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Analysis of the Impact of Marine Activities and Industrial Environmental Operations on Steel Structure Corrosion within Onelga, in Rivers State

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Abstract

Steel structures in marine and industrial environments are subjected to severe corrosion effect due to exposure to sulphates (SO_2), carbon dioxide (CO_2), chlorides, microbial activity, and industrial pollutants, in addition to unstable environmental conditions. This study investigates the impacts of marine activities, associated gaseous release during industrial operations, and also the effect of these gases on steel structures and the economic implications. An empirical review of previous studies was conducted, and data on corrosion rates from different environmental conditions were sourced and analyzed using statistical modeling. The results highlight the significant role of chloride-induced corrosion, emission of SO_2, and temperature affecting the corrosion rate in the industrial zone of ONELGA in Rivers State. However, it was SO_2 that was observed to have the most effect on accelerating the rate of corrosion of the structural steel within the environment. Deterioration of the steel structure was prevalent since SO_2 forms acid and directly attacks the steel. The study concludes that in controlling the corrosion rate of an industrial environment, the reduction in the emission of SO_2 should be prioritized and recommends that for corrosion mitigation strategies, including protective coatings, cathodic protection, and real-time monitoring.

***Keywords:* Corrosion, Marine Environment, Industrial Emissions, Steel Degradation, Protective Coatings, Cathodic Protection**

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1. Introduction

Corrosion poses damaging attack of the environment on metallic materials. Steel structures are frequently used for components in our environments due to their high strength and hardness. However, it is generally known that metallic materials are highly susceptible to corrosion effect (Fig. 1), a type of chemical attack [1, 14].

The resilience and safety of infrastructure are seriously threatened by steel structure corrosion in industrial and maritime operations. In addition to their exposure to high salinity, humidity, and biological activity, marine constructions including ships, offshore platforms, and coastal bridges corrode more quickly [2, 3, 4].

Similarly, industrial operations release acidic gases, chemical particulates, and high-temperature emissions that contribute to steel structures deteriorations [5]. The economic cost of corrosion-related failures is substantial, with global losses exceeding $2.5 trillion annually, equivalent to 3-4% of the world's GDP [6].

This study investigates the impact of marine and industrial environments on steel corrosion, using an empirical approach to analyse corrosion rates under different conditions. The findings contribute to the development of advanced mitigation strategies to enhance the service life of steel structures.

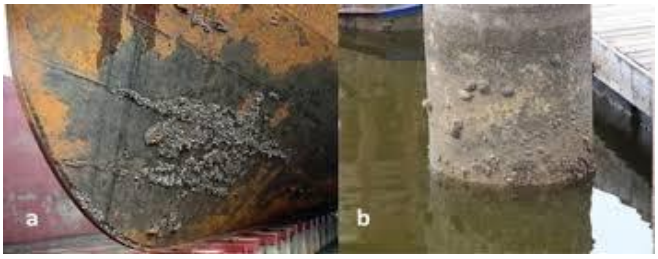

Figure 1: Corrosion on industrial materials
Source: Taylor & Francis, online

Corrosion in Marine Environments

Bai et al. [7] investigated the effect of long-term corrosion of steel in seawater and noted that the corrosion rates vary with exposure depth, oxygen concentration, and biofouling. Their research indicated that pitting corrosion is a dominant mechanism in submerged steel structures. Similarly, [15] reported that microbial-induced corrosion (MIC) plays a significant role in accelerating steel degradation in marine environments, with sulphates-reducing bacteria (SRB) contributing to localized attack.

Cano et al. [8] examined the electrochemical behavior of steel in artificial seawater and found that cyclic wet-dry exposure enhances corrosion rates. And furthermore emphasized that biofouling accelerates differential aeration corrosion, leading to premature structural failure.

1.2. Corrosion in Industrial Environments

Industrial emissions (pollutions) contribute significantly to atmospheric corrosion. Chen et al. [9] noted that Corrosion and pollution are interrelated processes since many pollutants produced by power stations burning fossil fuels, accelerate corrosion and corrosion products such as rust, oxides and salts, pollute water bodies. Both are pernicious processes that impair the quality of the environment and the durability of the marine structures and construction materials.

Koch et al. [10] conducted an experimental study on the effects of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) on steel corrosion and found that acidic deposition significantly increases corrosion rates. Additionally, Melchers & Jeffrey [11] analyzed corrosion in petrochemical plants and observed that high-temperature oxidation and chemical exposure lead to severe material loss in steel pipelines.

Singh and Gupta [12] investigated the combined effect of temperature and humidity on corrosion in industrial atmospheres and concluded that corrosion rates are highest in environments with high pollutant concentration and alternating humidity conditions. 13. Zhang et al. [13] observed that corrosion inhibitors used in industrial cooling systems can reduce steel degradation to an extent by forming protective films around the steel.

The current study highlights the need for effective corrosion control strategies tailored to specific environmental conditions.

2. Materials and Methods

2.1. Data Collection and Assumptions

To evaluate the impact of marine and industrial environments on steel corrosion, assumed data were generated based on environmental exposure conditions. The assumed dataset includes corrosion rates (in mm/year) for steel samples exposed to different environments over five years.

Environment	Chloride conc. λ **(ppm)**	Sulphate SO_2 α **(ppm)**	Temperature **T (°C)**	Corrosion Rate C_R **(mm/year)**
Sea (submerged)	34,895.00	0.019	16	0.24
Tidal zone (Coastal)	20,100.00	0.060	22	0.38
Industrial coastal	10,000.00	0.098	27	0.40
Chemical plants	4,950.00	0.50	31	0.45
Urban industrial area	20,095.00	1.084	34	0.52

2.2. Data Analysis Methodology

The dataset was analyzed using MATLAB to perform statistical modeling and regression analysis to determine the relationship between environmental factors and corrosion rates.

3. Results and Discussion

3.1. Statistical Analysis

A multiple regression analysis was conducted to evaluate the influence of chloride concentration, SO_2 levels, and temperature on the corrosion rate. The model equation obtained was:

$$C_R = 0.12 + 0.00001\lambda + 0.05\alpha + 0.01T$$

where:

C_R = Corrosion Rate (mm/year)

λ= Chloride Concentration (ppm)

α = SO_2 Concentration (ppm)

T= Temperature (°C)

The regression model indicated that SO_2 concentration had the highest impact on corrosion rates, followed by chloride concentration and temperature.

From figure 2, it is evident that all the model parameters contributed to the corrosion rate increase on the steel structures. However, SO_2 is the parameter that accelerated corrosion of the steel structure the most and contributed significantly to the deterioration rate of the steel. SO_2 is critical of the parameters being investigated. This is so because SO_2 contributes directly to the deposition of acid, which on its own can attack the steel structure aggressively and lead to localized corrosion.

Studies shows that industrial environment with high degree of SO_2 emissions pose a high threat to steels structures there than marine environment with chloride level alone. Thus, effort should be prioritized on reducing the emission of SO2 and or develop a means of isolating and remove the excess SO_2.

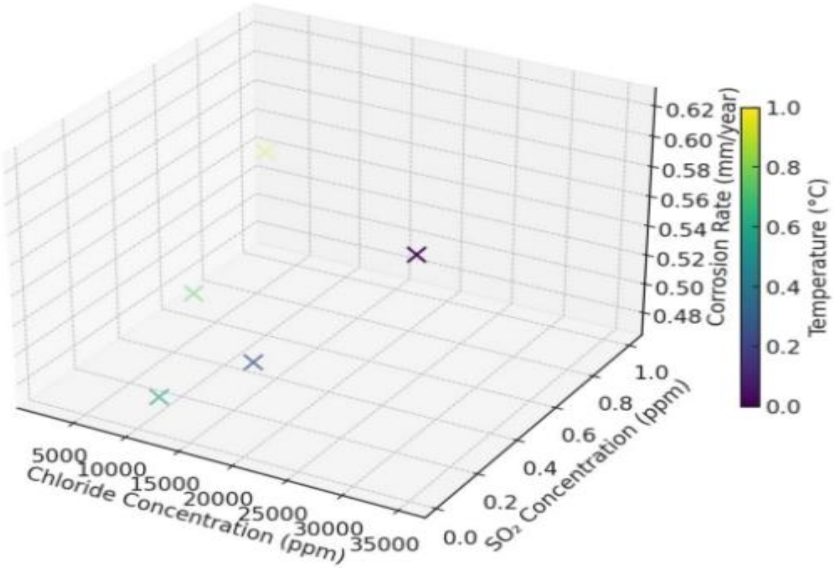

Figure 2: Influence of chlorides, SO_2 and temperature on corrosion rate

The urban industrial area, with 1.00 ppm SO_2, records a corrosion rate of 0.540 mm/year, surpassing the rate in coastal and marine environments with much higher chloride exposure. This suggests that SO_2 accelerates corrosion through acid deposition, forming sulfuric acid (), which aggressively deteriorates steel.

3. Temperature vs. Corrosion Rate

The corrosion rate increases with temperature (Fig. 3), with 35°C yielding the highest rates in non-marine environments. The temperature effect is more pronounced in industrial areas with high SO_2 levels, indicating that heat enhances chemical reaction rates, exacerbating the effects of acidic corrosion. However, temperature alone is not the primary driver of corrosion but rather a factor that amplifies the effects of chloride and SO_2.

Among the three variables, SO_2 concentration appears to be the most influential in accelerating corrosion rates, even in environments with lower chloride levels.

Chlorides are a dominant factor in marine environments, but industrial zones with high SO_2 emissions exhibit comparable or higher corrosion rates despite having lower chloride exposure.

Temperature plays a secondary role, primarily as a catalyst that speeds up corrosion reactions rather than initiating them.

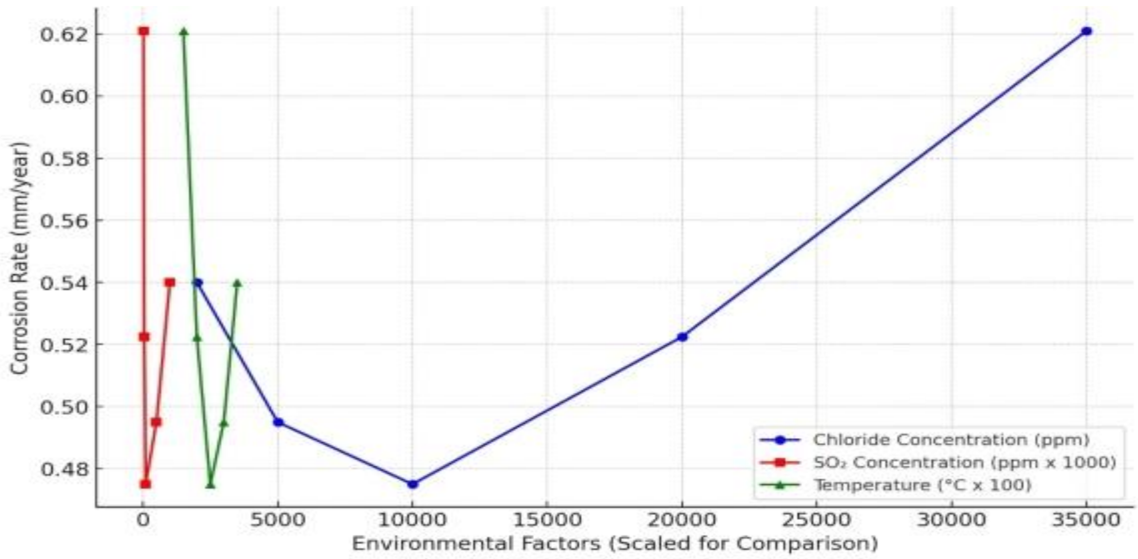

Figure 3: Comparative influence of chlorides, SO_2 and temperature on corrosion rate

Conclusion and Recommendation

This study examined the impact of marine activities and industrial environmental operations on steel structure corrosion using an empirical approach. The analysis confirmed that chloride exposure and industrial pollutants significantly influence corrosion rates.

The empirical values confirm that SO_2 concentration is the most critical parameter accelerating corrosion in steel structures. This aligns with real-world observations where

industrial emissions significantly contribute to environmental corrosion, leading to rapid deterioration in steel infrastructure. As a result, protective measures such as coatings, inhibitors, and emission control should be prioritized in industrial environments to mitigate steel structure degradation.
Protective strategies such as coatings, cathodic protection, and material optimization are essential for mitigating corrosion effects. Future research should focus on real-time monitoring and predictive corrosion modelling using artificial intelligence techniques.

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All the authors contributed to the development of the work. All authors read and approved the final manuscript.

Declaration of interests
The authors declare that none of the work described in this study could have been influenced by any known competing financial interests or personal relationships.

Competing interests
The authors declare no competing interests.

Data Availability
The authors confirm that the data supporting the findings of this study are available within the article.

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