

## Enhancing Detection and Mitigation of Toxicity in Marine Biota from Drilling Activities



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### Abstract

*The growing demand for petroleum-based energy has significantly contributed to environmental pollution, particularly in the oil mining industry. This study aims to evaluate the toxicity of oil drilling mud on marine biota, using tiger shrimp (*Monodon peneus*) as bioindicators. The shrimp were exposed to various mud concentrations (100%, 50%, 25%, 12.5%, 6.25%, 3.25%, 1.25%, and 0%) and observed over time intervals of 0, 24, 48, 72, and 96 hours. The methodology involved direct observation of the shrimp's survival rates at each mud concentration. The results revealed a significant decline in survival rates at higher mud concentrations, with a strong positive correlation ( $r = 0.81$ ) between mud concentration and toxicity. The pH levels remained stable and alkaline (7.81–8.28), while turbidity at lower concentrations (6.25%) was within acceptable limits after 96 hours, with a strong correlation ( $r = 0.73$ ). These findings underscore the importance of stringent monitoring and management of drilling mud disposal to safeguard marine ecosystems, aligning with Sustainable Development Goal (SDG) 14: Life Below Water.*

**Keywords:** Drilling Mud, LC50-96, Marine Life, % Survival, Turbidity



## 1. Introduction

This study aims to thoroughly evaluate the effects of oil drilling mud on the survival rate of tiger shrimp (*Penaeus Monodon*), an important species that inhabits coastal waters where oil drilling activities take place. Tiger shrimp are ecologically significant and economically valuable, especially in aquaculture, making them a suitable bioindicator for assessing environmental impact [1]. Drilling mud, a by-product of petroleum extraction, can pose a severe threat to marine life if not properly treated before being discharged into the sea. The Indonesian government has established guidelines for managing drilling waste, such as the Regulation of the Minister of Energy and Mineral Resources No. 45 of 2006, which mandates that drilling waste with an LC50 - 96 hours value of less than 30,000 ppm must be treated before being released into water bodies [2]. However, despite these regulations, there is a notable gap in research regarding the specific impact of drilling mud on the survival and health of marine species, particularly at varying concentrations and exposure times [3].

This study addresses this gap by conducting a detailed investigation into how different concentrations of drilling mud (100%, 50%, 25%, 12.5%, 6.25%, 3.25%, and 0%) affect the survival of tiger shrimp over multiple exposure periods (0, 24, 48, 72, and 96 hours). The research methodology includes comparing these concentrations of drilling mud mixed with seawater to observe changes in the survival rate of shrimp, aiming to quantify the level of toxicity associated with each concentration and exposure duration [4]. In addition to tracking survival rates, the study also monitors water quality parameters such as pH and turbidity, which are crucial in understanding the broader environmental impact of drilling mud on marine ecosystems [5]. The novelty of this research lies in its focus on both the biological impact on tiger shrimp and the accompanying environmental factors, such as water chemistry changes. While previous studies may have examined the broader environmental effects of oil spills and drilling mud, few have provided such detailed empirical data on the interaction between pollutant concentration, exposure time, and survival rates of specific marine species [6]. By filling this gap, the study offers valuable insights into the micro-level effects of drilling mud on marine life, contributing to a deeper understanding of the environmental risks posed by oil drilling operations [7].

The findings of this study are expected to reveal significant correlations between higher concentrations of drilling mud and lower survival rates of tiger shrimp, particularly at longer exposure times. These results will have important implications for improving regulatory frameworks and refining waste management practices for the oil drilling industry [8]. By establishing clearer guidelines on safe disposal methods for drilling mud, this research can contribute to minimizing the ecological footprint of offshore drilling activities and protecting marine biodiversity [9]. Additionally, the research aligns with Sustainable Development Goal 14 (Life Below Water), emphasizing the importance of responsible resource management to ensure the sustainability of marine ecosystems.

## 2. Research Method

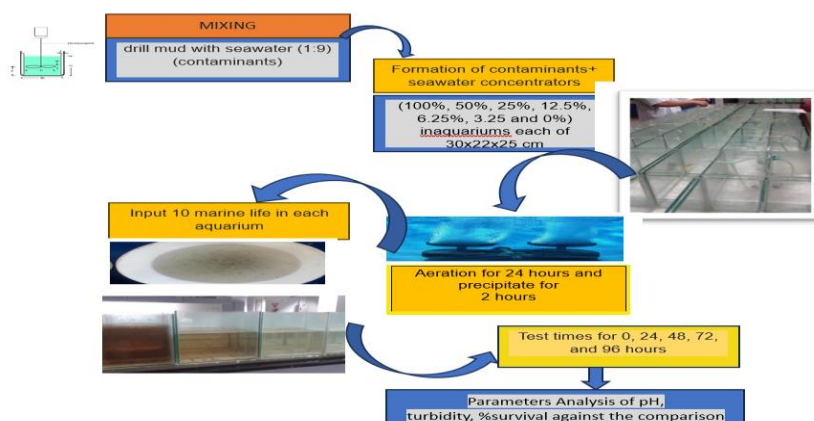


Figure 1. Research Scheme

This study examines the toxicity of oil drilling mud on the marine biota, particularly tiger shrimp (*Penaeus monodon*), using various concentrations of drilling mud and different exposure times [10]. The drilling mud used for the experiment was obtained from the PPPTMGB LEMIGAS Exploitation Laboratory, while the seawater samples were collected from Tanjung Lesung Beach, Tangerang. The research scheme is illustrated in Figure 1. The first stage of sample preparation involved mixing the drilling mud with seawater in a ratio of 1 part drilling mud to 9 parts seawater, forming the contaminant source for the study. This mixture was then further diluted with seawater at ratios of 1:1, 1:2, 1:3, 1:4, 1:5, 1:6, and 1:0, corresponding to concentration levels of 100%, 50%, 25%, 12.5%, 6.25%, 3.25%, and 0%.

Each concentration was placed in a separate aquarium, each measuring 30x22x25 cm. The aquariums were provided with aeration for 24 hours and left to settle for 2 hours before the introduction of 10 tiger shrimp per aquarium [11]. The tiger shrimp served as bioindicators for determining the effect of drilling mud toxicity on marine life. The exposure times were set at 0, 24, 48, 72, and 96 hours. During the experiment, key parameters such as pH, turbidity, and survival rate (mortality percentage) were recorded and analyzed.

The research applied a completely randomized design (CRD) at a 95% confidence interval, using SPSS software for statistical analysis. The data processing followed the USEPA Volume 4 method to evaluate the effects of drilling mud concentrations and exposure times on the survival rate of tiger shrimp, as well as on water quality parameters such as pH and turbidity [12]. The goal of the study was to assess the toxicity of drilling mud, determine the safe limits for its disposal, and contribute to understanding the potential environmental impacts on marine biota, aligning with Sustainable Development Goal 14: Life Below Water [13]. This research is expected to provide empirical evidence of how different concentrations of drilling mud affect the survival of tiger shrimp and offer insights into the broader environmental risks associated with offshore oil drilling activities.

## 2.1 Literature Review

Drilling mud is a liquid mixture of materials and additives used in drilling operations to facilitate the extraction of hydrocarbons. During the circulation of drilling mud, it can infiltrate geological formations and cause contamination, leading to significant damage to rocks, soil, and seawater, particularly in offshore drilling operations [14]. Studies have demonstrated the harmful effects of drilling mud on sandstone formations, showing considerable damage after exposure to oil emulsion drilling mud, as indicated by the increased skin value of the sample core. Drilling mud also possesses specific flow properties and viscosities, which are crucial in describing its movement during drilling [15]. Research has shown that an increase in viscosity is often a result of a rise in solids content, which can lead to complications in the drilling process if not managed properly. Reducing solids content or adding thinners can mitigate these issues [16].

Drilling mud is typically composed of water, sludge, minerals, and chemicals. These by-products have the potential to be toxic if not treated properly, posing a significant threat to the marine environment around drilling platforms and onshore drilling sites [17]. Drilling mud is essentially a suspension of various chemicals and minerals in water, oil, gas, air, or foam, depending on the specific needs of the drilling operation. Previous studies have reported that new drilling mud contains high concentrations of heavy metals, such as copper (54.50 ppm), cadmium (4.91 ppm), lead (121.10 ppm), and zinc (223 ppm), all of which exceed permissible levels for discharge into marine environments [18]. To mitigate this, materials like bentonite and barite are often used in drilling operations to reduce the risk of metal contamination. Soil contamination from oil drilling mud can also be treated through bioremediation. Research has shown that the inoculation of bacterial isolates into contaminated soil can reduce the concentrations of harmful components, such as organic carbon, nitrogen, phosphorus, potassium, and pH levels [19]. This highlights the potential for using biological methods to address contamination from oil drilling by-products, contributing to a more sustainable and eco-friendly solution for managing drilling waste [20].

Toxicity testing is a critical method for assessing the harmful effects of chemicals on living organisms. The LC50 value represents the concentration of a toxic substance that causes 50% mortality in test organisms [21]. Toxicity tests often involve the use of bioindicators, which are selected based on criteria established by organizations such as the Organization for

Economic Cooperation and Development (OECD) and the US Environmental Protection Agency (US-EPA). In this study, tiger shrimp (*Penaeus monodon*) are used as bioindicators to assess the environmental impact of drilling mud, as they represent marine ecosystem health [22]. Toxicity is defined as the ability of a chemical compound to cause damage to sensitive areas within or outside the body of an organism [23], [24]. A substance is considered toxic if its interaction with an organism results in harmful effects, such as disruptions to physiological and morphological processes. In this research, morphological changes in tiger shrimp are observed as indicators of the toxic effects of drilling mud. The exposure periods range from 3 to 96 hours over five days to assess both direct and indirect impacts. Indirect impacts often include a decline in water quality, which can disrupt aquatic ecosystems and reduce biodiversity [25].

Sustainable Development Goals (SDGs) play an essential role in guiding this study, particularly SDG 14: Life Below Water, which emphasizes the importance of conserving and sustainably using oceans, seas, and marine resources [26]. The contamination of marine environments by untreated drilling mud poses a significant threat to biodiversity and marine life. By investigating the effects of drilling mud on marine organisms such as tiger shrimp, this research aligns with SDG 14's objectives to prevent marine pollution and promote the sustainable management of marine ecosystems [27]. Additionally, this study supports SDG 6: Clean Water and Sanitation by exploring the impact of drilling waste on water quality, contributing to global efforts to reduce water pollution and improve water management practices [28]. Furthermore, by exploring bioremediation methods for treating contaminated soil, this study aligns with SDG 12: Responsible Consumption and Production, advocating for sustainable practices in managing industrial waste [29], [30]. In summary, this review underscores the environmental risks posed by drilling mud and the need for comprehensive toxicity testing to understand its impact on marine life. This study, using tiger shrimp as bioindicators, aims to contribute to the sustainable management of marine environments in line with the SDGs, promoting responsible practices that protect marine biodiversity and ensure clean, healthy oceans for future generations.

## 2.2 Hypotheses

This study aims to explore the effects of drilling mud dilution with seawater on marine life, particularly *Penaeus monodon*, and the environmental implications of oil drilling activities in coastal regions. Specifically, the research focuses on the interaction between varying concentrations of drilling mud, exposure duration, and their collective impact on marine organisms, as well as key environmental parameters such as salinity, pH, and turbidity [31]. The following hypotheses have been formulated to guide the investigation:

- H<sub>1</sub>:** The dilution of drilling mud with seawater at varying concentrations (100%, 50%, 25%, 12.5%, 6.25%, 3.25%, 1.25%, and 0%) significantly reduces the toxicity to marine life, particularly *Penaeus monodon*, over increasing exposure durations (0, 24, 48, 72, and 96 hours).
- H<sub>2</sub>:** Oil drilling activities conducted in coastal regions have a detrimental effect on marine life, specifically *Penaeus monodon* if untreated drilling mud is discharged into the aquatic environment.
- H<sub>3</sub>:** There is a significant relationship between the concentration of drilling mud and the exposure time in influencing toxicity levels in marine life, as measured through salinity, pH, and turbidity parameters.

These hypotheses aim to examine the interaction between drilling mud concentration, exposure time, and their impact on marine organisms and environmental parameters.

## 3. Findings

### 3.1 Observation of Percent Survival

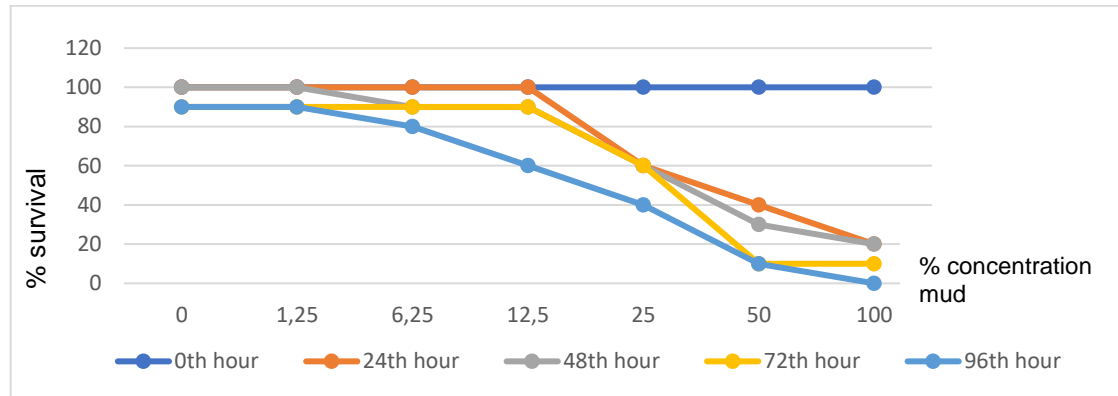
The survival rate (%) of tiger shrimp (*Penaeus monodon*) over time is a critical indicator of the toxic effects of different drilling mud concentrations. As shown in Table 1, the survival rate of tiger shrimp at various concentrations (0%, 1.25%, 6.25%, 12.5%, 25%, 50%, and 100%) was recorded at different exposure times (0, 24, 48, 72, and 96 hours). At the initial time (0 hours), all tiger shrimp exhibited 100% survival across all concentrations. However, by the 24th hour, the survival rate began to decrease, particularly at concentrations of 25% to 100%, where it

dropped significantly to 60% at 25% concentration and further to 20% at 100% concentration. Over time, the mortality rate increased, and by the 96th hour, all shrimp exposed to 100% concentration of drilling mud were deceased.

**Table 1.** Effect of Different Drilling Mud Concentrations on the Survival Rate (%) of Marine Biota (*Peneus monodon*)

Drill Mud Concentration (%)	0 Hour	24 Hour	48 Hour	72 Hour	96 Hour
0	100	100	100	90	90
1,25	100	100	100	90	90
6,25	100	100	90	90	80
12,5	100	100	90	90	60
25	100	60	60	60	40
50	100	40	50	10	10
100	100	20	20	10	0

The trend observed in Figure 2 illustrates a consistent decline in the survival rate as drilling mud concentration and exposure time increase. The survival rate dropped drastically from 100% at the start to 0% after 96 hours for the highest concentration (100%). These results are in agreement with prior research [1], which found a similar trend in increased mortality with prolonged exposure to drilling mud, particularly at concentrations of 0 to 200 ml/l, as the drilling mud had an LC50 value still below the standard of  $\geq 30,000$  ppm. Additionally, [12] reported similar findings with *Artemia salina*, where exposure to toxic waste for 72 to 96 hours caused significant internal and external damage to the organisms, leading to high mortality rates.



**Figure 2.** Survival Rate (%) of Tiger Shrimp (*Penaeus monodon*) at Different Concentrations of Drilling Mud

Statistical analysis of the data, as shown in Table 3, supports these findings. The results of the ANOVA show that the combination of drilling mud concentration and exposure time significantly affects the survival rate of tiger shrimp. The calculated F-value (31.846) exceeds the critical F-value (4.15) at a 95% confidence level ( $\alpha = 0.05$ ), indicating a significant relationship between the independent variables (drilling mud concentration and exposure time) and the dependent variable (survival rate). Furthermore, the correlation coefficient ( $r = 0.81$ ) indicates a very strong relationship between the factors, confirming that higher concentrations of drilling mud and longer exposure times lead to increased toxicity.

**Table 3.** Results of ANOVA for the Effect of Drilling Mud Concentration on the Survival Rate (%) of Tiger Shrimp (*Penaeus monodon*)

ANOVA <sup>a</sup>						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	26256.839	2	13128.419	31.846	.000 <sup>b</sup>
	Residual	13191.822	32	412.244		
	Total	39448.661	34			
a. Dependent Variable: Drill Mud Concentration (%)						
b. Predictors: (Constant), Survival, Long Exposure						

Additionally, the prediction of survival rates (%) based on drilling mud concentration and exposure time can be modeled using the following regression equation:

$$Y = 113.275 - 0.399X_1 - 0.921X_2 \dots\dots\dots(1)$$

where Y represents the survival rate, X<sub>1</sub> denotes the concentration of drilling mud, and X<sub>2</sub> represents the exposure time.

The findings support Hypothesis 1, which posits that the dilution of drilling mud with seawater at different ratios significantly decreases the survival rate of *Penaeus monodon* with increasing exposure time. Hypothesis 2 is also validated, as the results demonstrate the detrimental effects of untreated drilling mud on marine biota. Finally, Hypothesis 3 is confirmed by the strong correlation between drilling mud concentration, exposure time, and the survival rate of tiger shrimp, as indicated by the statistical analysis and regression model.

**3.2 Acidity (pH) observation**

The pH level, which indicates the concentration of hydrogen ions in a solution, is a critical parameter for assessing the environmental suitability of water for marine life. Higher pH values indicate an alkaline solution, while lower pH values suggest an acidic environment. In this study, the pH of drilling mud water at varying concentrations (0%, 1.25%, 3.25%, 6.25%, 12.5%, 25%, 50%, and 100%) was monitored over different exposure times (0, 24, 48, 72, and 96 hours). The pH levels observed, as shown in Table 4, remained relatively stable across all concentrations and time periods, ranging from 8.28 at 0 hours to a slightly lower value of 7.81 at 96 hours.

**Table 4.** pH of Drilling Mud at Different Concentrations and Exposure Times to Marine Biota (*Penaeus Monodon*)

Drill Mud Concentration (%)	0 Hour	24 Hour	48 Hour	72 Hour	96 Hour
0	8.28	8.32	8.26	8.22	8.18
1,25	8.21	8.21	8.19	8.20	8.20
3,25	8.20	8.18	8.17	8.18	8.19
6,25	8.21	8.16	8.13	8.15	8.14
12,5	8.20	8.05	8.06	8.11	8.09
25	8.23	8.03	7.97	8.02	8.07
50	8.24	8.12	7.81	7.88	7.93
100	8.24	8.12	7.81	7.88	7.93

The data in Table 4 demonstrate that the pH values remained within an alkaline range (7.81–8.28) throughout the exposure period, regardless of the drilling mud concentration. This stability in pH is consistent with typical marine water conditions, where the standard pH level for marine life is generally alkaline, as indicated by the Ministry of Environment Regulation No. 51 of 2004, which sets the acceptable pH for marine life at 8.5 [13]. The pH levels observed in this study suggest that the environment remained suitable for tiger shrimp (*Penaeus monodon*)

within the measured parameters, as marine biota such as shrimp can generally thrive in environments with a pH above 7 [14].

These findings also indicate that the pH levels, even at higher drilling mud concentrations (50% and 100%), did not deviate significantly from the normal alkaline range of marine waters. This suggests that drilling mud does not cause drastic changes in the pH of the surrounding water, thus supporting the notion that pH is not a primary factor influencing the toxicity observed in the survival rate of *Penaeus monodon*. Furthermore, the stability of pH aligns with the conditions in which marine organisms can live, provided that other factors such as chemical toxicity, as indicated by LC50 values, are within safe limits (LC50  $\geq$  30,000 ppm).

These findings confirm part of Hypothesis 3, which posits that pH levels would remain stable and within acceptable ranges despite variations in drilling mud concentration and exposure time. The results show that the concentration of drilling mud had minimal impact on the pH of the water, and the alkaline pH levels were maintained throughout the study period. Therefore, while pH stability contributes to the livability of the environment for marine biota, the toxicity observed in this study is likely influenced more by other factors, such as chemical components or heavy metals present in the drilling mud.

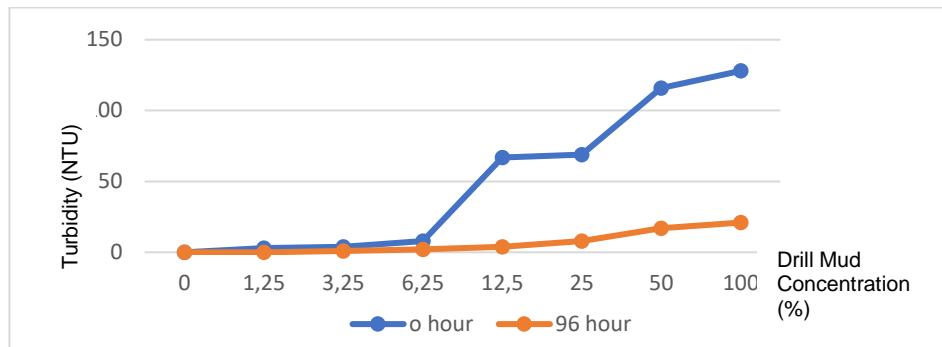
### 3.3 Turbidity Observation

Turbidity is a critical factor in assessing water quality, as it indicates the presence of particles suspended in the water. High turbidity levels suggest poor water quality, which can affect marine life. Previous research [15] has shown that coastal waters, such as those in Cirebon, experience high levels of turbidity due to sediment and waste from rivers, with turbidity levels exceeding the environmental quality standard of 5 NTU.

**Table 5.** Turbidity (NTU) of Drilling Mud against Time and Mud Concentration

Drill mud concentration (%)	0 Hour	96 Hour
0	0	0
1,25	3	0
3,25	4	1
6,25	8	2
12,5	67	4
25	69	8
50	116	17
100	128	21

In this study, the turbidity levels were measured at different concentrations of drilling mud (0%, 1.25%, 3.25%, 6.25%, 12.5%, 25%, 50%, and 100%) over two time points: 0 hours and 96 hours. The results are presented in Table 5 and Figure 3. At the start of the experiment (0 hours), the turbidity ranged from 0 NTU at 0% concentration to 128 NTU at 100% concentration, with even the lower concentrations (6.25% and above) exceeding the environmental quality standard of 5 NTU. After 96 hours, the turbidity decreased across all concentrations, with the highest concentration (100%) showing a turbidity of 21 NTU. The turbidity at the 25% concentration dropped to 8 NTU, just below the environmental quality standard, indicating that exposure time and particle settling played a role in reducing turbidity levels.



**Figure 3.** Turbidity (NTU) of drilling mud against time and mud concentration

The results suggest that turbidity is initially high due to the presence of particles from the drilling mud and potentially dead biota, as indicated by the increasing turbidity at higher concentrations. However, as the exposure time increased, the particles began to settle, leading to a decrease in turbidity over the 96-hour period.

**Table 5.** NOVA Results for the Effect of Drilling Mud Concentrations on the Turbidity of Marine Biota (*Penaeus Monodon*)

ANOVA <sup>a</sup>						
	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8840.013	2	4420.006	7.183	.008 <sup>b</sup>
	Residual	7999.097	13	615.315		
	Total	16839.109	15			
a. Dependent Variable: Drill Mud Concentration (%)						
b. Predictors: (Constant), Turbidity, Long exposure						

Statistical analysis of the data, as presented in Table 5, shows a significant relationship between drilling mud concentration and turbidity levels. The ANOVA results reveal a calculated F-value of 7.183, which is greater than the critical F-value of 4.15 at a 95% confidence interval ( $\alpha = 0.05$ ). This indicates a significant effect of drilling mud concentration and exposure time on turbidity levels. The correlation coefficient ( $r = 0.73$ ) further confirms a strong positive relationship between these variables.

The regression equation to predict turbidity levels is given by:

$$Y = -7.931 + 0.295X_1 + 0.699X_2 \dots\dots\dots(2)$$

The regression equation shows that Y represents the turbidity, X1 represents the concentration of drilling mud, and X2 represents the exposure time. This equation suggests that higher concentrations of drilling mud and longer exposure times result in increased turbidity. However, as time progresses, the rate of turbidity increase decreases due to particle settling. These findings confirm Hypothesis 3, which posits a significant relationship between drilling mud concentration and exposure time on environmental parameters, including turbidity. The strong correlation ( $r = 0.73$ ) and regression model indicate that both factors significantly influence water turbidity, affecting marine life such as *Penaeus monodon*. While turbidity decreases over time, indicating particle settlement, high initial turbidity levels can still have detrimental effects on marine organisms, particularly during the early stages of exposure, emphasizing the need for stringent monitoring of drilling mud disposal to protect marine ecosystems.

These findings are directly relevant to Sustainable Development Goal (SDG) 14: Life Below Water, which focuses on the conservation and sustainable use of oceans, seas, and marine resources. Effective management of drilling mud disposal and monitoring its effects on water quality can help reduce marine pollution, contributing to the protection of marine biodiversity. Additionally, the study supports SDG 6: Clean Water and Sanitation, as it highlights the importance of maintaining water quality by controlling turbidity levels, which is essential for the health and survival of marine organisms.

#### 4. Conclusion

The study demonstrated that the survival rate of tiger shrimp (*Penaeus monodon*) significantly decreased at drilling mud concentrations of 25%, 50%, and 100% after 24 hours of exposure, highlighting a strong correlation between higher concentrations and increased toxicity ( $r=0.81$ ). The pH levels remained alkaline (7.81 to 8.28) over 0 to 96 hours, indicating minimal impact on water acidity. Turbidity was within acceptable limits at a 6.25% concentration after 96 hours, with a value of 8 NTU, and showed a significant difference in turbidity levels across various concentrations and exposure times, with a correlation of  $r=0.73$ . These findings emphasize the need for careful monitoring of drilling mud disposal to protect marine ecosystems, in line with Sustainable Development Goal 14. Future research should investigate the long-term impacts of drilling mud on different marine species, bioaccumulation effects, and explore environmentally friendly alternatives to drilling mud, while also studying other key parameters such as dissolved oxygen and heavy metal contamination for a more comprehensive understanding of its effects on marine life.

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