A Study on Stability and Passenger Capacity of Traditional River and Lake Boats

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Abstract. **Traditional boats are vital for many Indonesians, particularly river and lake passenger boats, which are essential transportation links in specific regions. However, the absence of regulated passenger capacity limits has compromised safety standards. This study aims to determine safe passenger capacities for river and lake boats through shipping risk and stability analyses. Using the minimum passenger area requirements from the Indonesian National Standard (SNI) and stability criteria from the Indonesian Classification Bureau (BKI), passenger capacities were calculated for various boat types across four waters: Lake Matano, the Mahakam River, the Indragiri River, and the Musi River. Boat lengths varied from 3 to 15 meters, and widths varied from 1 to 4.5 meters. The analysis of 15x4.5 meter boats shows that the speed boat is the most stable (134.7 kN.m) and accommodates the most passengers (56 people), the trimaran offers the most significant space despite having the lowest stability (62.0 kN.m), the long boat has the largest passenger area, and the catamaran has the lowest capacity (36 people). This research provides a framework for determining minimum passenger capacities based on boat dimensions and types, contributing to improved river and lake transportation safety standards in Indonesia.**

1 Introduction

Boat stability is a crucial element of boat operation for evaluating maritime safety [1]. Stability refers to a boat's ability to maintain a balanced position under external forces. The loss of stability may lead to uncontrollable tilting, potentially resulting in the boat capsizing [2]. This scenario presents considerable dangers to all individuals aboard, encompassing potential fatalities and extensive property destruction [3]. International and national legislation have rigorously tackled this issue, as evidenced by the International Convention for the Safety of Life at Sea (SOLAS) in Chapter II-1, Part B-1, and its incorporation into national regulations by Ministerial Regulation Number 44 of 2021 [4][5]. Accident investigations indicate that many marine mishaps are due to stability breakdowns, frequently resulting from passenger overloading exacerbated by unfavorable ocean conditions [6].

The increase in boat passenger numbers during major holidays like Eid al-Fitr, Christmas, and New Year highlights a significant trend. Passenger data from seven days

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before to seven days after D-Day shows that routine travel remains well below boat capacity, while holiday periods see sharp surges, with peaks reaching up to 80% above capacity. The surge is most pronounced from three days before to three days after D-Day, often exceeding the boat's limit, before gradually declining to match or fall below capacity from four to seven days post-D-Day. This poses serious safety risks due to capacity discrepancies during peak periods. Addressing these measures, such as limiting passenger numbers to ensure boat stability, implementing ticket reservation systems, enforcing strict oversight, and educating operators and passengers on capacity compliance, is essential to improving water transportation safety [7].

The issue concerning river and lake watercraft is particularly significant, revealing a substantial deficiency in safety mitigating efforts. Not all boats operating on rivers and lakes adhere to procedural safety standards [8]. Non-adherence to maximum load capacity restrictions is a primary issue, sometimes influenced by economic pressures and inadequate supervision, resulting in boats operating over safe thresholds [9]. Numerous studies have investigated the assessment of passenger capacity for boats. Addressing the highlighted inadequacies in this subject poses a problem in establishing passenger capacity limits derived from stability calculations. Prior pertinent research encompasses Igor Backalov's examination of stability criteria for substantial inland passenger boats [10]. Abdul and Rosli created a sensor system that detects boat overload, preventing capacity exceedance and mitigating accident risk [11]. A separate report by the South Australia Department for Infrastructure and Transport offers detailed boat safety standards. The resultant guidebook has regulations about passenger limitations contingent upon boat dimensions, presented in a matrix format [12].

This study seeks to deliver precise recommendations concerning the maximum passenger capacity of the river and lake boats by meticulously assessing essential elements, including boat stability and passenger area requirements. This project aims to improve the safety of water transportation in Indonesia by mitigating the dangers linked to overloading, a longstanding issue in the sector. The study underscores the necessity of adhering to safety rules, guaranteeing that boats function within secure limits to safeguard passengers and crew. The research findings will facilitate the introduction of practical solutions, such as sophisticated load monitoring systems and extensive safety training programs for operators and passengers, promoting a culture of safety awareness. These recommendations are anticipated to function as essential instructions for regulators and boat operators, facilitating establishing and enforcing safe passenger load limitations. This effort ultimately fosters the advancement of a more sustainable, efficient, and safe water transportation system in Indonesia, tackling present difficulties and future requirements.

2 Methodology

Ensuring the safety of traditional river and lake boats requires determining their passenger capacity via a thorough and methodical stability investigation. This study employs a scientific methodology incorporating essential factors, such as the righting arm curve (GZ) and passenger area specifications, to assess boat stability thoroughly. The methodology evaluates the operational safety of boats by simulating diverse loading scenarios, assuring adherence to internationally recognized stability and capacity criteria. This method not only determines safe passenger thresholds but also offers a comprehensive framework for alleviating concerns linked to overloading and instability. The sequential procedure depicted in Figure 1 provides a systematic framework for assessing and establishing safe passenger capacity, improving safety standards for conventional boats in riverine and lacustrine settings.

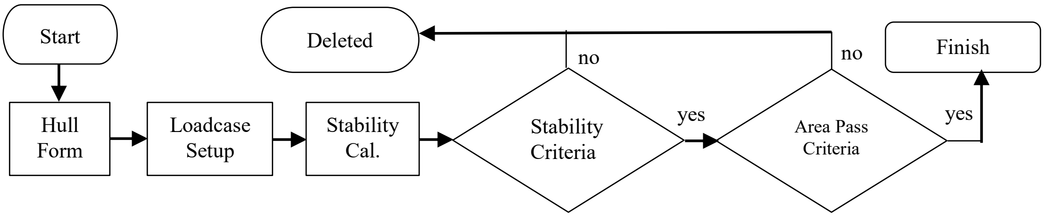

Fig. 1. Research Methodology

The research methodology is designed to facilitate understanding of the thought process outlined in the paper. The research begins with starting the study and then redrawing the ship model to obtain a more accurate representation. Next, loads and tanks are modeled, and the ship's stability is calculated. Subsequently, a filtering process is carried out based on stability criteria using the turning moment and passenger requirements; if these criteria are met (yes), the research proceeds to the next stage, but if not, the ship's moment results are discarded. The next step involves filtering based on the criteria for passenger area on the ship's deck; if these criteria are met (yes), the research continues, but if not, the ship's moment results are again discarded. The final step is drawing conclusions, which marks the completion of the research.

2.1 Hull Form Model

This research uses hull models adapted from typical river and lake boats in Indonesia, including a speed boat on the Indragiri River, a long boat on the Mahakam and Musi Rivers, a ketek boat on the Musi River, a trimaran boat on the Lake Matano, and a catamaran boat on the Lake Matano. These models reflect the diverse boat characteristics of traditional boats in Indonesia. Analyzing real-world designs, the study aims to provide accurate and relevant passenger capacity recommendations for each boat type.

- A speed boat on the Indragiri River is designed with hull shapes that prioritize high speed and maneuverability, featuring a flat bottom to enhance stability and a tapered front to reduce water resistance, as shown in the line plan model in Figure 2.
- A long boat on the Mahakam River has a narrow V-shaped hull designed for efficient navigation in narrow and winding waterways with varying currents, enhancing stability in shallow waters and maneuverability in tight channels; however, the V-shaped hull design can increase drag in calm waters, reduce fuel efficiency, and limit passenger or cargo capacity due to its narrow shape, as shown in the line plan model in Figure 3.
- The hull design of the ketek boat on the Musi River is characterized by a rounded shape and short draft, making it suitable for navigating shallow waters and circumventing bottom impediments. The substantial design improves stability and accommodates a greater carrying capacity, balancing stability and load. The boat effectively transports passengers or freight and is appropriate for diverse depths and tranquil currents. Figure 4 illustrates the lines plan model.

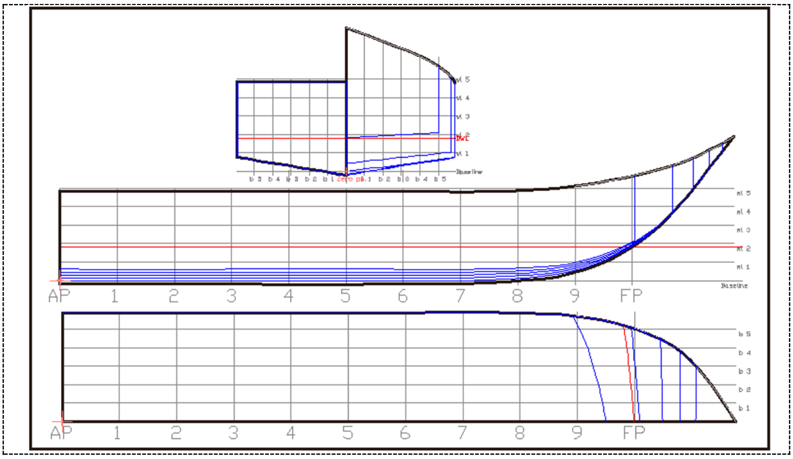

Fig. 2. Linesplan of a speedboat on the Indragiri River

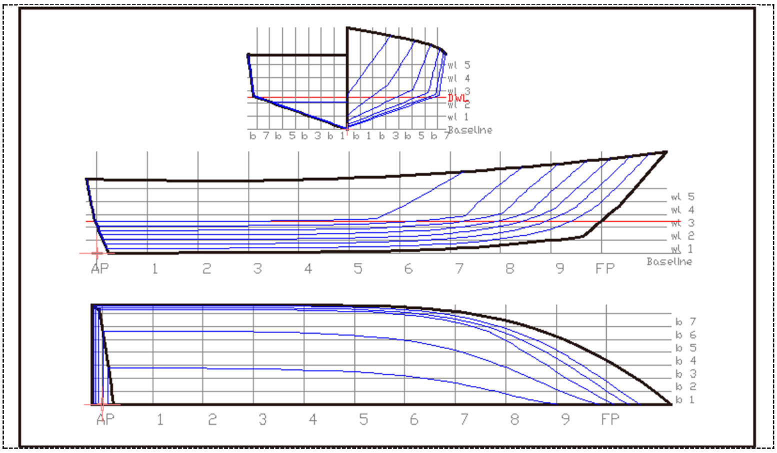

Fig. 3. Linesplan of a Long Boat on the Mahakam River

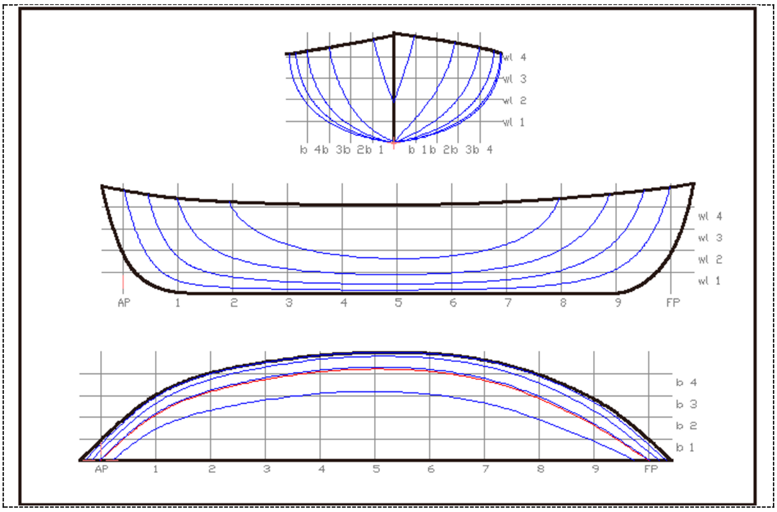

Fig. 4. Linesplan of a Ketek Boat on the Musi River

- The hull shape of a long boat on the Musi River: the long boat on the Musi River, a traditional motorized ketek boat, features a lightweight, flat-bottomed hull for efficient navigation in shallow waters with varying depths. It balances stability, maneuverability, and cargo capacity, making it ideal for short-distance local transportation. Figure 5 presents the lines plan model.
- The hull shape of a trimaran boat on Matano Lake: the outrigger canoe on Matano Lake has a V-shaped hull for stability and efficient navigation, reflecting varied uses from fishing to cargo transport. Attached is a trimaran that enhances stability and prevents capsizing, making it ideal for the calm, deep lake waters. Figure 6 presents the lines plan model.
- The catamaran boat on Lake Matano features a V-shaped hull designed for optimal hydrodynamic performance and stability. The boat is well-suited for the lake's calm, shallow shoreline areas with its low draft. The hull is exposed and lacks a deckhouse, prioritizing simplicity and practicality for transporting people or cargo. This design makes the catamaran ideal for operations on Lake Matano, ensuring consistent performance and adaptability to local conditions. The linesplan model of the boat is shown in Figure 7.

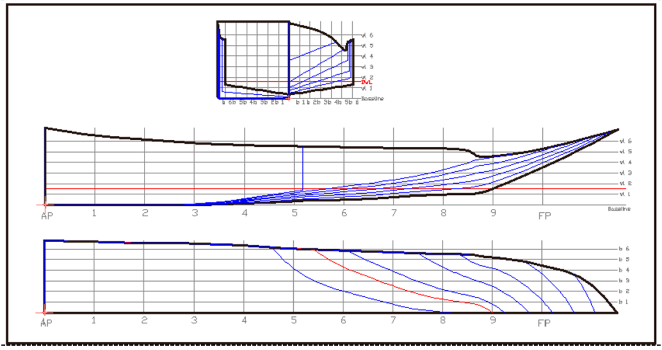

Fig. 5. Linesplan of a Long Boat on the Musi River.

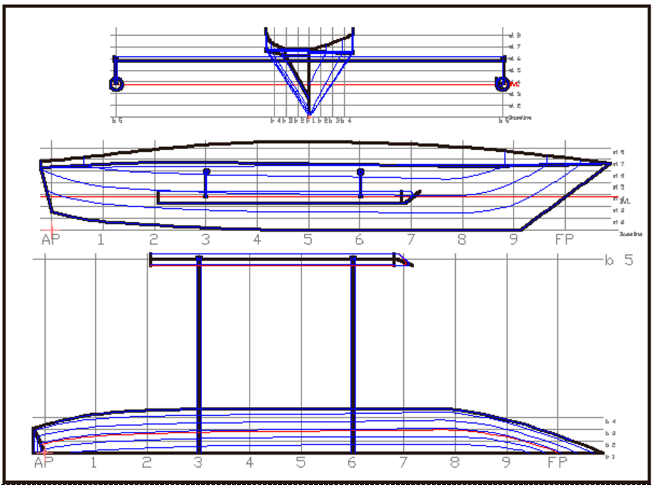

Fig. 6. Linesplan of a Trimaran Boat on the Matano Lake.

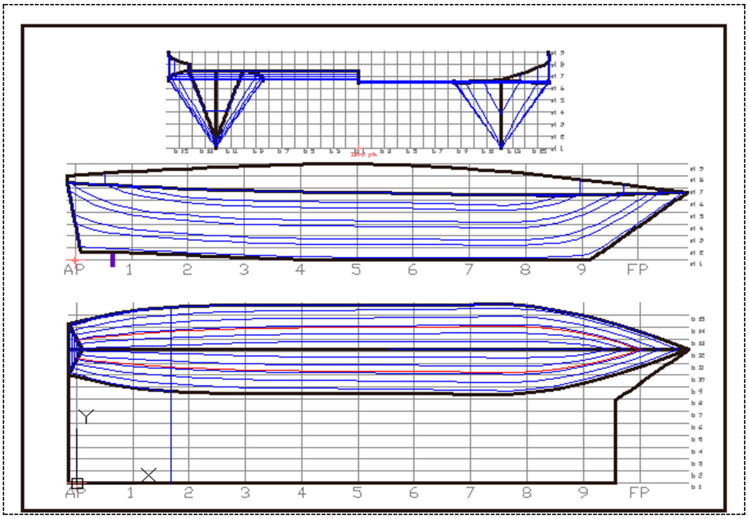

Fig. 7. Linesplan of a Catamaran Boat on the Matano Lake.

2.2 Loadcase Set Up

Setting up load cases is essential for boat stability simulations, ensuring accurate analysis of the boat's performance under various operational scenarios. Calculated parameters are input into stability software to verify compliance with the Indonesian Classification Bureau (BKI) stability criteria. This study's load case setup includes key stages involving the calculation and definition of boat load parameters.

- Calculating the boat's weight: the first step is calculating the lightship weight, which includes the weight of the hull structure, engine, equipment, and other fixed components. The weight is the foundation for determining the total weight when the boat operates under various loading scenarios. The calculation is based on the technical data of the boat's design or estimation methods based on hull volume and materials.

- Defining passenger and cargo weight: the next stage is defining the weight of passengers and their belongings. The standard average weight per passenger, such as 75 kg per person, is used according to safety guidelines, along with an estimated average luggage weight of 50 kg. Passenger weight distribution on the boat's deck is also carefully determined to ensure an even load distribution, avoiding any adverse effects on the boat's stability.

- Calculating the center of gravity: The boat's total center of gravity is calculated by considering the combination of the lightship weight, passenger weight, and other loads. The center of gravity is determined as the boat's total mass center's vertical, longitudinal, and transverse position. This position is crucial in determining the boat's stability, as it affects the ability of the boat to return to an upright position after being disturbed by external forces.

2.3 Stability Calculation

After preparing boat dimensions, passenger grids, and load cases, stability analysis ensures compliance with Indonesian Classification Bureau (BKI) safety standards. Load case data, including weight, passenger distribution, and center of gravity, is integrated with hull geometry for analysis. Initial stability is checked through metacentric height (GM) and righting moment (GZ) at small heel angles. The GZ curve and its area confirm compliance with stability requirements, while weight distribution effects are reviewed to prevent excessive heel or trim. Simulations across varying passenger capacities and hull dimensions evaluate stability under different scenarios. Results are compared to BKI criteria, including righting moment, heel angles, and height-to-breadth ratio, ensuring the boat is safe and operationally viable.

2.4 Stability Criteria

Stability criteria are rules and parameters designed to ensure a boat can maintain balance and return to an upright position after being affected by external forces such as waves, wind, or uneven loads. Key factors include metacentric height (GM), center of gravity (G), buoyancy center (B), and the righting moment [13]. These criteria help evaluate the boat's capacity to remain stable at various heel angles [14]. Their primary goal is to enhance safety by minimizing the risk of capsizing due to instability caused by external disturbances [15]. The International Maritime Organization (IMO) standards in Indonesia are complemented by Biro Klasifikasi Indonesia (BKI) regulations for domestic boats [17]. The regulation provides guidelines for stability parameters, including passenger capacity calculations using the formula:

$$M_{GZ} = \Delta . GZ_{at\ 12^o} \tag{1}$$

$$GZ_{at\ 12^o} = KN - KG . \sin \theta \tag{2}$$

$$M_{kr} = 0.25D\frac{v^2}{L}(0.7H - 0.5T) + n(0.2B + 0.1) \tag{3}$$

$$M_{GZ} \geq M_{kr} \rightarrow pass \tag{4}$$

Where M_{GZ} is the stability moment arm of the boat, measured in newton-meters (Nm), Δ refers to the displacement of the boat in newtons (N), and GZ is the stability arm at a 12-degree angle, expressed in meters (m). KN represents the form stability arm, the distance from the keel to the buoyancy center, measured in meters (m). At the same time, KG is the vertical distance from the keel to the center of gravity, measured in meters (m). M_{KR} is the heeling moment caused by the combined effects of turning and passenger movement, expressed in Newton meters (Nm). L, B, H, and T denote the boat's length, width, height, and draft, all measured in meters (m), while n represents the number of passengers onboard, expressed in persons. A stability study is conducted to determine if the boat is stable or unstable by comparing the values of M_{GZ} and M_{KR}. Suppose $M_{GZ} \geq M_{KR}$, the boat is classified as passing or stable. This comparison is crucial in ensuring the safety and operational reliability of the boat, particularly under varying conditions, such as passenger movement or external forces acting on the boat [16][17].

2.5 Area Passenger Criteria

Passenger capacity is calculated by dividing the deck area by the minimum space per passenger specified by the Indonesian National Standard (SNI) [18]. This guarantees the boat's capacity to adhere to safety rules while enhancing design efficiency. The research delineates configurations that enhance capacity within safe parameters by integrating stability analysis and area-based computations. SNI 10-4834-1998 stipulates that the minimum passenger area is 0.74 m^2, assuring comfort and safety according to the boat's type and usage. This strategy mitigates congestion, ensures stability, and improves passenger experience while adhering to regulatory requirements.

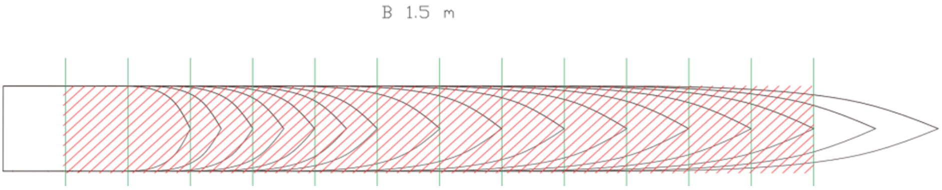

Fig. 8. Passenger Area for Boat with 1.5 m Breadth.

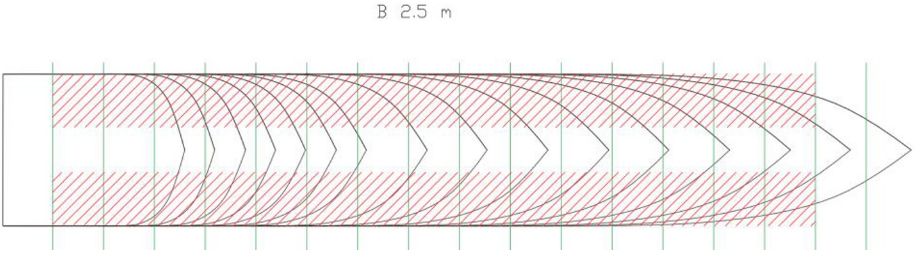

Fig. 9 Passenger Area for Boat with 2.5 m Breadth.

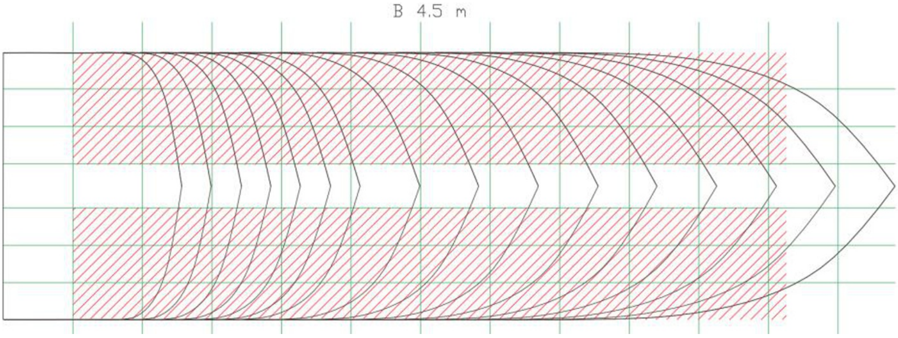

Fig. 10. Passenger Area for Boat with 4.5 m Breadth.

The images in Figure 8, Figure 9, and Figure 10 illustrate the minimum passenger area grid for a boat, which is used to calculate the number of passengers the boat can accommodate. Based on the hull's geometry, the shaded red area represents the designated passenger space. The curved lines depict the cross-sectional area of the hull, which varies in length and breadth as per the hull's design. By overlaying the grid on the hull's geometry, the total usable area for passengers can be determined. This method allows for the calculation of passenger capacity by dividing the shaded area by the minimum space requirement per passenger. The visualization ensures that the boat meets safety and comfort standards while adhering to the stability and space requirements.

3 Results and Discussions

3.1 Boat Stability (M_{GZ})

The stability moment of the boat at a 12-degree angle can be determined from the modeling and loading results utilizing equation (1). This computation is crucial for assessing the boat's capacity to sustain equilibrium under diverse settings. The stability study involved adjusting the boat's length (L) from 3 to 15 meters and its width (B) from 1 to 4.5 meters, facilitating a thorough analysis of various boat parameters. The findings of this research are displayed in Tables 1 to 6 below, which offer a comprehensive summary of the stability moments for each length and width combination. In these tables, vacant cells signify that the stability study yielded no moment, indicating that the boat's shape at those dimensions may not satisfy stability criteria. In contrast, cells with numerical values denote the computed stability moment, indicating the boat's capacity to withstand tipping or capsizing at a 12-degree angle. This method guarantees a comprehensive comprehension of how alterations in boat size affect stability, providing significant insights for design and safety considerations.

Table 1. Stability Moment of a Speed Boat on the Indragiri River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1																
1.5									1.2	1.4	1.5	1.7	1.8	2	2	2.3
2			2.3	2.6	2.8	3.1	3.4	4	4.6	5.2	5.7	6.3	6.9	7.5	8.1	8.6
2.5		5.1	5.7	6.6	7.2	8.1	8.8	10	12	13	15	16	18	19	21	22
3		11	13	14	16	17	19	23	26	29	28	36	39	43	46	39
3.5			21	24	27	30	32	38	44	49	44	61	66	72	78	63
4				37	41	46	50	58	67	76	67	93	102	110	119	98
4.5						65	71	84	95	107	93	132	145	157	169	135

Table 2. Stability Moment of a Long Boat on the Mahakam River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1								0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1
1.5	0.7	0.9	1	1.1	1.2	1.4	1.5	1.8	2	2.3	2.5	2.8	3.1	3.3	3.6	3.8
2	2.1	2.4	2.7	3	3.4	3.7	4	4.7	5.3	6.1	6.8	7.5	8.1	8.8	9.6	10
2.5		4.6	5.4	6.1	6.9	7.5	8.4	9.6	11	12	14	15	17	18	20	21
3			9.4	11	12	13	14	17	19	22	24	27	29	32	35	37
3.5				16	18	19	21	25	28	32	36	40	44	48	52	56
4					25	28	31	36	41	47	52	58	64	69	75	81
4.5						38	41	49	56	64	71	78	86	93	100	108

Table 3. Stability Moment of a Ketek Boat on the Musi River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1														0.5	0.6	0.6
1.5			0.8	0.9	1	1.1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3
2			2	2.3	2.6	2.8	3.1	3.6	4.1	4.6	5.2	5.7	6.2	6.7	7.3	7.8
2.5				4.7	5.2	5.8	6.3	7.3	8.4	9.5	11	12	13	14	15	16
3					12	13	15	17	20	22	25	27	30	32	35	28
3.5						20	22	26	30	34	38	42	45	49	53	42
4							32	38	43	49	54	60	65	71	76	61

4.5								51	59	66	74	81	88	96	104	82

Table 4. Stability Moment of a Long Boat on the Musi River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1									0.6	0.7	0.8	0.8	0.9	1	1.1	1.1
1.5		0.9	1	1.1	1.3	1.4	1.5	1.8	2	2.3	2.5	2.8	3	3.3	3.5	3.8
2	1.8	2.1	2.4	2.7	3	3.3	3.6	4.2	4.9	5.5	6.1	6.8	7.4	8	8.6	9.2
2.5	4.2	4.9	5.7	6.3	7.1	7.9	8.6	10	12	13	15	16	18	19	20	22
3		8.2	9.4	11	12	13	14	17	19	22	24	27	29	32	34	37
3.5			16	18	20	22	24	28	32	36	40	44	48	52	56	60
4				26	29	32	35	41	47	53	59	65	71	77	84	90
4.5				35	41	45	50	59	67	76	85	93	102	110	119	128

Table 5. Stability Moment of a Trimaran Boat on the Matano Lake (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1		2.2	2.5	2.8	3	3.3	3.8	4.4	5	5.7	6.3	6.9	7.6	8.2	8.8	9.3
1.5	2.1	2.4	2.7	3	3.3	3.9	4.2	4.8	5.7	6.4	7	7.8	8.5	9.3	10	10
2	2.3	2.6	2.9	3.6	3.9	4.5	4.8	5.8	6.5	7.1	8.1	9	10	11	12	13
2.5	3.1	3.6	4	4.8	5.3	6.1	6.6	7.8	8.8	10	11	13	14	15	16	17
3		5.1	6.1	7.1	7.7	8.7	9.6	11	13	14	16	18	19	21	22	23
3.5			8.2	9.6	10	12	13	15	17	20	23	25	27	29	31	25
4				13	14	16	17	21	24	27	30	33	36	40	43	46
4.5					19	22	25	29	33	37	42	46	50	55	59	62

Table 6. Stability Moment of a Catamaran Boat on the Matano Lake (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1								49	56	63	69	76	83	90	97	104
1.5									75	84	93	103	112	121	130	140
2									95	106	118	129	141	152	164	175
2.5										126	140	154	167	181	195	209
3										151	167	183	199	216	232	248
3.5											196	215	234	253	272	291
4											225	246	268	289	311	333
4.5											260	284	309	333	358	383

3.2 Criteria of Boat Stability ($M_{GZ} \geq M_{KR}$)

In this section, the boat's stability was filtered using the turning and passenger moments (M_{KR}) as comparison parameters. This filtering process ensures that only configurations meeting specific stability criteria are displayed in the analysis tables. Based on the analysis results, it was found that several cells in the tables had to be left blank or removed because the value of the restoring moment (M_{GZ}) was smaller than the critical passenger and turning moment (M_{KR}), i.e., $M_{GZ} < M_{KR}$. This condition indicates that these configurations do not meet the expected stability requirements. Conversely, for tables where the value of MGR is greater than or equal to M_{KR} ($M_{GZ} \geq M_{KR}$) according to equation (4), the cells were filled with calculated values representing valid stability moments. The results of this filtering process can be seen in tables 7 to 12 below, which provide a more precise overview of the boat configurations that meet the stability criteria based on the specified parameters.

Table 7. Stability Criteria ($M_{GZ} \geq M_{KR}$) of a speed boat on the Indragiri River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1																
1.5									1.2	1.2	1.2	1.6	1.6	1.6	2	2
2			2	2.5	2.5	3	3	4	4.5	5	5.5	6	6.5	7.5	8	8.5
2.5		3.5	3.5	4.7	4.7	5.9	5.9	7.1	8.3	9.5	10	11	13	14	15	16
3		4.1	4.1	5.5	5.5	6.9	6.9	9.7	11	13	13	17	20	21	22	25
3.5			6.3	6.3	7.9	9.5	9.5	13	16	19	22	24	27	30	34	37
4				8.9	11	13	13	16	20	23	26	29	32	36	40	43
4.5						17	18	24	26	30	35	40	44	48	52	58

Table 8. Stability Criteria ($M_{GZ} \geq M_{KR}$) of a Long Boat on the Mahakam River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1								0.4	0.4	0.4	0.4	0.4	0.7	0.7	0.7	1
1.5	0.6	0.6	1	1	1	1.4	1.4	1.8	1.8	2.2	2.2	2.6	3	3	3.4	3.4
2	1.7	1.7	1.7	1.7	2.2	2.2	2.2	3.2	3.2	4.2	5.2	5.2	5.2	6.2	7.2	7.2
2.5		1.5	2.7	2.7	3.9	3.9	5.1	5.1	6.3	6.3	7.5	8.7	9.9	11	12	14
3			3.4	3.4	4.8	4.8	6.3	7.7	9.1	11	12	13	15	18	19	20
3.5				5.5	7.2	7.2	8.8	10	10	14	17	20	23	26	30	33
4					8.1	8.1	9.9	12	14	17	21	24	28	32	35	39
4.5						13	15	19	23	27	31	35	39	43	47	51

Table 9. Stability Criteria ($M_{GZ} \geq M_{KR}$) of a Ketek Boat on the Musi River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1											0.5	0.5	0.5	0.5	0.5	0.4
1.5			0.7	0.7	0.7	0.7	1.1	1.1	1.5	1.5	1.9	1.9	2.3	2.3	2.7	2.7

2			2	2	2.5	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.2
2.5				4.2	4.8	5.4	6	6.6	7.8	9	9.6	11	11	13	14	14
3					6.6	6.6	8	9.4	12	14	15	16	18	19	22	24
3.5						9.2	11	12	16	19	22	24	25	27	30	32
4							14	16	18	23	25	27	30	32	34	37
4.5								22	26	28	32	34	36	42	46	47

Table 10. Stability Criteria ($M_{GZ} \geq M_{KR}$) of a Long Boat on the Musi River (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1									0.6	0.6	0.6	0.6	0.9	0.9	0.9	0.9
1.5		0.8	0.8	0.8	1.2	1.2	1.2	1.6	1.6	2	2.4	2.4	2.8	3.2	3.2	3.2
2	1	1	1.6	1.5	2.1	2.6	2.6	3.6	4.6	4.6	5.6	6.6	7.1	7.6	8.6	8.6
2.5	1.3	1.3	1.9	1.9	2.5	3.1	3.1	4.3	5.5	5.5	6.7	7.9	9.1	9.1	10	12
3		2.2	2.2	2.2	3.6	3.6	3.6	5	6.4	7.8	9.2	11	12	14	16	18
3.5			2.6	4.2	5.8	5.8	5.8	7.4	9	11	12	14	15	19	20	22
4				4.7	6.5	8.3	10	12	14	16	19	21	23	26	30	34
4.5					9.2	11	15	17	21	25	29	31	35	37	41	45

Table 11. Stability Criteria ($M_{GZ} \geq M_{KR}$) of a Trimaran Boat on the Matano Lake (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1		0.4	0.4	0.4	0.4	0.4	0.7	0.7	0.7	1	1	1	1.3	1.3	1.3	1.6
1.5	1	1	1	1	1	1.8	1.8	1.8	2.6	3	3	3.4	3.8	4.2	4.6	4.5
2	1.2	1.2	1.2	2.2	2.2	3.3	3.3	4.3	4.3	4.2	5.3	6.3	7.3	8.3	9.3	10
2.5	1.5	1.5	1.5	2.7	2.7	3.9	3.9	5.1	5.1	6.3	7.5	8.7	9.9	9.9	11	12
3		3.2	4.6	6	6	7.4	8.1	9.5	10	12	13	14	16	17	19	19
3.5			5.2	6.8	6.8	10	10	12	13	16	19	20	23	25	25	25
4				7.7	7.7	11	11	15	17	19	22	26	28	31	33	37
4.5					13	17	19	23	27	30	34	37	40	44	47	50

Table 12. Stability Criteria ($M_{GZ} \geq M_{KR}$) of a Catamaran Boat on The Matano Lake (kN.m)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1								10	10	11	12	13	14	15	16	16
1.5									13	14	15	17	18	19	20	20
2									17	18	19	20	22	23	24	24
2.5										23	25	26	27	30	31	31
3										30	31	32	34	35	36	36

3.5											36	38	39	41	42	42
4											43	45	47	48	50	51
4.5											55	56	58	60	61	61

3.3 Criteria of Passengers Number

Based on the analysis of stability criteria with the condition $M_{GZ} \geq M_{KR}$, further filtering was conducted to determine the passenger capacity allowed on the boat. This filtering was done by considering the area requirements explained in subsection 2.5. The analysis showed a reduction in the moment due to passengers on the boat, which determines the minimum number of passengers that can board the boat without compromising its stability. The results of this analysis are presented in detail in Tables 13 to 18 below.

Table 13. Passenger Number of a Speed Boat on the Indragiri River (People)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1																
1.5					1	1	1	1	2	2	2	3	3	3	4	4
2			3	4	4	5	5	7	8	9	10	11	12	14	15	16
2.5		4	4	6	6	8	8	10	12	14	16	18	20	22	24	26
3		4	4	6	6	8	8	12	14	16	18	22	26	28	30	34
3.5			6	6	8	10	10	14	18	22	26	28	32	36	40	44
4				8	10	12	12	16	20	24	28	30	34	38	42	46
4.5						16	16	22	24	28	34	38	42	46	50	56

Table 14. Passenger number of a long boat on the Mahakam River (People)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1								1	1	1	1	1	2	2	2	3
1.5	1	1	2	2	2	3	3	4	4	5	5	6	7	7	8	8
2	3	3	3	3	4	4	4	6	6	8	10	10	10	12	14	14
2.5		2	4	4	6	6	8	8	10	10	12	14	16	18	20	22
3			4	4	6	6	8	10	12	14	16	18	20	24	26	28
3.5				6	8	8	10	12	12	16	20	24	28	32	36	40
4					8	8	10	12	14	18	22	26	30	34	38	42
4.5						12	14	18	22	26	30	34	38	42	46	50

Table 15. Passenger number of ketek boat on the Musi River (People)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1														1	1	1

1.5			1	1	1	1	2	2	3	3	4	4	5	5	6	6
2			3	3	4	4	5	6	7	8	9	10	11	12	13	14
2.5				6	7	8	9	10	12	14	15	17	18	20	22	23
3					8	8	10	12	16	18	20	22	24	26	30	33
3.5						10	12	14	18	22	26	28	30	32	36	40
4							14	16	18	24	26	28	32	34	36	40
4.5								20	24	26	30	32	34	40	44	46

Table 16. Passenger Number of a Long Boat on the Musi River (People)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1									1	1	1	1	2	2	2	2
1.5		1	1	1	2	2	2	3	3	4	5	5	6	7	7	7
2	1	1	2	2	3	4	4	6	8	8	10	12	13	14	16	16
2.5	1	1	2	2	3	4	4	6	8	8	10	12	14	14	16	18
3		2	2	2	4	4	4	6	8	10	12	14	16	18	22	24
3.5			2	4	6	6	6	8	10	12	14	16	18	22	24	26
4				4	6	8	10	12	14	16	20	22	24	28	32	36
4.5					8	10	14	16	20	24	28	30	34	36	40	44

Table 17. Passenger Number of a Trimaran Boat on the Matano Lake (People)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1		1	1	1	1	1	2	2	2	3	3	3	4	4	4	5
1.5	2	2	2	2	2	4	4	4	6	7	7	8	9	10	11	11
2	2	2	2	4	4	6	6	8	8	8	10	12	14	16	18	20
2.5	2	2	2	4	4	6	6	8	8	10	12	14	16	16	18	20
3		4	6	8	8	10	11	13	14	16	18	20	22	24	26	27
3.5			6	8	8	12	12	14	16	20	23	25	28	30	31	31
4				8	8	12	12	16	18	20	24	28	30	34	36	40
4.5					12	16	18	22	26	29	33	36	39	43	46	49

Table 18. Passenger Number of a Catamaran Boat on the Matano Lake (People)

Breadth (m)	**Length (m)**															
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1								9	9	10	11	12	13	14	15	16
1.5									11	12	13	14	15	16	17	18
2									13	14	15	16	17	18	19	20
2.5										17	18	19	20	22	23	24

3										20	21	22	23	24	25	26
3.5											23	24	25	26	27	28
4											26	27	28	29	30	32
4.5											31	32	33	34	35	36

3.4 Discussion

From the analysis of the boat's stability moment, it was observed that a speed boat with a length of 15 meters and a width of 4.5 meters has the highest stability moment, reaching 134.7 kN.m. This indicates that the speed boat demonstrates the most significant resistance to tipping or capsizing under these dimensions. In contrast, the analysis also revealed that a trimaran boat with the same length and width has the lowest stability moment, recorded at 62.0 kN.m, suggesting a lower resistance to external forces than the speed boat. However, despite having the lowest stability moment, the trimaran boat offers the largest usable area, fulfilling almost all spatial requirements under various conditions, making it advantageous for space utilization. Meanwhile, the boat with the lowest area moment is the catamaran boat, which, although it may not provide as much usable area as the trimaran, still balances stability and space depending on the specific design and operational needs. This comparison highlights the trade-offs between stability and usable area across different boat types.

In contrast to the analysis of the boat's stability moment, the analysis of turning and passenger stability moments shows that, for a boat with a length of 15 meters and a width of 4.5 meters, the trimaran has the highest moment at 60.7 kN.m. Meanwhile, a long boat with the exact dimensions has the lowest moment, recorded at 45.3 kN.m. Despite having the highest moment, the trimaran offers the largest usable area, fulfilling almost all conditions across various scenarios. On the other hand, the boat with the lowest area moment is the catamaran. However, when considering the turning and passenger stability moments, there is almost no significant difference in the usable area after applying the stability criteria. This indicates that the area remains relatively consistent across different boat types under these conditions.

This is different again from the analysis of passenger capacity criteria, which shows that for a boat with a length of 15 meters and a width of 4.5 meters, the speed boat accommodates the highest number of passengers, reaching 56 people. Meanwhile, the passenger capacity criteria indicate that the catamaran boat has the lowest capacity under the exact dimensions, accommodating only 36 people. However, the long boat offers the largest passenger area, fulfilling almost all conditions across various scenarios. On the other hand, the boat with the lowest area moment is the catamaran. Additionally, when considering the stability moments for turning and passenger capacity, there is almost no significant difference in the usable area after applying the stability criteria, indicating consistent results across different boat types under these conditions.

4 Conclusion

In conclusion, the analysis of various boat types with a length of 15 meters and a width of 4.5 meters highlights the trade-offs between stability, usable area, and passenger capacity. The speed boat demonstrates the highest stability moment at 134.7 kN.m, indicating superior resistance to tipping or capsizing, while the trimaran has the lowest stability moment at 62.0 kN.m. Despite this, the trimaran offers the largest usable area, making it advantageous for space utilization. In contrast, the catamaran has the lowest area moment but balances stability and space depending on specific needs. For turning and passenger stability moments, the trimaran achieves the highest moment at 60.7 kN.m, while the long boat records the lowest at 45.3 kN.m. However, after applying stability criteria, the usable area remains relatively consistent across boat types. Passenger capacity: the speed boat accommodates the highest number of passengers at 56, while the catamaran has the lowest capacity at 36. The long boat, however, offers the largest passenger area, fulfilling most spatial requirements. These findings emphasize the importance of selecting a boat type based on the intended operational priorities, whether it be stability, space, or passenger capacity, as each design presents unique advantages and limitations.

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