org/10.2991/assehr.k.200214.055

[3] Nuraini, I., Rochminarni, A.B., Hariyani, H.F. (2021). The growth pattern and potential development of manufacturing industry in East Java. Ekuilibrium: Jurnal Ilmiah Bidang Ilmu Ekonomi, 16(2): 129-138. https://doi.org/10.24269/ekuilibrium.v16i2.2021.pp129-138

[4] Storlazzi, C.D., Norris, B.K., Rosenberger, K.J. (2015). The influence of grain size, grain color, and suspended-sediment concentration on light attenuation: Why fine-grained terrestrial sediment is bad for coral reef ecosystems. Coral Reefs, 34(3): 967-975. https://doi.org/10.1007/s00338-015-1268-0

[5] Saputra, D.K., Semedi, B., Yamindago, A., Dewi, C.S., et al. (2022). Characteristics of mangrove fisheries in essential ecosystem area Ujungpangkah, Indonesia. Journal of Environmental Management & Tourism, 13(3): 812-820. https://doi.org/10.14505/jemt.v13.3(59).20

[6] Rizqiah, L., Marzaman, A.P. (2023). Analysis of the impact of Jakarta Bay reclamation on fisheries and marine resource diversity. Jurnal Multidisipliner Kapalamada, 2(4): 247-253. https://doi.org/10.62668/kapalamada.v2i04.890
[7] Kenyo, A., Soesilo, T.E.B., Pranowo, W.S. (2018). Analysis of marine and coastal resources sustainability in Benoa Bay Reclamation Site. Jurnal Kelautan Nasional, 13(3): 121-136. https://doi.org/10.15578/jkn.v13i3.6973
[8] Cheng, Z., Jalón-Rojas, I., Wang, X.H., Liu, Y. (2020). Impacts of land reclamation on sediment transport and sedimentary environment in a macro-tidal estuary. Estuarine, Coastal and Shelf Science, 242: 106861. https://doi.org/10.1016/j.ecss.2020.106861
[9] Cantasano, N., Pellicone, G., Ietto, F. (2017). Integrated coastal zone management in Italy: A gap between science and policy. Journal of Coastal Conservation, 21(3): 317-325. https://doi.org/10.1007/s11852-016-0479-z
[10] Zhu, C., van Maren, D.S., Guo, L., Lin, J., He, Q., Wang, Z.B. (2021). Effects of sediment-induced density gradients on the estuarine turbidity maximum in the Yangtze Estuary. Journal of Geophysical Research: Oceans, 126(5): e2020JC016927. https://doi.org/10.1029/2020JC016927
[11] Majnooni, S., Fooladi, M., Nikoo, M.R., Al-Rawas, G., Haghighi, A.T., Nazari, R., Al-Wardy, M., Gandomi, A.H. (2024). Smarter water quality monitoring in reservoirs using interpretable deep learning models and feature importance analysis. Journal of Water Process Engineering, 60: 105187. https://doi.org/10.1016/j.jwpe.2024.105187
[12] Zhang, J., Lu, C., Werner, A.D. (2021). Analytical and experimental investigation of the impact of land reclamation on steady-state seawater extent in coastal aquifers. Water Resources Research, 57(6): e2020WR029028. https://doi.org/10.1029/2020WR029028
[13] Hunduma, S., Kebede, G. (2020). Measurement of soil particle size distribution using hydrometer analysis. American-Eurasian Journal of Agricultural & Environmental Sciences, 20(4): 243-254. https://doi.org/10.5829/idosi.aejaes.2020.243.254
[14] Axel, M., Zhibo, D. (2021). Geotechnical parameter study and solidification of marine sediment for road engineering. IOP Conference Series: Materials Science and Engineering, 1197(1): 012001. https://doi.org/10.1088/1757-899x/1197/1/012001
[15] Zăbavă, B.Ş., Tudor, P., Voicu, G., Constantin, G.A., Dincă, M.N. (2022). Sedimentation rate of liquid-solid suspensions, as a parameter of wastewater treatment. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 11.
[16] Orak, C. (2024). Treatment of sugar industry wastewater via Fenton oxidation with zero-valent iron. Cumhuriyet Science Journal, 45(1): 100-104. https://doi.org/10.17776/csj.1328817
[17] Santi, S.S., Wahyusi, K.N., Sumada, K., Muljani, S. (2021). Shrimp cracker industrial wastewater treatment with aerobic biological properties utilizing modified contact-stabilization method. Journal of Natural Sciences and Mathematics Research, 7(2): 92-102. https://doi.org/10.21580/jnsmr.2021.7.2.11284
[18] Ranghar, S., Baunthiyal, M. (2016). Ecological damage in the vicinity of two industrial areas of Uttarakhand. Environment Conservation Journal, 17(1&2): 179-186. https://doi.org/10.36953/ecj.2016.171219
[19] Bao, Y., Chen, X., Guo, Z., Li, Z., Zhuang, Y., Gao, M. (2024). Evidence of microbial activity in coal seam production water and hydrochemical constraints. Energies, 17(20): 5170. https://doi.org/10.3390/en17205170
[20] Sulastri, Akhdiana, I. (2022). Seasonal variation of water quality of three urban small lakes in West Java, Indonesia. IOP Conference Series: Earth and Environmental Science, 1036(1): 012113. https://doi.org/10.1088/1755-1315/1036/1/012113
[21] Aborisade, W.T., Ajao, A.T., Sadiq, A.I. (2024). Assessment of surface water quality using phytoplankton as base-line indicator organisms in Ilorin, Kwara State, Nigeria. UMYU Journal of Microbiology Research, 9(1): 26-33. https://doi.org/10.47430/ujmr.2491.003
[22] Bhardwaj, A.A., Vos, J.G., Beatty, M.E., Baxter, A.F., Koper, M.T., Yip, N.Y., Esposito, D.V. (2021). Ultrathin silicon oxide overlayers enable selective oxygen evolution from acidic and unbuffered pH-neutral seawater. ACS Catalysis, 11(3): 1316-1330. https://doi.org/10.1021/acscatal.0c04343
[23] Wang, A., Wu, X., Bi, N., Ralston, D.K., Wang, C., Wang, H. (2022). Combined effects of waves and tides on bottom sediment resuspension in the southern Yellow Sea. Marine Geology, 452: 106892. https://doi.org/10.1016/j.margeo.2022.106892
[24] Yang, L.J., Tao, Y., Jiang, X., Wang, Y., Li, Y.H., Zhou, L., Wang, P.Z., Li, Y.Y., Zhao, X., Wang, H.J., Jeppesen, E., Xie, P. (2023). Interactive effects of nutrients and salinity on zooplankton in Subtropical Plateau Lakes with contrasting water depth. Frontiers in Environmental Science, 11: 1110746. https://doi.org/10.3389/fenvs.2023.1110746
[25] Paparella, F., D'Agostino, D., Burt, J.A. (2022). Long-term, basin-scale salinity impacts from desalination in the Arabian/Persian Gulf. Scientific Reports, Nature Publishing Group UK, 12(1): 20549. https://doi.org/10.1038/s41598-022-25167-5
[26] Ibrahim, H.D., Xue, P., Eltahir, E.A.B. (2020). Multiple salinity equilibria and resilience of Persian/Arabian Gulf Basin salinity to brine discharge. Frontiers in Marine Science, 7: 550181. https://doi.org/10.3389/fmars.2020.00573
[27] Fernández-Torquemada, Y., Carratalá, A., Lizaso, J.L.S. (2019). Impact of brine on the marine environment and how it can be reduced. Desalination and Water Treatment, 167: 27-37. https://doi.org/10.5004/dwt.2019.24615
[28] Sola, I., Fernández-Torquemada, Y., Forcada, A., Valle, C., del Pilar-Ruso, Y., González-Correa, J. M., Sánchez-Lizaso, J.L. (2020). Sustainable desalination: Long-term monitoring of brine discharge in the marine environment. Marine Pollution Bulletin, 161: 111813. https://doi.org/10.1016/j.marpolbul.2020.111813
[29] Wang, Z., van Loosdrecht, M.C., Saikaly, P.E. (2017). Gradual adaptation to salt and dissolved oxygen: Strategies to minimize adverse effect of salinity on aerobic granular sludge. Water Research, 124: 702-712. https://doi.org/10.1016/j.watres.2017.08.026
[30] Kaushal, S.S., Likens, G.E., Pace, M.L., Utz, R.M., Haq, S., Gorman, J., Grese, M. (2018). Freshwater salinization syndrome on a continental scale. Proceedings of The

National Academy of Sciences, 115(4): E574-E583. https://doi.org/10.1073/pnas.1711234115

[31] Herbert, E.R., Boon, P., Burgin, A.J., Neubauer, S.C., Franklin, R.B., Ardon, M., Hopfensperger, K.N., Lamers, L.P.M., Gell, P. (2015). A global perspective on wetland salinization: Ecological consequences of a growing threat to freshwater wetlands. Ecosphere, 6(10): 1-43. https://doi.org/10.1890/ES14-00534.1

[32] Pangestika, I.W., Insafitri, I. (2020). The zooplankton community structure in the mangrove ecosystem that's different in its density in Gresik Regency, East Java. Juvenil: Jurnal Ilmiah Kelautan dan Perikanan, 1(2): 189-197. https://doi.org/10.21107/juvenil.v1i2.7573

[33] Oktaviana, A., Yanuhar, U., Suryanto Hertika, A.M. (2022). Coastal water quality of Kali Mireng, Manyar District, Gresik Regency, East Java. Syntax Idea, 4(4): 818-822. https://doi.org/10.46799/syntax-idea.v4i4.1831

[34] Sutanto, S., Supriyanto, T., Widjajanto, D. (2023). Effect of changes turbidity on oxygen solubility in fish pond water electrocoagulation process. Fluida, 16(sp1): 1-7. https://doi.org/10.35313/fluida.v16isp1.5596

[35] Jayawardhane, J.K.P.C., Weerasekara, K.A.W.S., Pathmalal, M.M. (2023). Spatial and temporal variation of physicochemical parameters of coastal waters in the southwestern region of Sri Lanka. Sri Lanka Journal of Aquatic Sciences, 28(1): 1-9. https://doi.org/10.4038/sljas.v28i1.7603

[36] Qari, R., Khalid, K. (2018). Impact of sewage and industrial pollution on the hydrographic conditions of seawater in Gwadar (East Bay), Balochistan. Global Journal of Biology, Agriculture & Health Sciences, 07(2): 1-5. https://doi.org/10.24105/2319-5584.100002

[37] Shah, K.A., Joshi, G.S. (2017). Evaluation of water quality index for River Sabarmati, Gujarat, India. Applied Water Science, Springer Berlin Heidelberg, 7(3): 1349-1358. https://doi.org/10.1007/s13201-015-0318-7

[38] Maroneze, M.M., Zepka, L.Q., Vieira, J.G., Queiroz, M.I., Jacob-Lopes, E. (2014). A tecnologia de remoção de fósforo: Gerenciamento do elemento em resíduos industriais. Revista Ambiente & Água, 9(3): 445-458. https://doi.org/10.4136/1980-993X

[39] Cui, H., Ding, A., Ma, W., Zhang, R., Lin, W., Desmond, P., Ngo, H.H., Li, G., Liang, H. (2024). Reconsidering the rationality of ultrafiltration as the ultimate safeguard for reclaimed water biosafety: Unexpected risks arise under different storage conditions. ACS ES&T Water, 4(5): 2235-2246. https://doi.org/10.1021/acsestwater.4c00042

[40] Chen, K., Lin, Y., Liu, J., He, Z., Jia, L. (2024). Combined effects of massive reclamation and dredging on the variations in hydrodynamic and sediment transport in Lingdingyang Estuary, China. Frontiers of Earth Science, 18(1): 127-147. https://doi.org/10.1007/s11707-022-1050-x

[41] Yu, S., Xu, F., Peng, Z., Guo, L., Wang, X., Xie, W., Zhu, C., Wang, Z., He, Q. (2024). Dynamic evolution of tidal networks under the combined effect of de-reclamation and decrease of sediment supply. Continental Shelf Research, 279: 105274. https://doi.org/10.1016/j.csr.2024.105274

[42] Harper, R.J., Dell, B., Ruprecht, J.K., Sochacki, S. J., Smettem, K.R.J. (2021). Salinity and the reclamation of salinized lands. In Soils and Landscape Restoration, pp. 193-208. https://doi.org/10.1016/B978-0-12-813193-0.00007-2

[43] Yin, C., Ye, S., Feng, X., Yin, Y. (2020). Study on the geo-environmental evolution of the Laolonggou lagoon under the impacts of the Caofeidian reclamation project in Hebei Province. Journal of Ocean University of China, 19(5): 1062-1072. https://doi.org/10.1007/s11802-020-4238-2

[44] Awotwi, A., Anornu, G.K., Quaye-Ballard, J.A., Annor, T., Nti, I.K., Odai, S.N., Arhin, E., Gyamfi, C. (2021). Impact of post-reclamation of soil by large-scale, small-scale and illegal mining on water balance components and sediment yield: Pra River basin case study. Soil and Tillage Research, 211: 105026. https://doi.org/10.1016/j.still.2021.105026

[45] Pramaningsih, V., Yuliawati, R., Sukisman, S., Hansen, H., Suhelmi, R., Daramusseng, A. (2023). Water quality index and public health impacts around Karang Mumus River, Samarinda. Jurnal Kesehatan Lingkungan Indonesia, 22(3): 313-319. https://doi.org/10.14710/jkli.22.3.313-319

[46] Isdianto, A., Luthfi, O.M., Asadi, M.A., Haykal, M.F., Harahab, N., Kurniawan, A., Wicaksono, A.D. (2021). Water quality of Sempu Strait to support the ecosystem resilience. IOP Conference Series: Earth and Environmental Science 797(1): 012002. https://doi.org/10.1088/1755-1315/797/1/012002

[47] Ghalib, H.S., Ramal, M.M. (2021). Spatial and temporal water quality evaluation of heavy metals of Habbaniyah Lake, Iraq. International Journal of Design & Nature and Ecodynamics, 16(4): 467-475. https://doi.org/10.18280/ijdne.160414

[48] Li, J., Pu, L., Zhu, M., Zhang, J., Li, P., Dai, X., Xu, Y., Liu, L. (2014). Evolution of soil properties following reclamation in coastal areas: A review. Geoderma, 226: 130-139. https://doi.org/10.1016/j.geoderma.2014.02.003

[49] Rozirwan, Az-Zahrah, S.A.F., Khotimah, N.N., Nugroho, R.Y., Putri, W.A.E., Fauziyah, Melki, Agustriani, F., Siregar, Y.I. (2024). Ecological risk assessment of heavy metal contamination in water, sediment, and polychaeta (Neoleanira Tetragona) from coastal areas affected by aquaculture, urban rivers, and ports in South Sumatra. Journal of Ecological Engineering, 25(1): 303-319. https://doi.org/10.12911/22998993/175365

[50] Isdianto, A., Amanda, S.S., Yamindago, A., Dewi, C.S.U., Aliviyanti, D., Luthfi, O.M., Fathah, A.L., Atikawati, D., Putri, B.M., Puspitasari, I.D. (2024). Water quality impact Christmas tree worms (Spirobranchus spp.) distribution and community structure on hard corals at Sempu Island Nature Reserve, Malang, Indonesia. Journal of Ecological Engineering, 25(5): 175-186. https://doi.org/10.12911/22998993/186161

[51] Fay, C.D., Nattestad, A. (2022). Advances in optical based turbidity sensing using LED photometry (Pedd). Sensors, 22(1): 254. https://doi.org/10.3390/s22010254

[52] Shehab, A.I., Fayyadh, A.F. (2024). The Gavrilovic model to estimate the volume of water erosion in Al-Ratka Valley Basin. International Journal of Design & Nature and Ecodynamics, 19(6): 2117-2126. https://doi.org/10.18280/ijdne.190628

[53] Chen, L., Zhou, Z., Xu, M., Xu, F., Tao, J., Zhang, C. (2018). Exploring the influence of land reclamation on sediment grain size distribution on tidal flats: A

numerical study. Coastal Engineering Proceedings, 1(36): 85. https://doi.org/10.9753/icce.v36.papers.85

[54] Grifoll, M., Cerralbo, P., Guillén, J., Espino, M., Boye Hansen, L., Sánchez-Arcilla, A. (2019). Characterization of bottom sediment resuspension events observed in a Micro-Tidal Bay. Ocean Science, 15(2): 307-319. https://doi.org/10.5194/os-15-307-2019

[55] Abebe, L.S., Chen, X., Sobsey, M.D. (2016). Chitosan coagulation to improve microbial and turbidity removal by ceramic water filtration for household drinking water treatment. International Journal of Environmental Research and Public Health, 13(3): 269. https://doi.org/10.3390/ijerph13030269

[56] Megersa, M., Beyene, A., Ambelu, A., Triest, L. (2019). Coupling extracts of plant coagulants with solar disinfection showed a complete inactivation of faecal coliforms. CLEAN-Soil, Air, Water, 47(1): 1700450. https://doi.org/10.1002/clen.201700450

[57] Fatahillah, E.R., Hasyim, A.W., Anggraeni, M., Jasmine, A.P., Isdianto, A. (2025). Urban harmony: Integrating spatial suitability and socio-economic factors to enhance quality of life in Kotalama Riverbank Settlements, Malang City, Indonesia. International Journal of Sustainable Development and Planning, 20(5): 1813-1829. https://doi.org/10.18280/ijsdp.200502

[58] Sulaiman, A.I., Prastyanti, S., Adi, T.N., Chusmeru, Novianti, W., Windiasih, R., Weningsih, S. (2023). Stakeholder communication and its impact on participatory development planning in rural areas. International Journal of Sustainable Development and Planning, 18(8): 2513-2521. https://doi.org/10.18280/ijsdp.180822

[59] Effendi, M., Nasution, M.A., Harahap, R., Amin, M. (2023). Model for ulayat land conflict resolution in North Sumatra, Indonesia. International Journal of Sustainable Development and Planning, 18(7): 2177-2182. https://doi.org/10.18280/ijsdp.180721

[60] Isdianto, A., Luthfi, O.M., Setyanto, A., Fathah, A.L., Putri, B.M. (2024). The effects of marine debris on Indonesia's coral reefs and mitigation initiatives. In Advances in Environmental Engineering and Green Technologies, pp. 33-64. https://doi.org/10.4018/979-8-3693-2436-3.ch002

[61] Zhang, W., Zhen, G., Tong, Y., Yang, L., Zhu, Y., Liu, G., Wang, X., Li, Y. (2016). Perspectives on policy framework for trans-boundary water quality management in China. Environmental Hazards, 15(2): 113-127. https://doi.org/10.1080/17477891.2016.1140631

[62] Neto, S. (2018). Territorial integration of water management in the City. Water Challenges of an Urbanizing World. https://doi.org/10.5772/intechopen.72876

[63] Isdianto, A., Pangestu, W.S., Yamindago, A., Dewi, C.S.U., Aliviyanti, D., Luthfi, O.M., Setyoningrum, D., Fathah, A.L., Putri, B.M., Puspitasari, I.D. (2024). The occurrence of marine debris and its impacts on coral reefs in the Sempu Island Nature Reserve, Malang, Indonesia. Journal of Ecological Engineering, 25(9): 70-80. https://doi.org/10.12911/22998993/190514

[64] Yustiana, D., Fadli, M., Kusumaningrum, A. (2021). Significant factors impact of reclamation on environmental, economic, and social cultural aspects in Makassar city. Global Journal of Engineering and Technology Advances, 7(3): 213-223. https://doi.org/10.30574/gjeta.2021.7.3.0094

[65] Okorigba, R.K., Ezema, I.C., Ekhaese, E.N. (2024). Assessment of awareness and adoption levels of environmental sustainability practices (ESP) in large-sized hotels (LSH) in Lagos, Nigeria. International Journal of Sustainable Development and Planning, 19(9): 3431-3442. https://doi.org/10.18280/ijsdp.190913

[66] Permana, A.S., Astuti, W., Er, E. (2017). Waterfront development concepts in Indonesia from the perspective of urban planning and environmental sustainability. International Journal of Built Environment and Sustainability, 4(3): 146-155. https://doi.org/10.11113/ijbes.v4.n3.207

[67] Rudianto, R., Darmawan, V., Isdianto, A., Bintoro, G. (2022). Restoration of coastal ecosystems as an approach to the integrated mangrove ecosystem management and mitigation and adaptation to climate changes in north coast of East Java. Journal of Coastal Conservation, 26(4): 37. https://doi.org/10.1007/s11852-022-00865-4

[68] Li, J., Ji, S. (2020). Empirical analysis on the relationship between institutional pressure, environmental strategy and corporate environmental performance. International Journal of Sustainable Development and Planning, 15(2): 173-184. https://doi.org/10.18280/ijsdp.150207

[69] Thongkong, S., Worawattanaparinya, S., Silpcharu, T. (2022). Guidelines for effective industrial waste management of the industrial business sectors. Asian Journal of Water, Environment and Pollution, 19(3): 51-57. https://doi.org/10.3233/ajw220039

[70] Farzadkia, M., Jorfi, S., Nikzad, M., Nazari, S. (2020). Evaluation of industrial wastes management practices: Case study of the Savojbolagh Industrial Zone, Iran. Waste Management and Research, 38(1): 44-58. https://doi.org/10.1177/0734242X19865777

[71] Alakaş, H.M., Gür, Ş., Özcan, E., Eren, T. (2020). Ranking of sustainability criteria for industrial symbiosis applications based on ANP. Journal of Environmental Engineering and Landscape Management, 28(4): 192-201. https://doi.org/10.3846/jeelm.2020.13689

[72] Carey, C.C., Woelmer, W.M., Lofton, M.E., Figueiredo, R.J., et al. (2022). Advancing lake and reservoir water quality management with near-term, iterative ecological forecasting. Inland Waters, 12(1): 107-120. https://doi.org/10.1080/20442041.2020.1816421

[73] Xu, H., Zheng, H., Chen, X., Ren, Y., Ouyang, Z. (2016). Relationships between river water quality and landscape factors in Haihe River Basin, China: Implications for Environmental Management. Chinese Geographical Science, 26(2): 197-207. https://doi.org/10.1007/s11769-016-0799-9

[74] Zhao, Z., Liu, G., Liu, Q., Huang, C., Li, H. (2018). Studies on the spatiotemporal variability of river water quality and its relationships with soil and precipitation: A case study of the Mun River Basin in Thailand. International Journal of Environmental Research and Public Health, 15(11): 2466. https://doi.org/10.3390/ijerph15112466

[75] Cardoso, I.M.F., Cardoso, R.M.F., Esteves da Silva, J.C.G. (2021). Advanced oxidation processes coupled with nanomaterials for water treatment. Nanomaterials, 11(8): 2045. https://doi.org/10.3390/nano11082045

[76] Li, Y., Han, T., Bi, K., Liang, K., Chen, J., Lu, J., He, C., Lu, Z. (2020). The 3D reconstruction of Pocillopora

colony sheds light on the growth pattern of this reef-building coral. Iscience, 23(6): 101069. https://doi.org/10.1016/j.isci.2020.101069
[77] Stavropoulos, S., Wall, R., Xu, Y. (2018). Environmental regulations and industrial competitiveness: Evidence from China. Applied Economics, Routledge, 50(12): 1378-1394. https://doi.org/10.1080/00036846.2017.1363858
[78] Astuti, H.D., Yulianah, Y., Safitri, I. (2024). Law enforcement against business actors who cause water pollution. Golden Ratio of Law and Social Policy Review, 2(2): 34-40. https://doi.org/10.52970/grlspr.v2i2.300
[79] Ningrum, V.P. (2023). Environmental law enforcement in law number 32 of 2009 concerning environmental protection and management. Asian Journal of Social and Humanities, 1(8): 351-356. https://doi.org/10.59888/ajosh.v1i08.38