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# Digitalization Technology in Capture Fisheries: A Pilot Study of Its Effects on Operational Efficiency and Environmental Sustainability

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**Abstract**

Background: Digital technologies are increasingly proposed to improve fisheries management, but empirical evidence from small-scale capture fisheries in developing countries remains limited.
Objective: This pilot study examines the implementation of a digitalization system (IoT sensors, e-logbook, AI-based analytics) and evaluates its preliminary effects on operational efficiency and environmental sustainability.
Methods: A mixed-method, pre-post intervention design without a control group was used. The system was deployed on seven fishing vessels in Gorontalo, Indonesia, over 12 months. Quantitative data (fuel consumption, bycatch, CPUE) were analyzed using paired t-tests and mixed-effects models. Qualitative data from interviews were analyzed thematically.
Results: Indicative reductions in fuel consumption (16.8%, 95% CI: -22.1 to -11.5, p=0.03) and bycatch (13.9%, 95% CI: -19.2 to -8.6, p=0.04) were observed. CPUE increased by 22% but was not statistically significant (p=0.07). Qualitative findings revealed perceived fuel savings but also technical maintenance challenges.
Conclusion: The findings are exploratory and should not be generalized. Larger-scale validation with control groups is needed. The study offers a replicable pilot framework.
**Key Words:** Digitalization, Capture Fisheries, Sustainability, Lot, Pilot Study, Gorontalo

## 1. Introduction

The capture fisheries sector is a cornerstone of food security and the coastal economy in Indonesia, contributing 12.5% to the Gross Regional Domestic Product (GRDP) of provinces like Gorontalo and employing over 85,000 people (BPS, 2023). However, it faces critical challenges, including overfishing, climate change, and unsustainable fishing practices (Lukambagire et al., 2023). Simultaneously, the rapid development of digital technologies presents a significant opportunity for transformation. Digitalization, through the integration of the Internet of Things (IoT), electronic logbooks (e-logbook), artificial intelligence (AI), and blockchain, offers a pathway to increase operational efficiency, provide real-time data for evidence-based policy, and enhance traceability (Li et al., 2021; Rahman et al., 2022; Rowan, 2022).

The capture fisheries sector is a cornerstone of food security and coastal livelihoods in Indonesia. However, it faces critical challenges including overfishing, climate change, and unsustainable practices (Lukambagire et al., 2023). Digital technologies such as the Internet of Things (IoT), electronic logbooks (e-logbooks), artificial intelligence

(AI), and blockchain have been proposed as tools to improve efficiency and transparency (Li et al., 2021; Rowan, 2022). Nevertheless, most existing studies remain conceptual or focused on aquaculture, with limited empirical research on small-scale capture fisheries in developing countries.

This study is grounded in **Sociotechnical Systems Theory** (Trist & Bamforth, 1951), which emphasizes the interdependence of social and technical elements in technology adoption, and the **Technology Acceptance Model (TAM)** (Davis, 1989), which explains user perceptions of usefulness and ease of use. These frameworks guide the investigation of how digital tools interact with local practices, skills, and infrastructure.

The research gap addressed here is not merely contextual (low adoption in Indonesia) but conceptual: few studies have empirically tested integrated digital systems in real-world small-scale capture fisheries using a mixed-method approach. Therefore, this study addresses the following focused research questions:

1. What are the measurable changes in fuel efficiency, bycatch rate, and catch per unit effort (CPUE) following the introduction of a digitalization system in a pilot fishing fleet?

2. How do fishermen perceive the usability, benefits, and challenges of the system?

By answering these questions, the study aims to provide an exploratory, replicable framework for digital adoption in coastal communities, while explicitly acknowledging the limitations of a pilot-scale intervention.2. Methodology

**2.1 Research Design and Location**

This applied research employed a mixed-method, pre-post intervention design **without a control group**, which limits causal inference. The study is exploratory and pilot-scale. It was conducted over 12 months (2025) in three coastal locations in Gorontalo Province, Indonesia: Kabupaten Boalemo, Kabupaten Bone Bolango, and Kota Gorontalo.

**Kabupaten Boalemo :** A region with 5,250 fishermen and a fish potential of 150,000 tons/year, dominated by gillnet and handline fishing gears.

1. **Kabupaten Bone Bolango :** A region with 4,800 fishermen and a fish potential of 120,000 tons/year, dominated by traps and bag nets.

2. **Kota Gorontalo :** A region with 3,500 fishermen and a fish potential of 80,000 tons/year, dominated by purse seine and handline fishing gears (BPS, 2023; DKP, 2023).

**2.2 Sample and Intervention**

The study involved **seven fishing vessels** (purse seine, longline, gillnet) selected purposively based on vessel owner willingness and local government support. A control group was not feasible due to budget and logistical constraints. The digitalization system installed on all vessels consisted of:

- IoT sensors and GPS trackers for monitoring vessel position, fuel consumption, and environmental parameters.

- Mobile e-logbook application for real-time recording of catch (species, volume), fishing effort, and bycatch.

- AI-based analytics dashboard using a convolutional neural network (CNN) trained on 5,000 labeled fish images (85% pre-deployment accuracy). Real-time validation was conducted weekly by onboard observers.

**2.3 Intervention and Technology Implementation**

**2.3 Data Collection**

Data were collected through: baseline survey (month 1–2), real-time monitoring (month 3–10), biological sampling, semi-structured interviews with fishermen from each vessel (n=7) at months 4 and 9, and drone imagery for habitat assessment.

**2.4 Data Collection**

Quantitative data were analyzed using R and SPSS. Pre-post differences were tested using paired t-tests and mixed-effects models (vessel as random effect). Effect sizes and 95% confidence intervals are reported. Qualitative data were analyzed thematically using NVivo.

**2.5 Methodological Limitations Acknowledged**

- Small sample size (n=7) and lack of control group.
- Short intervention period (10 months of active monitoring).

- Possible confounding factors (seasonality, fuel price changes).
- Limited generalizability beyond similar small-scale contexts.

**Qualitative Data:** Transcribed interviews and FGDs were analyzed using NVivo software for thematic analysis to understand technology adoption barriers and social impacts.

## 3. Results

### 3.1 Profile of Fishermen and Fishing Operations in Gorontalo

Baseline data from Gorontalo (DKP, 2023; BPS, 2023) revealed a region with significant fisheries potential but facing technological challenges. Key findings are summarized in Table 1.

## 3. Results

### 3.1 Quantitative Findings (Indicative)

Table 1. Key performance indicators before and after technology implementation (n=7 vessels)

| Indicator | Baseline (mean) | Post-intervention (mean) | Change | 95% CI | p-value |
|---|---|---|---|---|---|
| Fuel consumption (L/trip) | 250 | 208 | ↓ 16.8% | [-22.1, -11.5] | 0.03 |
| Bycatch rate (%) | 18.0 | 15.5 | ↓ 13.9% | [-19.2, -8.6] | 0.04 |
| CPUE (kg/trip) | 350 | 427 | ↑ 22.0% | [8.5, 35.5] | 0.07 |

*Note: Results are associational, not causal, due to study design. CPUE change was not statistically significant at $\alpha=0.05$.

### 3.2 Qualitative Findings

Thematic analysis of seven interviews revealed four major themes: operational efficiency (38 references), economic impact (35), technical challenges (30), and sustainability awareness (28). Fishermen reported perceived fuel savings and reduced search time but expressed concerns about maintenance costs and lack of local technical support. Representative quotes are provided in Table 2.

Table 2. Major themes from thematic analysis

| Theme | Key sub-themes | Representative quote |
|---|---|---|
| Operational efficiency | Route optimization, fuel savings | "We can save 20% on fuel because we no longer go around in circles" (KPL-02) |
| Technical challenges | Maintenance, skill gaps | "If it breaks, it's hard to find a technician" (KPL-04) |

Cross-tabulation analysis showed that larger vessels (GT > 30) like trawls and longliners had higher adoption rates, while smaller vessels like gillnets faced greater barriers related to both cost and skill.

### 3.3 Spatial Analysis of Fishing Effort

QGIS analysis of GPS data from the 7 respondent vessels showed a more concentrated and efficient spatial distribution of fishing effort post-intervention. The implementation of the digital system, supported by local regulations such as the Governor's Decree on Fishing Zone Allocation, helped vessels reduce overlap with critical habitats (e.g., coral reefs, seagrass beds) and avoid marine protected areas like the Suaka Perikanan Teluk Tomini.

## 4. DISCUSSION

### 4.1 Interpretation of Findings

The observed reductions in fuel consumption (16.8%) and bycatch (13.9%) are consistent with prior studies (Huang & Khabusi, 2025; Mustapha et al., 2021) but should be viewed as **associational rather than causal** due to the lack of a control group. The CPUE increase (22%) was not statistically significant, possibly because of high inter-vessel variability, short monitoring period, or confounding seasonal effects.

**4.2 Critical Reflection and Alternative Explanations**

Seasonal fish abundance and fluctuations in fuel prices may have contributed to the observed changes. The Hawthorne effect cannot be ruled out. The lack of a control group precludes attributing the improvements solely to the digital intervention.

**4.3 Risks and Challenges of Digitalization**

- **Technological dependency:** Fishermen may become overly reliant on digital tools without backup analog methods.
- **Digital inequality:** Smaller vessels and older fishermen faced greater adoption barriers.
- **Maintenance infrastructure:** Absence of local technicians increases downtime and costs.

**4.4 Policy Implications**

- Establish local technical support hubs in each fishing district.
- Introduce subsidized maintenance contracts for small-scale vessels.
- Integrate digital literacy into existing fisheries extension programs.
- Develop low-cost, open-source hardware to reduce entry barriers.

This research demonstrates that the implementation of an integrated digital system (IoT, AI, e-logbook) in capture fisheries yields substantial benefits across economic, ecological, and social dimensions, aligning with the findings of global studies.

The 15-18% reduction in fuel consumption supports the conclusions of studies on AIoT applications in aquaculture, which highlight the potential for optimizing operations through data-driven decision-making (Huang & Khabusi, 2025; Nayoun et al., 2024). This efficiency is crucial in regions like Gorontalo, where fuel costs are a major operational expense. Similarly, the 12-15% reduction in bycatch validates the use of AI for real-time species identification and habitat mapping, enabling more selective fishing and contributing to the goals of local conservation programs like the Gorontalo Marine Conservation Area (Ebrahimi et al., 2021; Mustapha et al., 2021).

The increase in CPUE (22%) and the 18-month ROI period underscore the economic viability of the technology, echoing the findings of Rather et al. (2024) on the productivity gains from AI tools. The high accuracy of the AI model in species identification (92.5%) and the predictive analytics for fishing grounds contribute directly to improved productivity and reduced waste, as noted by Tina et al. (2025). The economic benefits are further supported by the qualitative data, where fishermen (KPL-05) explicitly mentioned the return on investment from fuel savings.

From a sustainability perspective, the system's ability to provide real-time data on fish stocks, fishing effort, and ecosystem health facilitates a shift from reactive to proactive management. This addresses the concerns raised by Lukambagire et al. (2023) regarding the need for data analytics to support sustainable fisheries. The use of blockchain principles for traceability, as suggested by Pratiwi et al. (2024) and Ismail et al. (2023), can be a future extension to further combat IUU fishing and build consumer trust, aligning with the region's potential for ecolabel certification (DKP, 2023).

However, the study also identified persistent challenges. The high initial cost and the need for specialized technical support, as highlighted by Ramanathan et al. (2023) and Senoo et al. (2024), remain significant barriers to widespread adoption. This is particularly relevant in Gorontalo, where 70% of fishermen still use traditional gear (DKP, 2023). This underscores the need for government subsidies, the development of a local technical support network, and the creation of low-cost, robust hardware (Flores-Iwasaki et al., 2025). The local government's existing programs, such as the Minapolitan development and the CPIB certification program, provide a strong foundation for integrating these new digital initiatives.

The qualitative findings from NVivo analysis are critical. The fishermen's concerns about maintenance (KPL-04) and skills emphasize that technology transfer must be accompanied by comprehensive, ongoing training and capacity building, as argued by Shehzad et al. (2025). The success of the pilot, with an 85% adoption rate, confirms that a participatory, co-design approach is essential for user acceptance, building on the principles of inclusive engagement highlighted by Mannayong et al. (2024).

## 5. Conclusion

This pilot study provides preliminary, indicative evidence that digitalization technologies may contribute to operational and environmental improvements in small-scale capture fisheries. However, due to the **small sample size (n=7), lack of a control group, and short intervention period**, findings should not be generalized. The study does **not** claim to have validated a commercial-ready model. Instead, it offers a replicable pilot framework and identifies key barriers and enablers for future research.

**Future research directions:**

- Larger-scale randomized controlled trials with control groups.
- Longitudinal studies to assess long-term sustainability impacts.
- Cost-benefit analyses that include maintenance, training, and infrastructure.
- Integration with existing national fisheries monitoring systems

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