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Detection of Potential Blockage Points in Drains Using Divergence Analysis of Water Flow Vector Fields

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ABSTRACT

This study aims to detect potential blockage points in drainage channels using divergence analysis of water flow vector fields. The research applies a quantitative approach through a simple field experiment using the float method to measure flow velocity at several observation points. Data were collected by measuring the travel time of a floating object at distances of 3 meters, 5 meters, and 7 meters along a drainage channel. The velocity was calculated using the basic kinematics equation, and the data were analyzed using mathematical modeling and numerical derivative approaches to determine the divergence of the flow.

The results show that water flow velocity is not constant, with values of 0.214 m/s at 3 meters, 0.135 m/s at 5 meters, and 0.146 m/s at 7 meters. The analysis of velocity change indicates a negative divergence value (-0.0395) in the interval between 3 meters and 5 meters, which reflects flow deceleration and convergence. This condition suggests the potential accumulation of materials that may lead to blockage.

Therefore, the point around 5 meters from the initial position is identified as a potential blockage area. This study demonstrates that divergence analysis of vector fields can serve as an alternative mathematical method for early detection of blockage in drainage systems, contributing to more effective environmental management and maintenance strategies.

Keywords: drainage, divergence, vector field, flow velocity, blockage

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INTRODUCTION

Urban drainage systems play an important role in maintaining water flow, especially in channels that function to drain rainwater and domestic waste. However, blockages frequently occur due to the accumulation of garbage, sediment, or other materials, which may lead to flooding. Therefore, an analytical method is needed to detect potential blockage points early.

Conventional detection methods rely on visual inspection, which is time-consuming and often ineffective in identifying early-stage blockages. This limitation highlights the need for a more systematic and analytical approach.

One mathematical approach is the use of vector field analysis, particularly divergence.

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Divergence measures whether flow spreads or converges at a point. Negative divergence indicates convergence, which may signal accumulation and potential blockage.

This study aims to apply divergence analysis to detect potential blockage points in drainage systems, providing a mathematical approach to understanding water flow behavior.

MATERIAL AND METHODS

Research Type

This study is a quantitative research with a simple field experiment approach aimed at analyzing water flow patterns in a drainage channel using the concepts of vector fields and divergence. Water flow data were obtained through the float method and analyzed using mathematical modeling and visualization assisted by Python programming.

Research Location

The research was conducted in a drainage channel around the Faculty of Mathematics and Natural Sciences building at Medan State University. The channel is an open flow system used to drain rainwater, allowing observation of water flow dynamics.

Tools and Materials

The tools and materials used in this study include:
- Small ball or float as a marker of water flow
- Measuring tape to measure flow path distance
- Stopwatch to measure the travel time of the float
- Notebook to record observation results
- Computer with Python software for data analysis and graph visualization

Data Collection Technique

Data collection was carried out using the float method with the following steps:
- Determining the starting point of the flow in the observed channel.
- Measuring flow path distances of 3 meters, 5 meters, and 7 meters from the starting point.
- Placing a small float at the starting point of the flow.
- Measuring the time required for the float to reach each observation point using a stopwatch.
- Recording the travel time of the float at each observation distance.
- Using the data to calculate the water flow velocity.

Mathematical Modeling

The water flow velocity is calculated using the basic kinematics equation:

$$v = s / t \quad (1)$$

Where:
v = flow velocity (m/s)
s = distance traveled (m)
t = travel time (s)

Water flow in the channel is modeled as a one-dimensional vector field along the direction of flow:

$$F(x) = v(x)i \quad (2)$$

Where:

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$F(x)$ = velocity vector field
$v(x)$ = velocity as a function of position
i = unit vector in the direction of flow

The divergence of the vector field is expressed as:

$$\nabla \cdot F = \frac{dv}{dx} \tag{3}$$

The divergence value indicates the change in velocity with respect to position.

If:

$$\frac{dv}{dx} < 0 \tag{4}$$

then the flow experiences deceleration, which may indicate potential water accumulation or blockage.

Data Analysis Technique

Data analysis was carried out with the following steps:
- Calculating water flow velocity at each observation point.
- Compiling a table of calculated velocity results.
- Creating a graph of the relationship between position and flow velocity.
- Creating a visualization of the flow vector field using Python.
- Calculating changes in velocity with respect to position using a numerical derivative approach.
- Interpreting these changes in the context of vector field divergence to detect potential blockages.

RESULTS AND DISCUSSION

Discussion

This section may be divided by subheadings. Discussions should cover the key findings of the study: discuss any prior research related to the subject to place the novelty of the discovery in the appropriate context, discuss the potential shortcomings and limitations on their interpretations, discuss their integration into the current understanding of the problem and how this advances the current views, speculate on the future direction of the research, and freely postulate theories that could be tested in the future.

For further information, please check the descriptions defined in the journal's "Article Types" page, which can be seen from the "For Authors" menu on any journal page.

Measurement Data Results

Measurement of water flow velocity was carried out in an open drainage channel around the Faculty of Mathematics and Natural Sciences, State University of Medan. The condition of the drainage channel at the time of data collection is shown in the following documentation.

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Figure 1. float condition in the flow

Measurements were conducted using the float method in the drainage flow. The observed data are shown in the following table.

Table 1. Observation Results

No	Distance (m)	Time (s)
1	7	48
2	5	37
3	3	14

Flow Velocity Calculation

Flow velocity is calculated using the equation:

$v = \frac{s}{t}$

The calculations are carried out as follows.

For a distance of 7 meters:

$$v = \frac{7}{48} = 0.146\, m/s$$

For a distance of 5 meters:

$$v = \frac{5}{37} = 0.135\, m/s$$

For a distance of 3 meters:

$$v = \frac{3}{14} = 0.214\, m/s$$

Table 2. Calculation Results:

Distance (m)	Time (s)	Velocity (m/s)
3	14	0.214
5	37	0.135
7	48	0.146

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Based on the table, it can be seen that the water flow velocity is not constant at each observation point.

Flow Velocity Graph

Changes in flow velocity with respect to position can be visualized using a graph.

Python code:

```
import matplotlib.pyplot as plt
distance=[3,5,7]
time=[14,37,48]
velocity=[d/t for d,t in zip(distance,time)]
plt.plot(distance,velocity,marker='o')
plt.xlabel("Drain Position (m)")
plt.ylabel("Flow Velocity (m/s)")
plt.title("Water Flow Velocity Graph")
plt.grid(True)
plt.show()
```

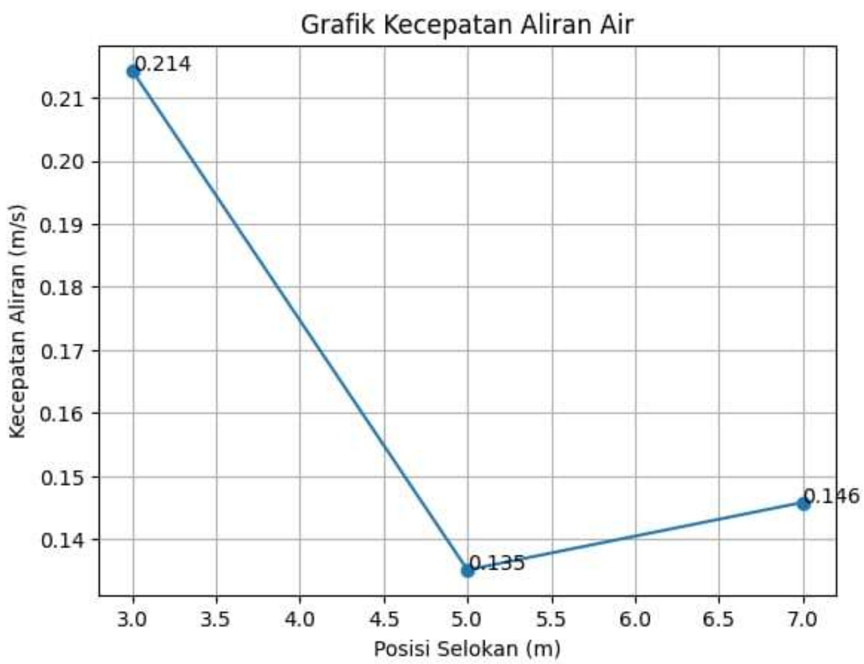

Figure 2. Water Flow Velocity Graph

This graph shows changes in flow velocity along the drainage channel.

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Flow Vector Field Visualization

To illustrate the direction and magnitude of water flow, a vector field visualization is used.

Python code:

```
import numpy as np
import matplotlib.pyplot as plt
x=np.array([3,5,7])
y=np.zeros(3)
u=np.array([0.214,0.135,0.146])
v=np.zeros(3)
plt.quiver(x,y,u,v)
plt.xlabel("Drain Position (m)")
plt.title("Water Flow Vector Field Visualization")
plt.show()
```

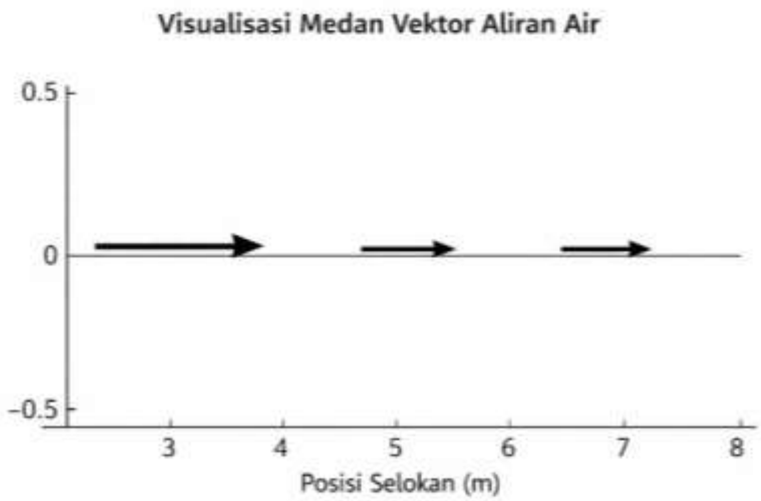

Figure 3. Results of Water Flow Vector Field Visualization

In this visualization, the length of the arrows represents the magnitude of the flow velocity at each observation point.

Flow Divergence Analysis

To observe changes in velocity with respect to position, a numerical derivative approach is used:

$$\frac{dv}{dx} \approx \frac{(v^2 - v^1)}{x^2 - x^1}$$

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Interval from 3 m to 5 m:

$$\frac{dv}{dx} = \frac{0.135 - 0.214}{5 - 3} = -0.0395$$

The negative value indicates that the flow experiences deceleration in this interval.

Interval from 5 m to 7 m:

$$\frac{dv}{dx} = \frac{0.146 - 0.135}{7 - 5} = 0.0055$$

The positive value indicates that the flow velocity increases again.

Detection of Potential Blockage Points

Based on the analysis of changes in flow velocity, it is found that the greatest decrease in velocity occurs in the interval between positions 3 meters and 5 meters. The negative derivative value indicates that the water flow experiences deceleration in this area. In the concept of vector fields, this condition is related to a tendency for flow convergence, which can cause accumulation of water or material in the channel. Therefore, the point around 5 meters from the initial observation point can be identified as an indication of a potential blockage point in the drainage channel.

CONCLUSION

The flow velocity varies along the drainage channel, with a significant decrease between 3 m and 5 m. The negative divergence value (-0.0395) indicates flow convergence, suggesting potential blockage.

Therefore, divergence analysis can be used as an effective method to detect blockage points in drainage systems.

AUTHOR CONTRIBUTIONS

Conceptualization, M.G.S.; methodology, G.S. and H.J.T.; formal analysis, C.P. and N.A.S.; investigation, A.S.N. and H.N.; writing—original draft, M.G.S.; writing—review and editing, all authors; supervision, M.G.S. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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