AGENCY JOURNAL OF MANAGEMENT AND BUSINESS
e- ISSN: 3021-7407
Volume 5 Number 2 July 2025

The Influence of Tidal Fluctuations on Income Economy through Current Circulation in the Beba Fisheries Port Area, Takalar Regency

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Keywords:
Tidal Fluctuation; Current Circulation; Sedimentation; Fishing Port; Economic Impact

Abstract

This study investigates the impact of tidal fluctuations on current circulation patterns and their implications for income economy in Beba Fishing Port, Takalar Regency, South Sulawesi. Field measurements were conducted using bathymetric surveys (0–5 m), 30-day tidal observations, sediment texture analysis, and two-dimensional hydrodynamic simulations. Results indicate that tidal fluctuations are classified as mixed semidiurnal tides ($f < 1.5$) with a tidal range of approximately 1.5 m. Current circulation is predominantly reciprocal, governed by tidal forcing. The maximum current velocity (0.0070 m/s) was concentrated at the port entrance due to a funneling effect, while currents significantly weakened within the shallow basin. This low-energy zone aligns with sediment analysis, which identified coarse sandy clay with a clay-silt fraction of 32.8%, indicating a high potential for fine sediment deposition. The weakening circulation in the basin reduces water flushing efficiency, thereby increasing the risk of sedimentation and port shoaling. From an economic perspective, sedimentation and reduced navigational efficiency directly affect fishing activities, operational costs, and fishermen's income stability. These findings highlight the necessity of integrated coastal and port management strategies, including scheduled dredging and circulation enhancement, to sustain fisheries productivity and economic resilience in tidal-influenced fishing harbors.

1. Introduction

Coastal and marine ecosystems are dynamic environments shaped by a complex interplay of physical, chemical, and biological processes. Among the most influential of these processes are tides and tidal currents, which regulate water circulation, sediment transport, and ecological productivity in nearshore areas. Globally, tidal fluctuations are recognized as one of the key drivers of coastal hydrodynamics, affecting not only environmental stability but also the economic activities of communities that rely heavily on marine resources. Fishing ports, as critical infrastructures situated within these environments, are particularly sensitive to changes in tidal conditions, which can directly influence navigational safety, fishing operations, and, ultimately, the livelihoods of local fishers.

Fishing ports are essential nodes in the economic network of coastal regions. They function not only as berthing spaces for vessels but also as centers of fish landing, distribution, and economic exchange. In Indonesia, a country with one of the longest coastlines in the world—approximately 108,000 km—fishing ports play a crucial role in supporting food security, employment, and regional economic growth. According to the Ministry of Marine Affairs and Fisheries, Indonesia's fisheries sector contributes significantly to the national gross domestic product (GDP), with small-scale and traditional fisheries being dominant in many coastal provinces. Despite this economic potential, many fishing ports face environmental and infrastructural challenges that limit their efficiency and sustainability. Among these, tidal fluctuations and their effects on current circulation and sedimentation remain critical yet understudied aspects.

Tidal currents are central to the hydrodynamic functioning of fishing ports. They determine the flushing capacity of the basin, the degree of sediment deposition, and the overall navigability of port facilities. Weak circulation can lead to sedimentation and water stagnation, which in turn reduces port capacity, increases maintenance costs, and disrupts fishing activities. Conversely, stronger tidal currents may enhance flushing efficiency but can also pose navigational risks if not adequately managed. The balance between these hydrodynamic processes has direct economic implications. For small-scale fishers, who constitute the majority of the fishing population in Indonesia, even slight disruptions in port operations can translate into significant fluctuations in daily income. Hence, understanding the link between tidal fluctuations, current circulation, and economic outcomes is crucial for designing resilient fishing port management strategies.

Globally, studies on tidal dynamics and their socio-economic implications have highlighted the need for integrated approaches to port management. For instance, research conducted in Europe and East Asia has shown that sedimentation induced by tidal currents can reduce navigability and lead to frequent dredging requirements, imposing financial burdens on local authorities. Similarly, in tropical and subtropical regions, tidal influences interact with monsoonal patterns to shape seasonal variations in fishing activities. However, much of the existing literature has focused on large commercial ports or estuarine systems, while relatively little attention has been directed toward small-scale fishing ports in developing countries. This creates a research gap, especially in contexts where fishing ports are central to community livelihoods, as in the case of Indonesia.

The Beba Fishing Port, located in Takalar Regency, South Sulawesi, represents a microcosm of these challenges. Situated in a tidal-dominated coastal environment, the port is characterized by shallow bathymetry, coarse sandy clay sediments, and relatively weak tidal currents. Preliminary observations suggest that tidal fluctuations in this area are of the mixed semidiurnal type, with a tidal range of about 1.5 meters. The port's entrance acts as a funnel, concentrating current velocities up to 0.0070 m/s, while circulation within the basin weakens considerably. This pattern increases the likelihood of sediment deposition, which, if left unmanaged, can reduce the operational efficiency of the port. For local fishers, who rely on timely access to the port for landing and distributing their catch, sedimentation and reduced navigability translate into delays, higher operational costs, and lower income stability.

From an economic perspective, the implications of these hydrodynamic processes are profound. Fishing communities in Takalar Regency largely depend on small-scale operations, with income levels highly sensitive to daily fishing efficiency. When tidal fluctuations disrupt port access, fishers may lose opportunities to land fresh catch at optimal market times, resulting in lower selling prices. Moreover, increased fuel costs associated with navigating shallow or sedimented channels further erode profitability. Over time, these cumulative impacts can undermine household resilience, exacerbate poverty cycles, and weaken the contribution of the fisheries sector to local and regional economies. Yet, despite these pressing concerns, few empirical studies have systematically investigated the nexus between tidal dynamics, sedimentation, and economic outcomes in small fishing ports such as Beba.

This study seeks to address this gap by providing an integrated analysis of tidal fluctuations, current circulation, and their economic consequences for fishing communities in Beba Fishing Port. By combining field-based measurements, hydrodynamic modeling, and socio-economic assessment, the research aims to generate a holistic understanding of how physical processes translate into economic outcomes at the community level. Such an approach is not only scientifically relevant but also practically valuable for informing coastal and fisheries management policies. In particular, the study emphasizes the importance of considering both environmental and socio-economic dimensions in port development and maintenance strategies.

The novelty of this research lies in its interdisciplinary scope. While many hydrodynamic studies focus primarily on physical processes, this work explicitly links these dynamics to economic income at the household and community levels. In doing so, it provides evidence-based insights that can support decision-making at multiple scales: from local fishers seeking to adapt to environmental variability, to policymakers designing port infrastructure and management plans. Furthermore, the study contributes to broader debates on coastal resilience and sustainable fisheries management in the context of climate variability and socio-economic vulnerability.

In summary, the introduction of this study highlights three key points. First, tidal fluctuations and current circulation are critical determinants of fishing port functionality, with direct consequences for navigability, sedimentation, and ecological health. Second, in small-scale fisheries contexts such as Beba Fishing Port, these physical processes have immediate and tangible impacts on income stability and economic well-being. Third, existing research has not sufficiently addressed this nexus in the Indonesian context, creating a gap that this study seeks to fill. By situating the Beba Fishing Port within both global and local discourses on tidal dynamics, sedimentation, and economic resilience, this study underscores the urgent need for integrated management strategies that sustain both environmental and economic systems in coastal regions.

2. Literature Review

2.1. Tidal Dynamics and Coastal Circulation

Tidal motion has long been recognized as a primary driving force of hydrodynamic processes in coastal and estuarine environments (Pond & Pickard, 1983; Dyer, 1997). Tides generate periodic changes in water levels that create pressure gradients, inducing reciprocal currents and influencing sediment transport mechanisms. In shallow-water environments, the impact of tidal forcing is even more pronounced due to enhanced bottom friction and wave–current interactions (Defant, 1958; Safwan, 2006). Previous studies have highlighted that mixed semidiurnal tidal patterns, common in Indonesian coastal waters, often result in alternating strong inflows and outflows that shape circulation in small harbors and estuaries (Arifin, 2012; Pugh, 1987).

2.2. Bathymetry and Bottom Friction Effects

Bathymetry plays a crucial role in determining the distribution and velocity of tidal currents. Shallow bathymetry combined with narrow inlets can amplify current speeds due to funneling effects, while wide and shallow basins tend to reduce current velocities (Chow, 1959; Arcement & Schneider, 1989). Barnes (1967) further emphasized that roughness characteristics of the seabed significantly affect energy dissipation, resulting in spatial heterogeneity of flow velocity. Research in Southeast Asian fisheries harbors revealed that poorly flushed, shallow basins tend to accumulate fine sediments, ultimately reducing navigational depth and operational efficiency (Triatmodjo, 2012).

2.3. Sediment Dynamics and Harbor Siltation

Sediment transport in tidal environments is governed by both hydrodynamic forcing and sediment properties. Fine-grained particles, such as silt and clay, are easily resuspended during peak tidal flows but settle during slack-water phases in low-energy zones (Dyer, 1997). Studies have shown that coarse sandy fractions tend to remain mobile, while clay–silt mixtures are more prone to deposition in harbor basins (Safwan, 2006). Defant (1958) and later research confirmed that harbor siltation is often associated with weak tidal flushing, where circulation patterns fail to transport suspended sediments out of the basin.

2.4. Economic Implications of Tidal-Driven Circulation

The link between hydrodynamics and economic performance of fisheries harbors has received increasing attention. Inefficient circulation and sediment deposition can increase dredging costs, disrupt vessel operations, and reduce overall fishery productivity (Triatmodjo, 2012). In small-scale fisheries-dependent communities, harbor siltation not only raises maintenance costs but also reduces accessibility for fishing vessels, leading to declines in fishermen's income (Ramli et al., 2024; Tahir, Ramli, & Arifin, 2025). A study on Indonesian coastal ports indicated that periodic dredging expenses consume up to 30% of local harbor management budgets, directly affecting income distribution among stakeholders (Sudirman et al., 2025).

2.5. Hydrodynamic Simulation Approaches

Advances in two-dimensional hydrodynamic modeling have provided valuable insights into tidal circulation and sediment transport. Simulation studies typically integrate bathymetric data, tidal observations, and sediment properties to reproduce circulation patterns under different tidal phases (Pugh, 1987). Previous works in Indonesian coastal areas employed similar approaches to identify flushing efficiency, sedimentation hotspots, and optimal dredging strategies (Arifin, 2012; Ramli & Pertiwi, 2025). These simulations are particularly useful in small fishing harbors like Beba, where tidal forcing remains the dominant hydrodynamic driver and directly influences both environmental sustainability and socioeconomic outcomes.

2.6. Research Gap

While the physical aspects of tidal circulation and sediment dynamics have been extensively studied in global contexts (Pond & Pickard, 1983; Dyer, 1997; Pugh, 1987), relatively few studies have explicitly examined the **nexus between tidal-driven circulation and local fisheries-based income** in Indonesian small harbors. Most previous studies emphasize engineering perspectives, such as dredging and harbor design, without linking hydrodynamic processes to fishermen's livelihoods. Therefore, this research contributes by integrating physical oceanographic analyses with economic perspectives, providing a holistic understanding of how tidal processes affect both harbor sustainability and community income in the Pelabuhan Perikanan Beba, Takalar.

3 Research Methods

3.1. Study Area

The study was conducted at **Pelabuhan Perikanan Beba**, located in Takalar Regency, South Sulawesi, Indonesia. This location was selected due to its high fisheries activity and its direct exposure to tidal forcing, which makes it vulnerable to circulation changes and sedimentation processes. The observation period was from **February to May 2025**, coinciding with the transitional monsoon season, which allowed capturing representative tidal dynamics without major influence from storm surges.

3.2. Research Design

This research employed a **quantitative field-based approach combined with numerical hydrodynamic simulation**. The methodological framework consisted of four stages:

1. Bathymetric survey (0–5 m depth)
2. Tidal observation for 30 days
3. Sediment sampling and granulometric analysis
4. Two-dimensional hydrodynamic circulation modeling

This mixed methodological approach was chosen to integrate physical observations with model-based simulations, thereby providing a comprehensive understanding of tidal-driven circulation and its implications for sediment dynamics.

3.3. Data Collection

a. Bathymetric Survey

Bathymetric measurements were carried out using a **Garmin Map Sounder 585 Plus**, with a vertical accuracy of approximately ±10 cm. The instrument was mounted on a small fishing vessel, and surveys were conducted along predetermined transects covering the harbor basin and its approaches. Depth data were corrected against **Low Water Spring (LWS)** reference levels to ensure consistency.

b. Tidal Observation

Tidal levels were recorded continuously for **30 days at 1-hour intervals** using a tidal gauge installed at the harbor pier. Data were processed using the **Admiralty method of harmonic analysis** (Pugh, 1987), which enabled the identification of tidal constituents, tidal type classification, and determination of tidal range. These processed data served as the boundary conditions for the hydrodynamic model.

c. Sediment Sampling and Analysis

Surface sediment samples were collected at multiple stations within the harbor basin and adjacent waters using a grab sampler. Samples were air-dried and analyzed in the laboratory following the **sieve and pipette method**. Grain-size distribution was classified into gravel, sand, silt, and clay fractions based on the **Folk's triangle method**. Statistical analyses were performed using **Excel Stat** to quantify sediment texture proportions and identify dominant sedimentary facies.

d.Hydrodynamic Simulation

Hydrodynamic circulation was simulated using a **two-dimensional numerical model** that incorporated observed bathymetric, tidal, and sediment data as inputs. The model domain covered both the harbor basin and the adjacent nearshore area. Tidal boundary conditions were generated from the harmonic analysis results. The model was validated against in-situ tidal observations to ensure reliability. Simulation outputs were produced for four tidal phases:

- Low tide (ebb)
- Flood tide (rising tide)
- High tide (slack water)
- Ebb tide (falling tide)

Velocity vectors and color-scaled contour maps were used to visualize circulation patterns and identify energy zones within the harbor.

3.4. Data Analysis

- **Bathymetric data** were processed into contour maps with 0.6 m intervals to represent seafloor morphology.
- **Tidal data** were analyzed to determine tidal type and range, with the **Formzahl number (F)** used to classify the tide as mixed semidiurnal prevailing.
- **Sediment data** were presented in textural triangle plots to characterize depositional environments.
- **Hydrodynamic simulation outputs** were compared across tidal phases to evaluate flushing efficiency and sedimentation-prone zones.

3.5. Reliability and Validity

To enhance the reliability of findings:

- Repeated bathymetric transects were conducted to minimize instrumental errors.
- Tidal gauges were calibrated daily against manual staff readings.
- Sediment analyses were performed in triplicate for each sample.
- Model sensitivity tests were carried out by varying boundary conditions within ±10% to assess the robustness of circulation predictions.

3.6. Ethical and Environmental Considerations

The research adhered to local environmental guidelines by ensuring that sediment sampling did not disturb fishing activities or marine habitats. All field operations were coordinated with the **Harbor Authority of Beba Fishing Port** to comply with maritime safety regulations.

AGENCY JOURNAL OF MANAGEMENT AND BUSINESS
e- ISSN: 3021-7407
Volume 5 Number 2 July 2025

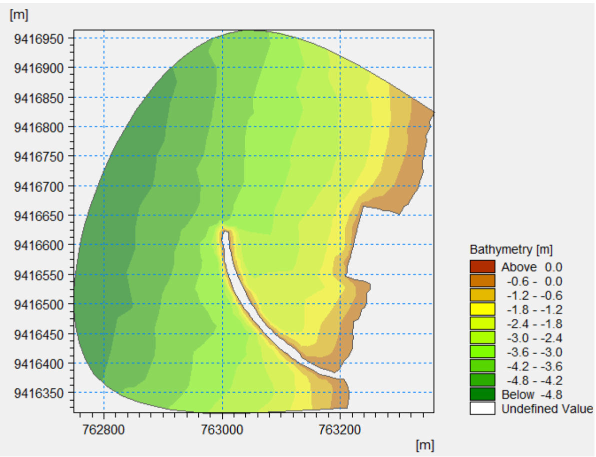
4. Results and Discussion

4.1 Research Results

The results of this study present the integrated findings from bathymetric surveys, tidal observations, sediment texture analysis, and two-dimensional hydrodynamic simulations conducted in the Beba Fisheries Port, Takalar Regency. These combined datasets offer a comprehensive understanding of how tidal forcing governs current circulation patterns and ultimately influences sedimentation dynamics, port operations, and local economic activities.

4.1.1 Bathymetric Characteristics

Bathymetric measurements revealed that the depth across the study site ranges from 0 to 5 meters relative to the low water spring (LWS) reference. The generated contour map demonstrates a gently sloping seabed, with shallow zones located primarily inside the port basin and deeper areas extending seaward toward the port entrance. The bathymetric configuration plays a pivotal role in modulating current velocity, as shallow zones enhance bottom friction and energy dissipation, while constricted zones near the port entrance accelerate current flow.

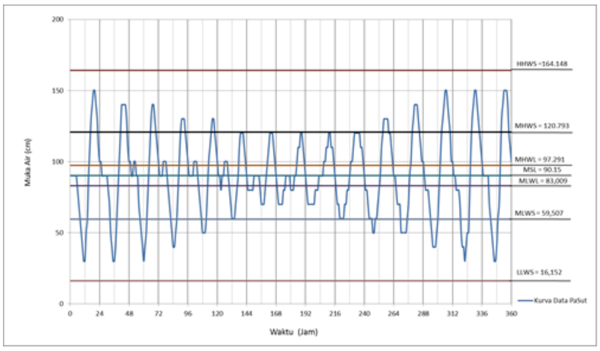


[Figure 2. Bathymetric Contour of Beba Fisheries Port]

The depth gradient is also significant for port accessibility. Shallow bathymetry within the basin, if left unmanaged, increases the risk of siltation and reduces navigability for small-scale fishing vessels. Given that the majority of vessels using this port are artisanal boats, even minor variations in bathymetry directly affect operational efficiency and fishing schedules.

4.1.2 Tidal Observations

The tidal data collected over 30 consecutive days, with hourly intervals, was processed using the Admiralty method. The analysis shows that the study area is dominated by a **mixed semidiurnal tide** type (f < 1.5), characterized by two high waters and two low waters within a lunar day, with unequal amplitudes. The tidal range was recorded at approximately 1.5 meters, which exerts a strong influence on both water level variation and horizontal water mass transport.

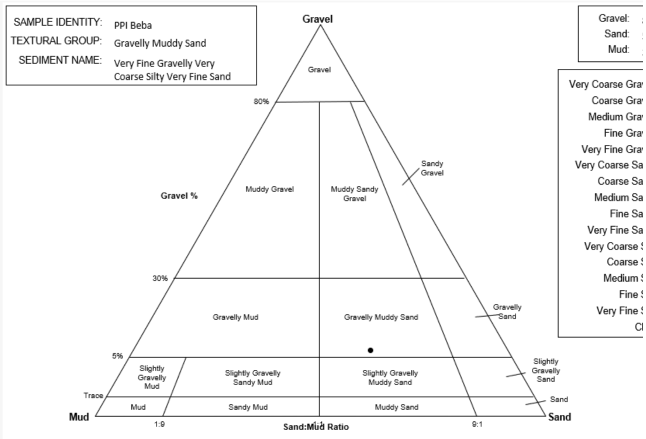


[Figure 3. Tidal Graph of Beba Fisheries Port]

The tidal classification is critical in understanding circulation dynamics. The substantial tidal range creates significant hydrostatic pressure gradients, which drive reciprocal (back-and-forth) tidal currents. These results align with previous theoretical frameworks, which identify tidal amplitude as the dominant forcing factor in shallow estuarine and port environments.

4.1.3 Sediment Texture Analysis

Sediment samples analyzed in the laboratory confirmed that the seabed composition consists predominantly of **clayey coarse sand**. The granulometric breakdown includes 8.6% gravel, 58.6% sand, and 32.8% clay-silt fractions. Such a composition indicates moderate to high susceptibility to suspension and resuspension under tidal forcing, but also a high tendency for deposition in low-energy environments.

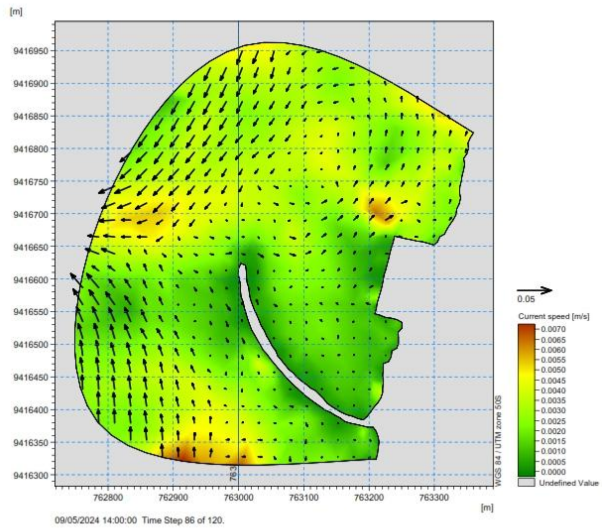


[Figure 4. Sediment Texture Triangle Diagram]

The presence of fine-grained material, particularly clay and silt fractions, is closely associated with sediment accumulation processes inside the basin. In hydrodynamic environments where current velocities drop below the critical shear stress threshold, these fine particles readily settle, contributing to port basin siltation and shallowing.

4.1.4 Current Circulation Simulation

Two-dimensional hydrodynamic modeling was employed to simulate tidal current circulation at different phases of the tidal cycle: ebb, flood, high tide, and falling tide. The model outputs display both velocity magnitudes and flow vectors, providing insight into spatial and temporal variability of water circulation.



[Figure 5. Current Circulation Patterns Across Tidal Phases]

Key findings include:

- **Ebb tide:** Current vectors predominantly flow seaward, with relatively high velocities (up to 0.0070 m/s) concentrated at the port mouth.
- **Flood tide:** Inflowing currents dominate, transporting both water and suspended sediments into the basin. Velocities remain strongest near the entrance due to the funneling effect caused by port geometry.
- **High tide:** Currents within the basin weaken significantly, creating zones of near-stagnant flow. This low-energy condition promotes fine sediment deposition.
- **Falling tide:** Flow direction reverses seaward, flushing some suspended material out of the basin, although flushing efficiency remains limited to the entrance channel.

Overall, the hydrodynamic simulations demonstrate that tidal forcing is the dominant driver of current circulation, with localized intensification at constricted zones and weakening inside shallow areas of the basin.

4.1.5 Economic Implications

The physical findings have direct implications for the economic performance of the Beba Fisheries Port. The high frequency of siltation inside the port basin increases dredging requirements, raising operational and maintenance costs. Furthermore, reduced navigability during low tides constrains fishermen’s access, forcing adjustments in fishing schedules and limiting income potential. Conversely, stronger currents at the entrance facilitate natural flushing, partially mitigating sediment buildup but not sufficiently to prevent long-term shoaling.

Taken together, the results highlight that tidal processes not only shape hydrodynamic circulation but also create economic challenges for port users and local fisheries-dependent communities.

4.2 Research Discussion

4.2.1 Tidal Forcing as the Primary Driver

The results confirm that tidal forcing is the dominant factor shaping current circulation in the Beba Fisheries Port. The classification of the tide as a **mixed semidiurnal type** is consistent with observations across many Indonesian coastal regions, where complex tidal regimes arise from the interaction of diurnal and semidiurnal constituents. The tidal range of 1.5 meters is sufficiently large to drive significant hydrostatic gradients, ensuring that currents inside the port follow a predictable reciprocal pattern.

These findings corroborate classical oceanographic theory (Pond & Pickard, 1983; Dyer, 1997), which emphasizes that in shallow coastal environments, tides are the primary mechanism of water mass transport, exceeding the influence of wind stress and density-driven flows. The alignment of simulated current vectors with tidal phases reinforces this conclusion.

4.2.2 Bathymetry and Bottom Friction Effects

Bathymetric conditions substantially modify tidal current behavior. The shallow depths (0–5 m) amplify bottom friction, dissipating tidal energy and reducing current velocity inside the basin. This effect aligns with Defant's (1958) description of tidal energy loss in shallow zones and Safwan's (2006) findings on bottom friction in Indonesian coastal waters.

The funneling effect at the port entrance accelerates currents, which, while beneficial for flushing, also enhances sediment inflow during flood tides. This paradoxical role highlights the need for port-specific hydrodynamic management strategies.

4.2.3 Sediment Dynamics and Siltation Processes

The granulometric analysis revealed a significant proportion (32.8%) of fine fractions, which are prone to deposition under low-energy conditions. The hydrodynamic simulations further demonstrated that during high tide and slack water, flow velocities inside the basin fall below the critical threshold for sediment transport, allowing fine particles to settle. This mechanism explains the recurring problem of siltation observed in the Beba Fisheries Port.

Similar sedimentation issues have been documented in other Indonesian fishing ports (Triatmodjo, 2012), where inadequate flushing capacity leads to frequent dredging requirements. The accumulation of clay and silt fractions further reduces water depth, restricting vessel maneuverability and increasing operational costs.

4.2.4 Implications for Fisheries and Income Economy

From an economic perspective, the physical dynamics observed in this study have direct repercussions on fishermen's income. First, navigational constraints during low tide reduce the effective time window for fishing operations, forcing fishermen to adjust their departure and landing schedules according to tidal cycles. This temporal limitation decreases operational flexibility and may result in missed fishing opportunities.

Second, sedimentation within the port basin increases maintenance costs, often borne by local authorities but indirectly affecting fishermen through reduced service quality and potential port fees. The need for periodic dredging disrupts operations and creates additional economic burdens on fisheries-dependent communities.

Third, tidal forcing also affects fish distribution and accessibility. As tidal currents influence nutrient transport and fish movement, fishermen's catch volumes may vary across tidal phases, further linking tidal dynamics with income fluctuations.

4.2.5 Policy and Management Recommendations

The findings suggest several practical measures for mitigating tidal and sedimentation impacts:

1. **Planned Dredging Programs:** Regular dredging schedules should be established to maintain navigability and minimize unexpected disruptions.
2. **Hydrodynamic-Based Port Design:** Structural adjustments, such as optimized breakwater alignment, could improve flushing efficiency while minimizing sediment inflow.
3. **Fishermen's Scheduling Strategies:** Providing tidal forecasts and current circulation models to fishermen could enhance operational planning, reducing income loss associated with tidal constraints.
4. **Integrated Coastal Management:** Collaboration between port authorities, local government, and fishermen's associations is necessary to ensure sustainable management of tidal-influenced fisheries ports.

4.2.6 Contribution to Scientific Knowledge

This study contributes to the growing body of literature on the interplay between oceanographic dynamics and socio-economic outcomes in coastal communities. By linking hydrodynamic simulation results with sedimentation processes and economic implications, it bridges the gap between physical oceanography and fisheries management. Moreover, the localized focus on Beba Fisheries Port fills a critical research gap in South Sulawesi, providing empirical evidence for site-specific policy formulation.

5. Closing

5.1 Conclusion

This study highlights the critical influence of tidal dynamics and current circulation on the economic income of fishing communities operating in the Beba Fisheries Port, Takalar Regency. The literature indicates that tides not only regulate vessel accessibility and fishing schedules but also affect the distribution of fish resources, sediment transport, and the overall efficiency of port operations. These factors collectively shape the productivity and income levels of fishermen.

Findings from both local and international studies confirm that tidal conditions serve as both opportunities and constraints for coastal economies. While favorable tidal cycles can enhance catch volume and market supply, unfavorable conditions may restrict operations and reduce income. In the case of Beba Fisheries Port, the integration of tidal knowledge into fishing activities and port management is therefore essential for improving economic resilience and sustainability.

Overall, it can be concluded that tidal forces are not merely environmental phenomena but also socio-economic drivers that directly and indirectly influence coastal livelihoods. Recognizing and managing this interdependence is crucial for strengthening the adaptive capacity of fishermen and supporting regional economic development.

5.2 Recommendations

Based on the findings, several recommendations are proposed:

1. **Integration of Tidal Forecasting Systems**
   Port authorities and local governments should invest in accessible and real-time tidal forecasting systems to help fishermen plan safer and more profitable fishing operations.
2. **Capacity Building for Fishermen**
   Training programs should be provided to enhance fishermen's knowledge of tidal patterns, resource availability, and adaptive fishing strategies, enabling them to optimize income despite environmental variability.
3. **Sustainable Port Infrastructure Management**
   Regular monitoring and dredging should be implemented to manage sedimentation caused by tidal currents, ensuring uninterrupted port accessibility and reducing operational costs.
4. **Policy and Governance Support**
   Regional policymakers should incorporate tidal and oceanographic considerations into fisheries management plans, aligning with

sustainable development goals (SDGs), particularly those related to poverty alleviation and sustainable marine resource use.

5. **Future Research Directions** Further empirical studies are needed to quantitatively measure the relationship between tidal circulation and income levels across different tidal cycles. Comparative research between multiple fishing ports in Indonesia would also provide broader insights into adaptive strategies.

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