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Rainwater Quality Monitoring as an Air Pollution Evaluation Strategy in Urban and Industrial Areas

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Abstract

This study aims to evaluate rainwater quality as an indicator of atmospheric pollution in Dumai City, Indonesia. Rainwater samples were collected from seven kecamatan during September 2024 and analyzed for pH, total dissolved solids (TDS), turbidity, total coliform, nitrates (NO_3^-), nitrites (NO_2^-), hexavalent chromium (Cr^{6+}), iron (Fe), and manganese (Mn). The results showed that the pH value in certain locations, especially Kecamatan Bukit Kapur (pH = 5.0), dropped below the neutral threshold, indicating the presence of acid rain. Some heavy metal concentrations, as well as total coliform levels, exceed generally accepted environmental reference values. These findings suggest that emissions from industrial and urban activities significantly contribute to atmospheric pollution. Rainwater quality monitoring thus provides a valuable approach to assessing the impact of air pollution in densely populated and industrial zones.

Keywords: rainwater quality, acid rain, air pollution, contaminants, industry.

1. Introduction

Atmospheric pollution is one of the main challenges in the management of urban environments and industrial estates. Emissions from the transportation sector, the burning of fossil fuels, as well as heavy industrial activities such as petrochemicals and metal processing make a significant contribution to the increase in the concentration of pollutants in the air. Pollutant particles and gases released into the atmosphere can undergo chemical transformation and deposition in dry and wet form, one of which is through rain [1], [2].

Rainwater has the ability to carry a variety of atmospheric pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), heavy metals, as well as microbiological particles[3]. This process can produce acid rain or pollute the surface environment where rainwater falls [4]. Therefore, rainwater quality can be used as an indirect indicator to evaluate the level of air pollution and its impact on the environment.

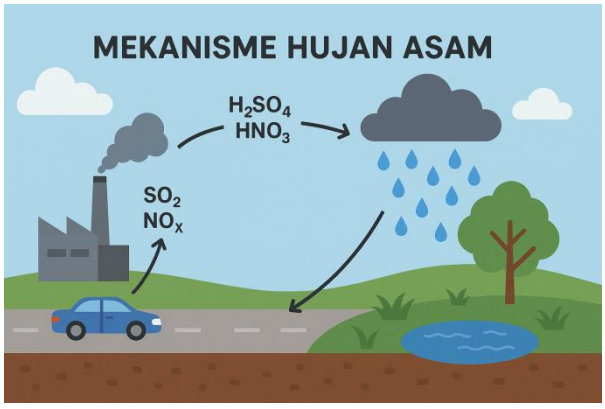

Figure 1. Mechanism of Acid Rain

Dumai City is a strategic industrial area in the coastal area of Riau with a high intensity of oil and gas industry activities, ports, and heavy vehicle traffic[5], [6]. High industrial and transportation activities have the potential to produce significant air pollutant emissions, making Dumai an area vulnerable to atmospheric pollution, including acid rain phenomena. This research was conducted with the aim of evaluating rainwater quality as an indicator of air pollution in the region. Given the limited previous scientific studies that specifically highlighted acid rain in Dumai City, this research is expected to make a scientific contribution in filling the literature gap as well as being a basis for consideration in the formulation of environmental management policies in coastal industrial areas.

2. Research Methods

Sampling was carried out in September 2024 in 7 (seven) districts (kecamatan): Dumai Timur, Medang Kampai, Dumai Barat, Dumai Selatan, Bukit Kapur, Sungai Sembilan, and Dumai Kota. The coordinate points of each location were recorded to ensure a spatial representation of the monitoring area.

2.1. Analysis parameters

Rainwater samples were collected using open sterile containers placed in representative locations in each district (kecamatan). The analyzed parameters include:

a. Physical-chemical: pH, TDS, turbidity
b. Microbiology: total coliform
c. Nutrients: nitrates (NO_3^-), nitrite (NO_2^-)
d. Heavy metals: Cr^{6+}, Fe, Mn

Laboratory analysis refers to the standard methods of APHA 2017 and SNI 6989 for each parameter [7], [8]. The results were compared with the reference values of surface water quality standards and indirect rainwater

(because there are no special quality standards for rainwater in Indonesia).

3. Results and Discussion

Rainwater samples were collected in 7 (seven) district (kecamatan) in Dumai City with 9 (nine) quality parameters, as shown in Table 1 below.

Table 1. Rainwater Quality Test Results in Dumai City

Location	pH	TDS	Turb	Coli	NO_3	NO_2	Cr_6	Fe	Mn
1	6.53	22	0.82	58	0.56	0.0039	0.0065	0.005	0.032
2	6.83	40	0.7	0	1.02	0.0039	0.0017	0.005	0.028
3	6.28	22	0.58	0	0.47	0.0039	0.0018	0.006	0.034
4	6.07	31	0.73	103	0.37	0.0084	0.0022	0.018	0.017
5	5	14	0.59	157	0.0751	0.0066	0.0018	0.018	0.006
6	6.93	105	2.83	0	0.15	0.0075	0.0017	0.079	0.021
7	6.46	76	2.24	210	0.2	0.0039	0.0017	0.109	0.012

Information:

1. Kecamatan Dumai Timur
2. Kecamatan Medang Kampai
3. Kecamatan Dumai Barat
4. Kecamatan Dumai Selatan
5. Kecamatan Bukit Kapur
6. Kecamatan Sungai Sembilan
7. Kecamatan Dumai Kota

3.1. Indications of Acid Rain

The pH value of rainwater ranges from 5.0 to 6.93. The lowest point is in Bukit Kapur district (pH = 5.0), which indicates acid rain. Acid rain is usually formed as a result of a reaction between rainwater with SO_2 and NO_x in the atmosphere, forming sulfuric acid and nitric acid[3]. In general, rainwater with a pH below 5.6 is categorized as acid rain, which is formed as a result of a chemical reaction between water vapor in the atmosphere and polluting gases such as sulfur dioxide (SO_2) and nitrogen oxide (NO_x). This acidity has the potential to have a detrimental impact on the environment, including a decrease in soil and surface water quality, disturbances to vegetation growth, and acceleration of corrosion in building infrastructure and metal materials. In the long term, acid rain can also accelerate ecosystem degradation and threaten environmental sustainability in the affected areas[4].

3.2. Contamination of e Coliform and Heavy Metals

The results of microbiological analysis showed that the total coliform content in rainwater collected in several areas of Dumai Kota was at a fairly high level, with values reaching 210 MPN/100 mL in Kecamatan Dumai Kota and 157 MPN/100 mL in Kecamatan Bukit Kapur. The presence of coliform indicates the presence of contamination of microorganisms that have the potential to come from two main sources, namely bioaerosols in the atmosphere and secondary contamination from rainwater storage containers exposed to the open environment. Bioaerosols are biological particles in the air consisting of bacteria, viruses, fungi, and other organism fragments that can be suspended in the atmosphere through human, animal, vegetation, and organic waste activities [9]. Rainwater storage containers that are not covered or placed in an open area without protection from dust, dirt, or animals can be a secondary contamination pathway that affects the results of microbiological tests.

Analysis of chemical parameters showed the presence of heavy metals such as iron (Fe), hexavalent chromium (Cr^{6+}), and manganese (Mn) with moderate concentrations in several locations, which should be of concern from the environmental toxicological side. In Dumai Kota, Fe content was detected at 0.109 mg/L and Cr^{6+} at 0.0017 mg/L. The presence of these heavy metals in rainwater is generally closely related to atmospheric emissions from anthropogenic activity. Emissions from motor vehicles produce metal particles such as Fe, Mn, and Cr through the processes of brake abrasion, fuel combustion, and wear of metal components [10]. In addition, the activities of the oil and gas processing industry, as well as the burning of fossil fuels, contribute to the release of heavy metals into the atmosphere in the form of fine particles (PM2.5 and PM10), which can then undergo wet deposition through rain. Port loading and unloading activities, especially those involving metal materials or chemicals, can also release dust and harmful particles that have the potential to disperse into the local atmosphere. The accumulation of heavy metals in rainwater not only reflects the level of air pollution, but also risks contaminating soil and surface waters if the rain enters drainage systems or is absorbed by soil media, which in turn can affect human health and ecosystems [11].

3.3 Environmental Pressures from Industrial Activities

Dumai City, as one of the industrial centers and strategic ports on the east coast of Sumatra, contributes significant atmospheric emissions from various anthropogenic sectors. Heavy transportation activities, especially fossil-fueled motor vehicles, contribute to the release of nitrogen oxide (NO_x), sulfur dioxide (SO_2), and heavy metal particles through incomplete combustion processes and brake and tire wear. In

addition, the existence of an oil processing industry (refinery) in this region is a major source of emissions of volatile compounds and particulate matter containing metals such as Fe, Mn, and Cr, which are released into the atmosphere in the form of fine particles (PM2.5 and PM10). The practice of open combustion, both from domestic waste and agricultural and industrial activities, also exacerbates air pollution by producing black carbon, semi-volatile organic compounds, and various other reactive compounds that can trigger photochemical reactions in the atmosphere.

The combination of these various pollutant sources causes an increase in the concentration of pollutants in the atmosphere, which in certain meteorological conditions can form local accumulation. These polluting particles and gases then undergo chemical transformations in the air and can interact with atmospheric water vapor to form strong acids such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3). In the process of wet deposition, these compounds will be carried down to the earth's surface in the form of acid rain, causing the vertical transport of pollutants from the atmosphere to water, soil, and vegetation systems. Therefore, rain in industrial areas such as Dumai is not only an important indicator in air quality monitoring, but also acts as a medium for the deposition of pollutants that can have an ecological impact and public health at large.

4. Conclusion

This study shows that the quality of rainwater in Dumai City in 2024 indicates atmospheric pollution, both in terms of acidity (acid rain) and the content of metal contaminants and microorganisms. Low pH values and high levels of coliform and heavy metals that exceed reference values reinforce the suspicion that industrial and transport activities in the region have a direct impact on atmospheric quality.

Rainwater quality monitoring can be used as part of the air quality and environmental monitoring system, especially in areas with high anthropogenic activity densities such as Dumai City. In the future, the development of emission control policies and integrated monitoring systems needs to be strengthened to maintain environmental quality in a sustainable manner.

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