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RESEARCH ARTICLE

ENVIRONMENTAL IMPACT OF HEAVY METAL CONTAMINATION IN INDUSTRIAL WASTEWATER :A CASE STUDY IN SOHAR PORT AREA

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ABSTRACT

The purpose of this study to evaluate the influence of industrial wastewater pollution in the Sohar Industrial Port (SIP) with a particular focus on the presence heavy metals. It aims to highlight the urgent need to balance between economic development and environmental sustainability, urging stricter regulations and improved monitoring systems to protect both the local community and the surrounding ecosystem. This research investigates the environmental and public health effects resulting from industrial activities in the SIP area. The methodology included both primary and secondary data collection to obtain a comprehensive understanding of industrial wastewater pollution in the region. Primary data were collected through the sampling and laboratory analysis of wastewater from SIP. Samples were collected quarterly, specifically in June, September, and December, to monitor seasonal variations. The findings showed heavy metals are health hazards where there were some metals level exceeding the WHO standards, these results considered as risks alarm and has to work on to mitigate its bad effects on the human health. The presence of these pollutants not only threatens the environment but also poses a significant risk to human health. Immediate action is necessary to mitigate these effects and to promote sustainable industrial practices in the area.

KEYWORDS

Pollution, Pollutants, Sustainability, hazards, Economy, Environment

1. INTRODUCTION

During the past years, Oman, like other countries, sought to develop its economy. Oman worked on many economic and industrial projects, and one of these was the Sohar Industrial Port (Ali Ibrahim et al., 2019). Previous research this port is located in the north of Oman in Al Batinah North, about 240 km from Muscat's capital (Allen, 2016). Its total area is 123 km2. The analysis states that Sohar Industrial Port includes many industries, the most important of which are mineral processing, petrochemical production, water desalination plants, and power plants (van den Bosch et al., 2017).

Despite the importance of these areas in the growth of Oman's economy, they may threaten the environment and the people who live there as an industrial wastewater considers one of the primary pollutants of water, as industrial wastewater is poured into the sea near the areas where the population lives (Wu et al., 2011).

Sohar Industrial Port is considered one of the most important ports and economic projects for Oman. In this paper, the quality of factories located in SIP was reviewed, pollutants were identified, and solutions were proposed to overcome them. Sohar Industrial Port contains various industries such as mineral processing, petrochemical production, power stations and others. These industries produce a lot of industrial wastewaters. This industrial water must contain heavy metals that are harmful to human life and the environment. These heavy metals are capable of destroying human health when they accumulate in their vital organs, such as arsenic and mercury. Industrial wastewater must be treated in factories before being discharged into the ocean due to the presence of heavy metals in the industrial wastewater. The use of appropriate techniques for the pollutants that result from them. There are many techniques such as photocatalysis, nanotechnology and other techniques. Which differs in the degree of its efficiency in removing heavy metals. Governments must also set regulations, laws and regulations that control the quality of industrial wastewater, and imposing fines when violating the regulations established to protect the environment.

A reason behind conducting this study where industrial wastewater is considered one of the most dangerous water pollutants, and its discharge near residential areas may result in many environmental and health impacts. This is regarded as a global problem, as many industrial ports around the world are affected by the environment and the population around them due to the discharge of industrial wastewater from them. Moreover, the study was essential in the way it approaches a significant environmental and human health problem within the Sohar Port area. It may be helpful in the stakeholder and policymakers' design of the most effective control measures that will ensure the sustainability of the SIP project by researching the causes and impacts of industrial wastewater pollution

1.1 Environmental Impact of Industrial Wastewater

Discharging industrial wastewater near residential and agricultural areas has been reported to degrade farms, crops, and fisheries (Ho et al., 2012). Similar cases in Nigeria highlight the harmful effects on local soil and water bodies (Okereke et al., 2016).

1.2 Pollutants in Industrial Wastewater

Heavy metals such as chromium (Cr), nickel (Ni), arsenic (As), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn) are common in industrial effluents

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(Appenroth, 2010; Bharagava, 2017). Their persistence and toxicity make them particularly hazardous.

Through what the author states, it can focus on the quality of the industrial waste generated from the factories in the Sohar Industrial Port. Sohar Industrial Port has mineral processing, petrochemical production, power plants, and water desalination plants. These types of industries result in heavy metals in industrial wastewater.

A study mentions that Heavy metals are called heavy metals because of their weight, and they are present in nature, and it is natural for them to exist. However, the problem is increasing their percentage because they may cause a buildup in the ecosystem (Appenroth, 2010). Chromium (Cr), nickel (Ni), arsenic (As), copper (Cu), zinc (Zn), mercury (Hg), lead (Pb), and cobalt (Co) are examples of heavy metals.

Given that they are present in many industrial ports worldwide, there might be a significant concentration of heavy metals in the SIP region. Three studies have been conducted on heavy metals in the Sohar port area.

The first is the research done by (Jupp et al., 2017). Their research focused on heavy metals and petroleum hydrocarbons on the beaches and ports of Oman. The research study the surface sediment in various ports in Oman. However, their research focused on external pollution causes, such as shipping accidents, crude oil tankers, and liquefied gas tankers. Another research to be considered is paper (Sawai, 2015). The paper also focuses on surface sediment in SIP berth of ships area and the areas surrounding the SIP by different distances. On the other hand, the research focused on the geological side; regardless of the reasons, they looked at the soil in the farms and the amount of heavy metals in it (Al-Jabri et al., 2019).

The previous three investigations focused on heavy metals without focusing on their cause. However, this study will focus on industrial wastewater, its quality, and the percentage of heavy metal concentration before discharging seawater.

1.3 Health Effects Of Industrial Wastewater Into People

Heavy metals bioaccumulate and can cause severe health effects including organ damage, cancer, and neurological disorders (Jaishankar et al., 2014; Rehman,K. et al., 2018; Balali-Mood et al., 2021). Arsenic and mercury are especially toxic, even in small amounts (Jan et al., 2015; Geier et al., 2015).

In their study water and soil pollution is a critical environmental challenge in developing countries. Heavy metals did not cause environmental problems in the past because they were in natural proportions and found in nature in the right places (Masindi and Muedi.K.L., 2018). However, minerals have now become pollutants that spread rapidly and threaten the environment and humans.

Moreover, when exposed to it in a small amount in the short term, Arsenic may cause nausea and vomiting, irregular heartbeat and damage to blood vessels. Exposure to it for long periods may lead to lung and heart diseases and types of cancer (Jan, et al., 2015). In addition, most heavy metals cause severe diseases if they become high proportions in the human body, so they must be controlled and concentrated in the environment (Fu and Xi, 2020).

1.4 Control Measures for Industrial Wastewater

Due to the seriousness of heavy metals present in industrial wastewater and their impact on people's lives, they must be treated and rendered harmless to the environment and human beings before being discharged. There are many ways to treat industrial wastewater, some traditional and some modern. An earlier study classified it in their research into the following classification (Azimi et al., 2017). First, electrochemical treatment, this type of treatment requires a lot of financial investments and expensive electrical supplies. It is considered one of the traditional technologies. It is one of the most efficient methods compared to other techniques, but it is not widely used due to its high cost.

Secondly, chemical precipitation, including chemical precipitation, is when other chemicals are used to remove heavy metals to a proper extent. However, sometimes they fail and may become a source of further pollution. The third is the membrane filtration process (MFP). MFP is one of the modern methods used and is highly effective in removing minerals and not producing any other pollution. It is less energy consumption compared to traditional methods.

Fourth, the photocatalysis process uses a new technique called AOP. It is better than chemical processes because the process is free of chemicals. Excellent stability, low cost, and high efficiency characterize the photocatalytic process. Finally, nanotechnology technology is widely used in treating industrial wastewater containing heavy metals, and it has high efficiency. However, it can increase the risk of nano pollutants in the environment.

The existence of these technologies is useless without applying them in practice. Therefore, governments are forcing companies to use industrial water treatment methods. If it is detected that the proportions of heavy metals leaving a company exceed the permissible limit, fines will be imposed on the company that violates this limit. Applying regulations will help preserve the environment and the health of people (Naser, 2013).

Prior studies focused on sediment contamination but did not directly analyze the wastewater itself, highlighting a research gap addressed by this study (Jupp et al., 2017; Sawai, 2015; Al-Jabri et al., 2019).The current study aims to investigate the effects of industrial wastewater pollution in the Sohar port area and identify the polluted materials in the industrial wastewater. Also to determine the perceived health and environmental impacts of industrial wastewater on the Sohar port area residents.

2. Materials And Methods

2.1 Materials

The material used for the study is Laboratory-grade bottles for sampling, Ice boxes for transport and Analytical instruments for APHA 3120 B/ICP and ICP/AFS methods

2.2 Methods

2.2.1 Primary Data Collection

This study's methods involves using both primary and secondary data. Therefore, to achieve a clear understanding of SIP industrial wastewater. The primary sources include the collection and examination of samples. Special attention will be given to the before-discharge point of industrial wastewater, and a sample will be collected every three months, a sample in June, a sample in September and sample in December. The samples will be collected by using laboratory bottle and transported in a cool box with ice to maintain the temperature of the samples. The American Public Health Association (APHA) method will be used to measure the concentration of heavy metals. The analysis for all metals is to be carried out using the APHA 3120 B/ICP method, except for mercury, which will be tested with the help of the APHA/ICP/AFS method. The three months' worth of results will be taken and put into the graphs to take a more straightforward course in understanding and working over it. From this, a questionnaire survey of the residents' area around the Sohar Port area of industrial waste wastewater's subjective health and environmental effects will be conducted through Google Forms. Following this, the feedback obtained will be in the form of data collected from a Google Forms survey, which will assess the perceived health and environmental impact of industrial wastewater on the residents. The existence of primary data in this study will help support clear evidence of heavy metals that contributed to ensuring quality in this study.

So the steps are summaried as follows:

- Wastewater samples were collected quarterly in June, September, and December from discharge points before release into the sea.
- Samples were preserved and transported under controlled temperatures.
- Heavy metal analysis followed the APHA standard methods (3120 B/ICP for most metals; ICP/AFS for mercury).
- A Google Forms survey was distributed to residents near SIP to assess perceived health and environmental impacts.

Figure 1: Discharge area of SIP.

2.2.2 Secondary Data Collection

The following secondary resources are going to be used to determine the health effects resulting from the presence of these heavy metals. Government regulations will be compared with the results obtained from primary data. These will further help determine whether SIP has fulfilled or broken these regulations and laws. Besides, the findings from the secondary data will be compared with the primary findings to provide results based on proven information and data. This will lead to the source of the heavy metals and to what extent they have affected the environment and human health.

Using primary and secondary data and combining them is one of the best methods to obtain results. Laboratory examination of water samples will provide the percentages of heavy metals present, and data analysis will provide conclusions that may be useful in this and future studies.

The steps are summaried as follows:

- Government guidelines and regulatory standards were reviewed.
- Past studies on SIP and relevant literature were analyzed.
- Results from water samples were compared against WHO and Omani standards.

3. RESULTS

3.1 Laws and Regulation Section

The Sultanate of Oman's interest in industrial wastewater is to protect its environment from pollution, especially water pollution, and its citizens from health risks, as the ministerial decision clarified the concentrations of heavy metals allowed for water discharge in Table 1. No institution can discharge its industrial water that contains a percentage of heavy metals greater than the permissible limit. If these controls are violated, the government will impose strict penalties. For example, lead is forbidden in discharge water containing lead at 0.5 mg/L in Oman due to environmental and health risks that may affect residents' health.

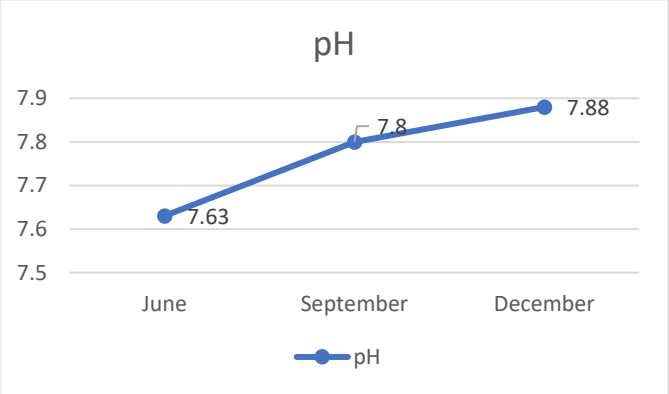

Figure 1: % of WHO Guideline per Parameter

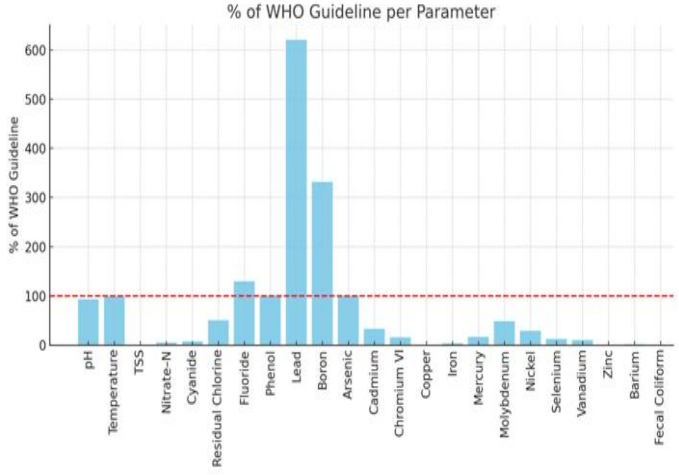

Figure 2: pH levels of industrial wastewater of SIP 2023

Figure 2 shows the pH of industrial wastewater for SIP. A slight increase can be observed with the advent of winter. According to Zhang, et al. (2018), there is a relationship between the degree of toxicity of heavy metals and pH. The lower the pH, the greater the toxicity of heavy metals due to their increased solubility.

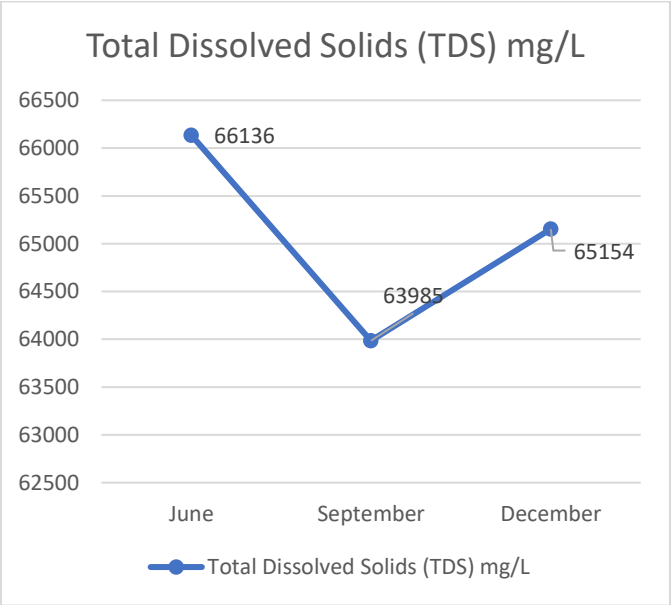

Figure 3: Total Dissolved Solids in industrial wastewater of SIP

Figure 3 represents the concentration of total dissolved solids (TDS). An increase in the level of TDS is an indicator of an increase in pollutants in the water, including heavy metals. Interestingly, the TDS in SIP industrial wastewater is very high above the natural level of seawater (Wang, et al., 2021).

3.2 Comparison With Sediment Data

Table 1: Heavy Metals limits of discharged wastewater in Oman

Parameter	Arsenic As	Cadmium Cd	Chromium Cr	Lead Pb	Mercury Hg	Nickel Ni	Copper Cu	Zinc Zn
Maximum Limit (mg/L)	0.2	0.03	0.5	0.5	0.005	0.5	0.3	5

Table 2: Heavy metals in surface sediment of SIP after discharge point in 2009

Parameter	Arsenic As	Cadmium Cd	Chromium Cr	Lead Pb	Mercury Hg	Nickel Ni	Copper Cu	Zinc Zn
(mg/Kg)	1.2	2.2	150	33	0.05	920	23	35

Table 2 reveals historically high concentrations of heavy metals in SIP sediments, suggesting:

1. Long-term accumulation of low-level discharges.

2. Previously poor compliance or lack of treatment.

3. External pollution sources (ruled out due to proximity to discharge point).

From Figer 4, the heavy metals present in industrial wastewater in SIP were determined with their concentration in June, September, and December of 2023. One sample of discharge industrial wastewater has been tested each month. These metals include lead, mercury, nickel, and other metals whose concentrations are shown in mg/L in Table 2. There are other heavy metals, but in this study, the focus was on the metals that researchers found in 2009 according to Jupp, et al. (2017) concentrated in the surface soil downstream of industrial wastewater discharge point.

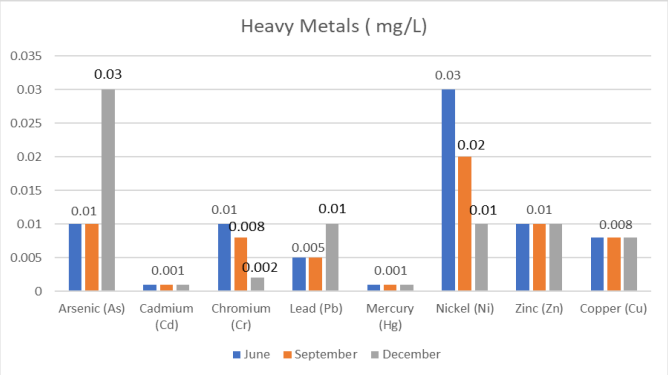

Figure 4: heavy metals in industrial wastewater of SIP (June and September 2023)

Figure 4 shows that most heavy metals remained at the same level or had a slight, negligible difference in chromium, nickel, arsenic, and lead between June, September, and December. It can also be noted that nickel and zinc are in a relatively high percentage compared to the other metals, which explains their high percentage in the surface soil downstream of the discharge point Table 2.

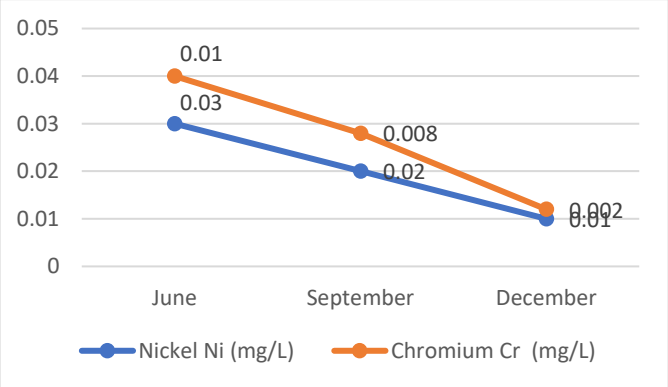

Figure 5: Nickel and Chromium concentration in industrial wastewater of SIP (June,September, and December 2023)

Figure 5 shows the metals whose concentration decreased between June, September, and December. A slight decrease in concentration can be observed. The concentration of nickel decreased from 0.03 mg/L to 0.02. The decline continued for December until its concentration reached 0.01mg/L. Also, chromium concentration decreased from 0.01 to 0.008 mg/L. The decline continued for December until its concentration reached 0.002 mg/L.

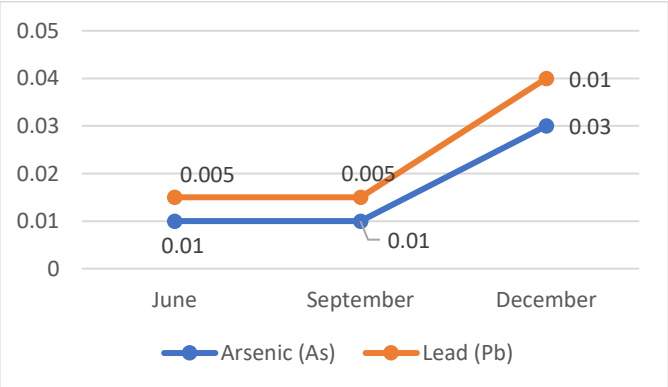

Figure 6: Arsenic and Lead concentration in industrial wastewater of SIP (June, September, and December 2023)

Figure 6 shows the metals whose concentration decreased between June, September, and December. The concentration of lead and arsenic remains stable between June and September, but it increases in December. Lead was constant at 0.005 mg/L in June and September and rose to 0.01 mg/L in December. Also, arsenic was constant at 0.01 mg/L in June and September and rose to 0.03 mg/L in December.

When comparing Figure 4 with Table 1, it can be concluded that the companies in the SIP area are committed to the laws and requirements of Oman; however, when looking at Table 2, which represents the results obtained in 2009, which studied surface sediments of the soil below the discharge point of the industrial wastewater. High levels of heavy metals can be seen clearly, which may lead to three possibilities. First, heavy metals in industrial wastewater with little concentration may not be practical or noticeable. However, when deposited for several years, it may accumulate on the surface soil below the discharge point of the industrial wastewater. Secondly, companies may have yet to comply with the laws in the past because there was no excellent industrial wastewater treatment. Third, these heavy metals may not be industrial wastewater but from external sources such as cargo ships and oil tankers. However, this point can be ruled out because ships do not need to come close to the point of industrial wastewater drainage.

3.3 Chemical Composition and Compliance

Table 3: Evaluate chemical quality in wastewater against WHO standards

Parameter	Result (mg/L)	WHO Guideline (mg/L)	% of Guideline	Compliance
Nitrate–N	0.6	11.3	5.3%	Compliant
Cyanide	<0.005	0.07	<7.1%	Compliant
Residual Chlorine	<0.1	0.2	<50.0%	Compliant
Fluoride	1.94	1.5	129.3%	Non-compliant
Phenol	<0.002	0.002	<100.0%	Compliant
Lead	0.062	0.01	620.0%	Non-compliant
Boron	7.95	2.4	331.2%	Non-compliant
Arsenic	<0.01	0.01	<100.0%	Compliant
Cadmium	<0.001	0.003	<33.3%	Compliant
Chromium VI	0.008	0.05	16.0%	Compliant
Copper	<0.008	2.0	<0.4%	Compliant
Iron	<0.01	0.3	<3.3%	Compliant
Mercury	<0.001	0.006	<16.7%	Compliant
Molybdenum	0.034	0.07	48.6%	Compliant
Nickel	0.02	0.07	28.6%	Compliant
Selenium	<0.005	0.04	<12.5%	Compliant
Vanadium	<0.007	0.07	<10.0%	Compliant
Zinc	<0.01	3.0	<0.3%	Compliant
Barium	0.012	0.7	1.7%	Compliant

The above table (3) summarizes the measured concentrations of each parameter alongside the corresponding WHO guideline values. Values exceeding 100%which are 3 components : Lead (620% of guideline), Boron (331% of guideline),Fluoride (129% of guideline) represent 16% indicate non-compliance with recommended limits and represent potential health risks, while values below 100% which are 16 components represent 84% denote compliance and acceptable water quality for that parameter. In addition, Residual Chlorine (50% of minimum requirement).

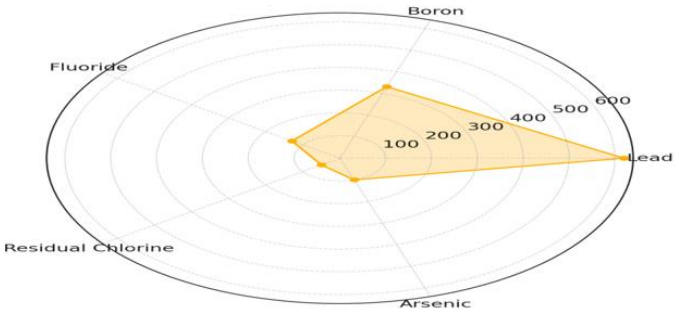

Figure 7: Radar Chart of Key Contaminants

Figure 7 represents Radar chart comparing Lead, Boron, Fluoride, Residual Chlorine, and Arsenic relative to WHO guidelines, highlighting the most severe exceedances.

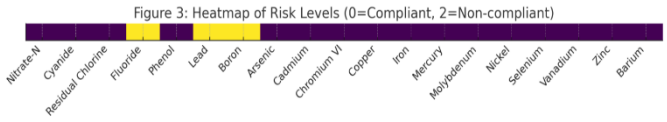

Figure 8: Heatmap of Risk Levels

Figure 8 shows Heatmap visualizing compliance: 0=compliant 2=non-compliant. Parameters are ordered as in the results

3.4 Community Survey Results

Survey Results

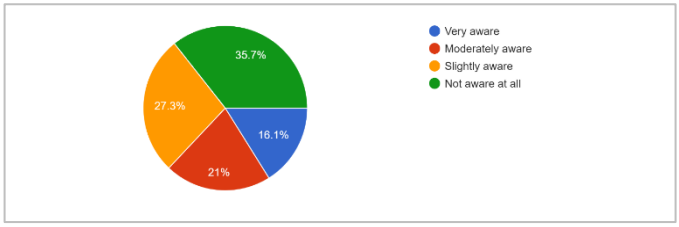

Figure 9: Community that is acutely aware of the presence of heavy metals in industrial wastewater in SIP.

The data from 143 responses reveal a community that is acutely aware of the presence of heavy metals in industrial wastewater, with 35.7% of participants indicating they are Not aware at all Figure 9. This awareness reflects a potential direct impact on the residents' daily lives and health.

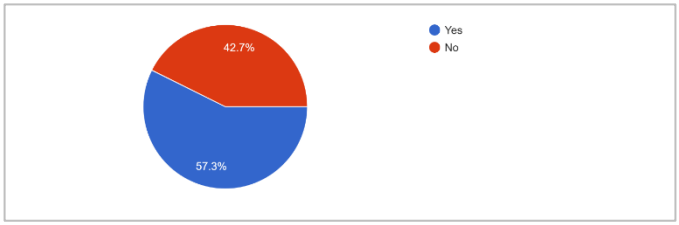

Figure 10: Observed visible signs of environmental degradation, which they believe are linked to heavy metal pollution.

From Figure 10 more than half of the respondents (57.3%) have observed visible signs of environmental degradation, which they believe are linked to heavy metal pollution.

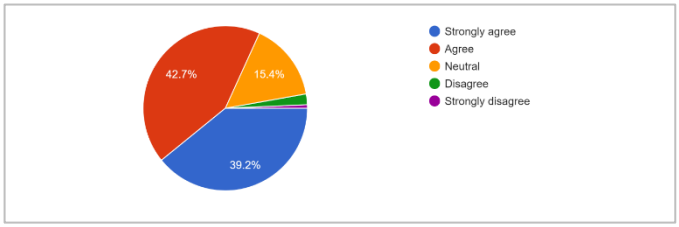

Figure 11: Recognition of the substantial impact of this pollution on the local ecosystem suggests deep-rooted concerns about ecological and personal health.

A significant majority, 81.9% (combining those who agree and strongly agree), recognize the substantial impact of this pollution on the local ecosystem, suggesting deep-rooted concerns about ecological and personal health Figure 11.

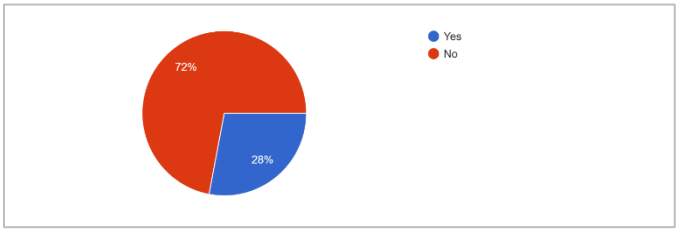

Figure 12: Acknowledged adverse health effects attributed to heavy metal pollution.

Figure 12 shows that adverse health effects attributed to heavy metal pollution are acknowledged by 28% of the participants, with a majority highly concerned about the potential health risks.

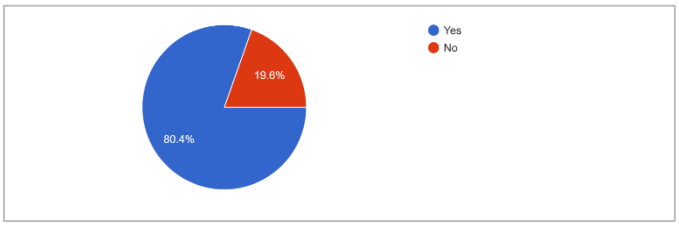

Figure 13: Willingness of respondents to participate in community initiatives that raise awareness on the matter

Figure 13 shows that is further emphasized by the willingness of 80.4% of respondents to participate in community initiatives that raise awareness on the matter, indicating a proactive community stance Figure 12.

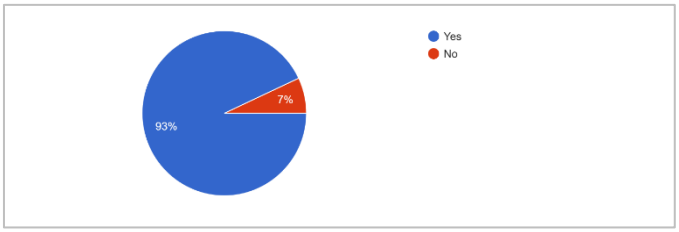

Figure 14: Surveyed support the implementation of more stringent regulations on industrial discharges

An overwhelming 93% of those surveyed support the implementation of more stringent regulations on industrial discharges Figure 14. This indicates a community consensus for stronger governance. However, confidence in local authorities' ability to enforce such regulations is mixed, highlighting a crucial gap that needs addressing.

4. Discussion

The survey responses reveal a comprehensive understanding of the environmental and health challenges posed by heavy metal pollution in the Sohar port area. Concerns highlighted include the bioaccumulation of toxins in the food chain, leading to health risks for humans consuming contaminated marine life, the detrimental impact on marine ecosystems and the livelihoods of communities reliant on fishing and related industries, soil contamination affecting agricultural productivity and food safety, and the direct health risks associated with contaminated water sources. These insights underscore the interconnectedness between environmental health and community well-being. Additionally, the responses emphasize the need for comprehensive solutions that address both immediate pollution concerns and ensure the sustainability of local industries and the overall workflow of the port area. Policymakers and industry leaders are urged to consider these community insights when designing and implementing interventions to tackle the pollution problem effectively.

This focused analysis should help to frame the discussion around the immediate concerns of health and environmental degradation as it pertains to heavy metal pollution, without diluting the narrative with broader pollution issues such as air quality.

This study confirms the presence of heavy metals in SIP industrial wastewater. While some metals are within acceptable limits, others such as lead and boron pose serious health risks. The decline in some metal concentrations suggests partial improvement, possibly due to regulation or better treatment technologies.

However, sediment data and survey responses indicate ongoing issues. The long-term accumulation of heavy metals in soils and marine

ecosystems could have irreversible consequences if not addressed urgently.

Community feedback reflects strong support for regulatory reforms and indicates a readiness for collective action, though confidence in enforcement remains mixed.

5. Conclusion

The findings of the research indicated the significant impacts caused by the pollution of industrial wastewater in the Sohar Port area, mainly produced from heavy metals, on the environment and health. The study revealed through in-depth analysis of water samples and community survey that a critical level of heavy metal contamination emanating from high concentrations from diverse industries in the area has occurred. Arsenic, lead, nickel, and chromium, among others, were found in industrial effluent discharged into the environment. Without a doubt, it remained a grave threat to the ecosystem and even further to human health, whereby possible effects could be acute and further have long-lasting repercussions. The survey results point out that the community is aware of such risks and supports strict regulations and proactive measures on the issue. The study also indicated innovative technologies for wastewater treatment to reduce heavy metal pollution in the port area. Generally, the research aimed to address the need for comprehensive solutions to ensure environmental and public health safety sustainability due to economic development projects in the region. The study aligns with the Sultanate of Oman's vision 2024 which it interests in industrial wastewater is to protect its environment from pollution, especially water pollution, and its citizens from health risks, as the ministerial decision clarified the concentrations of heavy metals allowed for water discharge. The study also indicated innovative technologies for wastewater treatment to reduce heavy metal pollution in the Sohar port area.

Generally, the study aims to address the need for comprehensive solutions to ensure environmental and public health safety sustainability develop in Oman.

The study stresses the importance of:

- Strengthening enforcement of discharge standards.
- Using innovative treatment technologies (e.g., photocatalysis, nanotechnology).
- Increasing community involvement and awareness.
- Ensuring alignment with Oman Vision 2040 for sustainable development

Recommendations

- A Real-time Monitoring to be conducted at all discharge points.
- To improve Wastewater Treatment by using high-efficiency technologies like AOP, MFP, and nanotechnology.
- To build up the regulations and policies such as introducing stricter penalties for non-compliance and set lower thresholds for persistent contaminants.
- Public Awareness Campaigns to be conducted to communities about risks and encourage participation in environmental governance.
- To develop Transparency of industries to disclose their wastewater treatment data publicly.

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