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Analysis of Drainage Conditions and Their Relationship to Inundation Problems in the Belawan Bahari Fishermen Settlement, Medan

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ABSTRACT

Flooding is a common environmental issue in coastal settlements due to the interaction between natural conditions and environmental infrastructure performance. Belawan Bahari Fishermen Settlement in Medan Belawan District is particularly vulnerable to flooding because of its low-lying topography and exposure to tidal influences. Understanding the relationship between drainage conditions and flooding is important to support sustainable environmental management in coastal settlements. This study aims to analyze the condition of the drainage system and examine its relationship with flooding problems in Belawan Bahari Fishermen Settlement, Medan City. A descriptive qualitative approach was employed through field observations, literature reviews, and secondary data analysis related to drainage conditions, flooding occurrences, and coastal environmental characteristics. The results indicate that suboptimal drainage performance, caused by sedimentation and waste accumulation, contributes to flooding in the study area. In addition, high settlement density, limited infiltration areas, and tidal influences increase the area's vulnerability to flooding. The study concludes that flooding in Belawan Bahari is influenced by the interaction between drainage system conditions and coastal environmental characteristics. These findings highlight the importance of integrated drainage management that considers the specific characteristics of coastal settlements to reduce flooding risks and improve environmental quality.

Keywords: Coastal settlement, Drainage system, Flooding, Tidal influence

ABSTRAK

Banjir merupakan salah satu permasalahan lingkungan yang umum terjadi di kawasan permukiman pesisir akibat interaksi antara kondisi alam dan kinerja infrastruktur lingkungan. Permukiman Nelayan Belawan Bahari di Kecamatan Medan Belawan termasuk kawasan yang rentan terhadap banjir karena memiliki topografi yang rendah serta dipengaruhi oleh pasang surut air laut. Pemahaman mengenai hubungan antara kondisi sistem drainase dan kejadian banjir menjadi penting sebagai dasar untuk mendukung pengelolaan lingkungan permukiman pesisir yang berkelanjutan. Penelitian ini bertujuan untuk menganalisis kondisi sistem drainase serta mengkaji hubungannya dengan permasalahan banjir di Permukiman Nelayan Belawan Bahari, Kota Medan. Penelitian ini menggunakan pendekatan deskriptif kualitatif melalui observasi lapangan, studi literatur, dan analisis data sekunder yang berkaitan dengan kondisi drainase, kejadian banjir, serta karakteristik lingkungan pesisir. Hasil penelitian menunjukkan bahwa kinerja sistem drainase yang belum optimal akibat sedimentasi dan penumpukan sampah menjadi salah satu faktor utama penyebab banjir di kawasan penelitian. Selain itu, tingginya kepadatan permukiman, terbatasnya daerah resapan air, serta pengaruh pasang surut air laut turut meningkatkan tingkat kerentanan kawasan terhadap banjir. Penelitian ini menyimpulkan bahwa permasalahan banjir di Permukiman Belawan Bahari dipengaruhi oleh interaksi antara kondisi sistem drainase dan karakteristik lingkungan pesisir. Oleh karena itu, diperlukan pengelolaan sistem drainase yang terintegrasi dengan mempertimbangkan karakteristik



husus kawasan pesisir guna mengurangi risiko banjir serta meningkatkan kualitas lingkungan permukiman..

Kata kunci: *Banjir, Pengaruh pasang surut, Permukiman pesisir, Sistem drainase*

Introduction

Coastal areas play a significant role as centers of economic activities, residential development, and transportation networks. However, these areas are also highly vulnerable to various environmental problems, particularly inundation. The occurrence of inundation in coastal regions is influenced by several factors, including low-lying topography, high surface runoff, inadequate drainage systems, and tidal fluctuations. These conditions make coastal settlements more susceptible to flooding and waterlogging than inland areas (Suripin, 2004). Inundation not only disrupts daily community activities but also negatively affects environmental quality, public health, infrastructure performance, and the long-term sustainability of residential areas. Drainage systems serve as essential infrastructure for managing excess surface water by conveying runoff to receiving water bodies (Chow, 1988). Effective drainage systems can reduce the risk of inundation and support the functionality of urban and residential environments. However, in densely populated settlements, drainage performance often deteriorates due to sediment accumulation, channel narrowing, waste disposal into drainage networks, and reduced infiltration areas caused by intensive land use.

These factors decrease the hydraulic capacity of drainage channels, resulting in inefficient water conveyance and an increased likelihood of inundation. The complexity of drainage-related problems becomes more pronounced in coastal settlements because drainage performance is influenced not only by rainfall and surface runoff but also by tidal dynamics. During high tide conditions, seawater can impede the discharge of drainage flows into coastal waters and may even generate a backwater effect within the drainage network. Consequently, inundation may occur because of the interaction between multiple factors, including rainfall, surface runoff, drainage deficiencies, and tidal fluctuations. This phenomenon is commonly referred to as compound flooding, which has become a growing concern in many coastal regions worldwide (Wahl, 2024). One coastal settlement experiencing these challenges is the Belawan Bahari Fishermen Settlement, located in Medan Belawan District, Medan City. This area is characterized by high building density, relatively flat and low topography, and proximity to coastal waters. Such physical characteristics increase the settlement's vulnerability to inundation caused by both rainfall events and tidal influences. Field observations indicate that several drainage channels within the settlement experience sediment accumulation and waste obstruction, which reduce drainage efficiency and contribute to water stagnation during periods of heavy rainfall and high tides.

Previous studies have examined flooding and environmental issues in the Belawan coastal area. Siregar and Hasibuan (2020) reported that inadequate environmental infrastructure significantly contributes to inundation vulnerability in coastal settlements. Prasetyo (2023) found that changes in coastal land-use characteristics and community



activities influence inundation patterns in the region. Furthermore, Wahyuni (2024) emphasized that sedimentation and channel blockage are among the primary causes of declining drainage performance in densely populated residential areas. These studies provide valuable insights into coastal flooding issues; however, they generally focus on tidal flooding, coastal settlement conditions, or drainage systems at broader spatial scales. Despite these contributions, studies specifically investigating the relationship between existing drainage conditions and inundation problems at the fishermen settlement scale remain limited. Most previous research examines tidal flooding, settlement vulnerability, or drainage performance separately, without comprehensively analyzing their interactions within a localized coastal residential environment. As a result, there is still a need for research that integrates physical drainage conditions, settlement characteristics, and tidal influences to better understand inundation mechanisms in coastal communities.

The novelty of this study lies in the development of an integrated analysis framework that combines drainage physical conditions, settlement density characteristics, and tidal influences to evaluate inundation vulnerability in the Belawan Bahari Fishermen Settlement. Unlike previous studies that examined these factors separately, this research investigates their interrelationships at the neighborhood scale, providing a more comprehensive understanding of inundation problems in a coastal fishermen settlement environment. Based on the background, this study aims to analyze the existing condition of the drainage system and examine its relationship with inundation problems in the Belawan Bahari Fishermen Settlement, Medan City. In addition, the study seeks to identify the factors contributing to inundation occurrences and to provide recommendations for improving drainage management in coastal residential areas.

Research Method

This study employed a descriptive qualitative approach supported by a simple quantitative assessment to analyze the condition of the drainage system and its relationship with inundation problems in the Belawan Bahari Fishermen Settlement, Medan City. This approach was selected to provide a comprehensive understanding of the existing drainage conditions, inundation characteristics, and the factors contributing to inundation occurrences in a coastal settlement environment.

Data Collection

Data were collected through field observations, literature review, and secondary data sources. Field observations were conducted to directly assess the physical condition and performance of the drainage system within the study area. The observations focused on several indicators, including channel cleanliness, sediment accumulation, waste accumulation, drainage flow conditions, settlement density, and evidence of inundation occurrence. To support the field observations, a literature review was conducted by examining books, scientific journals, and previous studies related to drainage systems,



inundation issues, coastal settlements, and tidal flooding. In addition, secondary data were obtained from scientific publications and relevant institutions, including tidal data, flood vulnerability information, and other supporting data related to the environmental conditions of the Belawan Bahari area.

Table 1. The Assessment of Drainage Conditions was Based on the Indicators Presented

Variable	Observation Indicator
Drainage Condition	Physical condition of drainage channels
Sedimentation	Presence of sediment deposits within drainage channels
Waste Accumulation	Presence of waste within drainage channels
Drainage Performance	Water flow condition within drainage channels
Settlement characteristic	Building density and proximity to drainage channels
Inundation Condition	Presence of standing water or inundation
Tidal Influence	Evidence of tidal effects on drainage performance

Data Analysis

The collected data were analyzed using descriptive qualitative techniques supported by simple quantitative assessment. Quantitative assessment was used to summarize the proportion of drainage segments affected by sedimentation, waste accumulation, and other observed conditions.

The analysis was conducted through the following stages:

1. Identification of existing drainage conditions through field observations and documentation.
2. Assessment of drainage performance based on the established observation indicators.
3. Identification of inundation characteristics, including locations, physical evidence, and contributing factors.
4. Analysis of the relationship between drainage conditions and inundation occurrences within the study area.
5. Comparison of observation results with relevant theories and previous studies to strengthen the interpretation of findings.
6. Formulation of conclusions and recommendations regarding drainage management and inundation mitigation in coastal residential settlement

Result and Discussion

The Belawan Bahari Fishermen Settlement is a coastal residential area located in Medan Belawan District, Medan City. The settlement has developed as a fishermen community characterized by relatively high building density and economic activities related to fisheries and marine products. Geographically, the area is situated on low-lying coastal land directly adjacent to coastal waters, making it highly influenced by tidal fluctuations.

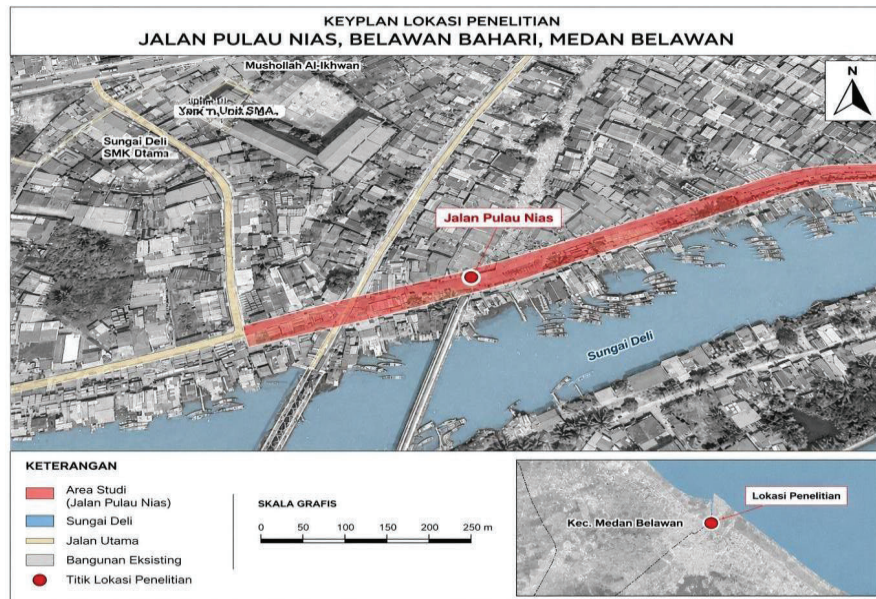


Figure 1. Research Area Keyplan

Citra Google Earth, 2026 Processed by the Author, 2026

Figure 2 illustrates the location of the study area within the coastal zone of Medan Belawan. Due to its proximity to coastal waters, the settlement is highly exposed to tidal influences and coastal flooding hazards. Previous studies indicate that Medan Belawan District has a high vulnerability to tidal flooding. Siahaan and Abdiyanto (2024) reported a tidal flood risk index of 0.78, which falls within the high-risk category. This vulnerability is mainly influenced by low ground elevation and seawater intrusion through rivers and drainage channels during high tide conditions. In addition, the dense settlement pattern reduces the availability of infiltration areas, thereby increasing surface runoff during rainfall events. As a result, greater pressure is placed on the existing drainage infrastructure.



Figure 2. Environmental Condition of Belawan Bahari Fishermen Settlement

Source: Google Earth, 2026

The site plan illustrates the arrangement of buildings, circulation networks, and drainage channels within the settlement. The spatial pattern reflects the gradual development of the area according to the needs of the fishermen community.



Figure 3. Site Plan of the Study Area

Author Documentation, 2026

Existing Drainage Conditions

Field observations indicate that the drainage system within the Belawan Bahari Fishermen Settlement exhibits several conditions that may reduce its effectiveness in conveying surface runoff. Some of the drainage channels within the study area are open channels that function to convey surface runoff to nearby receiving water bodies. Field observations revealed sediment accumulation and waste deposits at several locations, reducing the effective cross-sectional area of the drainage channels. These conditions obstruct water flow and increase the potential for inundation during rainfall events. In addition to the physical condition of the channels, drainage performance in the study area is also influenced by the dense residential environment. High building density and limited open spaces reduce the area's infiltration capacity, causing a greater proportion of rainfall to become surface runoff that enters the drainage system.



Figure 4. Drainage condition in a High-Density Residential Settlement

Google Earth, 2026

The limited availability of open spaces and infiltration areas causes a large proportion of rainfall to be converted into surface runoff, which is subsequently conveyed into the drainage channels. When the capacity of the drainage system is insufficient to accommodate the runoff volume, the likelihood of inundation increases significantly



Figure 5. Existing Open Drainage Channel

Author Documentation, 2026



Figure 5 illustrates the condition of an open drainage channel located within the settlement area. The channel serves as the primary infrastructure for conveying surface runoff from residential areas to nearby receiving waters. However, field observations indicate scattered waste deposits along the channel, suggesting limited maintenance and potentially reduced drainage efficiency.



Figure 6. Waste Accumulation in Residential Drainage Channel

Author Documentation, 2026

Figure 6 shows waste accumulation within a drainage channel. The presence of solid waste and stagnant water may obstruct water flow and reduce the effective capacity of the drainage system. Such conditions can increase the risk of localized inundation, particularly during periods of heavy rainfall or high tide. Field observations revealed the presence of waste accumulation and stagnant water within several drainage channels. As shown in Figure 5, solid waste partially obstructs water flow and may reduce the hydraulic capacity of the drainage system.



Figure 7. Standing Water Observed Between Residential Buildings
Author Documentation, 2026

Figure 7 presents evidence of standing water between residential buildings. The occurrence of water ponding in residential spaces indicates inadequate drainage performance and limited water discharge capacity. This condition suggests that excess water cannot be effectively conveyed away from the settlement area.

Table 2. Summary of Field Observation Results

Observation Point	Drainage Condition	Waste Accumulation	Standing Water
Point 1 (Figure 6)	Fair to Poor	Present	Not Observed
Point 2 (Figure 7)	Poor	Present	Present
Point 3 (Figure 8)	Poor	Limited	Present

It summarizes the results of field observations conducted at three observation points within the Belawan Bahari Fishermen Settlement. The observations indicate that the overall condition of the drainage system ranges from fair to poor. Waste accumulation was identified at two of the three observation points (66.7%), while evidence of standing water was also observed at two locations (66.7%). The presence of waste within drainage channels suggests that routine maintenance and waste management practices remain inadequate. Waste deposits can obstruct water flow and reduce the effective capacity of drainage channels, thereby limiting their ability to convey runoff efficiently. In addition, standing water observed at several locations indicates that the drainage system is not functioning optimally under existing environmental conditions. The findings further reveal a relationship between drainage conditions and inundation occurrence. Observation points characterized by waste



accumulation and stagnant water showed a greater tendency to experience water ponding in surrounding residential areas. This condition suggests that drainage obstruction reduces flow capacity and increases the settlement's vulnerability to inundation. Furthermore, the dense settlement pattern and limited availability of open spaces reduce rainwater infiltration, causing a larger proportion of rainfall to become surface runoff. When combined with inadequate drainage performance and tidal influences, these conditions increase the likelihood of inundation within the study area. These findings are consistent with Suripin (2004), who stated that sedimentation and channel blockage are among the primary factors contributing to the decline of drainage system performance.

Inundation Conditions in Belawan Bahari Settlement

Inundation is one of the most common environmental problems affecting the study area. The occurrence of inundation is influenced not only by rainfall intensity but also by tidal fluctuations that directly affect drainage performance in coastal settlements. Rahmad et al. (2017) reported that Belawan Bahari experiences periodic tidal flooding, which may occur up to twice daily following tidal cycles. Consequently, inundation may occur even in the absence of rainfall. Tidal analysis indicates that Belawan experiences a semi-diurnal tidal pattern, characterized by two high tides and two low tides per day (Anggraini, 2024). Tidal data show that sea level can reach approximately 2.48 m during high tide and decrease to approximately 0.22 m during low tide, resulting in a tidal fluctuation of approximately 2.26 m.

Such fluctuations may hinder the discharge of drainage flows into coastal waters during high tide conditions. Previous research by Pinem et al. (2019) reported that tidal inundation in Medan Belawan covered approximately 540.938 hectares, highlighting the area's vulnerability to flooding. Field observations further revealed evidence of standing water at two out of three observation points (66.7%), particularly in areas located near drainage channels and low-lying residential zones. These findings suggest that inundation is influenced by both environmental characteristics and drainage system performance.

Relationship Between Drainage Conditions and Inundation Problems

The results indicate a strong relationship between drainage conditions and inundation occurrences within the Belawan Bahari Fishermen Settlement. Field observations and literature reviews identified three major contributing factors.

a. Influence of Sedimentation and Waste Accumulation

Waste accumulation and sediment deposits reduce the effective capacity of drainage channels. As a result, runoff cannot be conveyed efficiently, increasing the likelihood of water overflow into residential areas. This finding is consistent with Suripin (2004), who identified sedimentation and channel blockage as major causes of declining drainage performance.



b. Influence of Settlement Density

Satellite imagery and field observations show that the study area is characterized by high building density and limited open space. These conditions reduce rainwater infiltration and increase surface runoff. As rainfall-generated runoff enters drainage channels, the limited channel capacity may be exceeded, resulting in inundation. The dense spatial arrangement of buildings also restricts opportunities for drainage improvement and environmental management.

c. Influence of Tidal Fluctuations

As a coastal settlement, Belawan Bahari is significantly influenced by tidal fluctuations. The tidal range of approximately 2.26 m can obstruct drainage discharge during high tide events. This condition creates a backwater effect, in which elevated sea levels impede the outflow of water from drainage channels. Consequently, water remains within the drainage network for longer periods, increasing the duration and extent of inundation. The influence of tidal processes is supported by Siahaan and Abdiyanto (2024), who identified seawater intrusion through drainage channels as one of the primary causes of tidal flooding in Medan Belawan.

Discussion

The findings demonstrate that inundation problems in the Belawan Bahari Fishermen Settlement are not solely caused by drainage deficiencies but rather by the interaction of drainage conditions, settlement density, and tidal influences. Field observations revealed the presence of waste accumulation, stagnant water, and standing water within several parts of the drainage network. At the same time, the dense settlement pattern limits infiltration capacity and increases surface runoff. Furthermore, tidal fluctuations reduce the effectiveness of drainage discharge during high tide conditions. The novelty of this study lies in its integrated analysis of physical drainage conditions, settlement characteristics, and tidal influences at the neighborhood scale. Unlike previous studies that examined these factors separately, this research demonstrates how their interaction contributes to inundation vulnerability within a coastal fishermen settlement.

Therefore, inundation mitigation in Belawan Bahari should not rely solely on drainage channel normalization. Effective strategies should also include routine waste management, improvement of environmental infrastructure, and drainage planning that accounts for tidal influences. Such integrated approaches are essential for reducing inundation risks and improving environmental quality in coastal residential areas.

Conclusion

This study analyzed the relationship between drainage conditions and inundation problems in the Belawan Bahari Fishermen Settlement, Medan City. Field observations revealed that



the drainage system generally ranged from fair to poor condition, with waste accumulation observed at two of the three observation points (66.7%) and standing water identified at two locations (66.7%). These findings indicate that drainage performance within the settlement has been reduced by inadequate maintenance and environmental conditions. The results demonstrate that inundation problems in the study area are influenced not only by drainage system conditions but also by the characteristics of the coastal environment. High settlement density, limited infiltration areas, low-lying topography, and tidal fluctuations collectively increase the vulnerability of the area to inundation. The interaction of these factors becomes particularly significant during periods of heavy rainfall and high tide, when the drainage system is unable to effectively discharge excess water. This study further confirms that drainage conditions, settlement characteristics, and tidal influences are closely interconnected in shaping inundation vulnerability within the Belawan Bahari Fishermen Settlement. The novelty of this research lies in its integrated analysis of these three factors at the neighborhood scale, providing a more comprehensive understanding of inundation mechanisms in a coastal fishermen settlement. Unlike previous studies that primarily focused on tidal flooding or drainage performance separately, this study demonstrates how their combined effects contribute to inundation occurrence. Therefore, efforts to reduce inundation risk in Belawan Bahari should not be limited to drainage channel improvement alone. Integrated management strategies involving regular drainage maintenance, waste management, enhancement of environmental infrastructure, and consideration of tidal influences are essential to improve drainage performance and environmental quality in coastal residential areas.

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