JURNAL OPTIMALISASI
Teknik Industri
Journal homepage : http://jurnal.utu.ac.id/joptimalisasi
E - ISSN - 2502 - 0501
P - ISSN - 2477 - 5479

Farmer-Perceived Seaweed Quality Risks and Expert Mitigation Preferences in Bulukumba: A Sequential FMEA–AHP Case Study

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ARTICLE INFO

Received: 25-10-2026
Revision: 12-11-2026
Accepted: 17-11-2026

Keywords:
Failure Mode and Effects Analysis
Analytic Hierarchy Process
Seaweed quality
Risk prioritization
South Sulawesi

ABSTRACT

Quality risks in smallholder seaweed production are often prioritized from judgments rather than direct measurements. This exploratory case study assessed five questionnaire-defined quality-risk factors in Babana Hamlet, Bulukumba, using data from 37 farmers (33 active and 4 experienced but temporarily inactive) surveyed during March–June 2026. Each farmer rated severity, occurrence, and detection for five factors (185 assessments). We audited the recorded Risk Priority Numbers (RPNs) and compared the pooled mean, median, and interquartile range (IQR) summaries with an active-only analysis. Mean RPNs were highest for nutrient limitation (304.62) and salinity instability (262.14), followed by sudden weather change during drying (133.70), suspected but undetected disease symptoms (96.68), and sediment resuspension-induced turbidity (92.19). All 185 final RPNs matched their component products; pooled IQRs were 441 and 540 for the two highest-ranked factors. Excluding four temporarily inactive respondents preserved all mean-based ranks but changed median-based ordering. Two agricultural office assessors independently ranked three mitigation alternatives using the Analytic Hierarchy Process (AHP); both preferred collaboration with experts and research institutions (descriptive mean weight: 0.69). The two methods were interpreted sequentially, without a quantified link between risk and intervention effectiveness. These findings reflect local perceptions and expert preferences, not measured water conditions or tested mitigation. They offer Bulukumba agencies a basis for piloting shared water-quality diagnostics.

1. INTRODUCTION

Smallholder farms underpin much of Indonesia's seaweed production, where decisions during cultivation and early handling can affect product consistency. A recent review identifies continuing challenges in eucheumatoid cultivation and industry development [1]. In Takalar, South Sulawesi, an observational study examined links between farmers' risk-management practices and production [2]. Research elsewhere in the province has measured monsoon-related variation in water conditions, seaweed growth, and color [3]. These studies place local quality-risk assessments at the intersection of environmental conditions and farm decisions.

Quality concerns continue after harvest. Open-air drying can expose the crop to changing weather, while farmers must decide whether alternative drying technologies are worth adopting [4]. Seaweed value chain research has also mapped potential food and environmental safety hazards [5], and biosecurity remains a management concern in Indonesia [6]. The practical question is therefore which locally perceived conditions warrant attention first-not whether one hazard explains every quality problem.

Seaweed risk studies have used fuzzy FMEA in Sabah [7], House of Risk in Jeneponto [8], and other combinations of FMEA or fuzzy AHP for supply-chain decisions [9], [10]. The Babana setting also has direct precedents: a 2022 study examined product-quality specifications [11], and a 2023 macroergonomic analysis identified rain-related disruptions to drying and proposed supply-chain responses [12]. The current study does not introduce FMEA or seaweed risk research to Babana for the first time. Rather, it asks whether five farmer-rated conditions retain their priority when their RPN distributions and respondent composition are examined, and how separately assessed mitigation preferences can be interpreted without claiming a measured risk–action link.

FMEA converts severity, occurrence, and detection ratings into a product used for prioritization, and hybrid variants are common in agricultural decision support [13], [14]. However, the ordinal properties of these scales limit what the product can mean: a methodological validity study questioned the arithmetic interpretation of the product of scores [15]. At the same time, subsequent engineering research has explored alternative approaches to RPN prioritization [16]. AHP weights capture preferences over options, not the expected risk reduction from those options. These differences motivate a transparent sequential reading of FMEA and AHP rather than an effectiveness model.

Against that background, we used farmer ratings to describe five quality-risk priorities and a separate AHP exercise to describe three mitigation preferences. The analysis followed three objectives:

(1) identify and prioritize the five factors from farmer-reported severity, occurrence, and detection ratings
(2) audit respondent-level RPN calculations and assess rank sensitivity to summary statistics and respondent composition
(3) determine the relative preferences of two AHP assessors among three mitigation alternatives using AHP while keeping perceived risk priority separate from demonstrated mitigation effectiveness.

The contribution is specific: a reproducible arithmetic check of 185 farmer RPNs, a description of their dispersion and rank sensitivity, and separate reporting of two assessors' mitigation preferences. The study does not propose a new decision algorithm or establish that any intervention is effective.

2. RESEARCH METHOD

2.1 Study design and setting

An exploratory cross-sectional case study was conducted in Babana Hamlet, Bulukumba Regency, South Sulawesi, Indonesia. Babana was selected as one of the regency's potential seaweed-producing communities, as described in an earlier local study of seaweed product-quality requirements [11]; the site was not selected as a statistically representative location. We collected field data from March to June 2026. Farmers cultivated cottonii seaweed, locally reported as Kappaphycus alvarezii, using conventional floating long-line practices. The species designation followed local commercial records; no morphological, molecular, or laboratory-based taxonomic verification was performed.

The analysis had two descriptive stages. FMEA summarized farmer-assigned risk priorities, and AHP summarized two assessors' preferences among the proposed responses. No effectiveness scores linked individual FMEA risks to AHP alternatives, so the outputs were not mathematically combined.

2.2 Participants and questionnaire administration

Administrative records listed 228 registered seaweed farmers, and the original recruitment target was 37 respondents. During fieldwork, all 33 farmers engaged in cultivation or primary post-harvest activities were approached, and four experienced but temporarily inactive farmers (coded R34-R37 in the de-identified dataset) were purposively added to provide experience-based judgments. All 37 completed the questionnaire. Because retrospective judgments may differ from contemporaneous experience, respondent-composition sensitivity was examined by comparing the 37-person sample with the 33 currently active farmers. Recall-related error and selection bias cannot be excluded, and the nonprobability sample is not statistically representative of all 228 registered farmers.

Before the farmer questionnaire, five risk indicators were determined by two personnel from the Bulukumba Regency agriculture office. This instrument-development function was separate from the subsequent AHP assessment stage; the available record does not establish whether the same individuals participated in both stages. The researcher administered the questionnaire individually in Bahasa Indonesia. It covered sudden changes in weather during open-air drying, nutrient limitation, salinity instability, sediment resuspension-induced turbidity, and suspected but undetected disease symptoms. These questionnaire-defined factors are not equivalent formal failure modes because they represent different conceptual levels; the disease item was not laboratory-confirmed. The indicator-selection step does not establish formal content validity; no quantitative content-validity coefficient was reported.

2.3 FMEA calculation, arithmetic audit, and ranking sensitivity

Each respondent rated the five factors on 1–10 scales for severity (S), occurrence (O), and detection (D), yielding 185 respondent–risk-factor assessments. For each assessment, the conventional Risk Priority Number was calculated as RPN = S × O × D. In this study, the RPN served only as a local prioritization index and was not interpreted as an objective probability, biological prevalence, or quantified economic loss.

Each respondent–factor RPN was recalculated as S × O × D and compared with the submitted value. For each factor, we summarized the 37 RPNs using the mean, median, maximum, sample standard deviation, and interquartile range (IQR = Q3 − Q1; inclusive quartiles computed as in Excel's QUARTILE.INC). Mean- and median-based rankings were compared,

and the same calculations were repeated for active farmers after excluding R34–R37. This composition sensitivity analysis was descriptive; it was not a test for the absence of recall bias. No inferential population estimates were calculated.

2.4 AHP assessment and sequential interpretation

Two assessors affiliated with the Bulukumba Regency agriculture office completed AHP pairwise comparisons separately. AHP-01 brought longstanding experience in seaweed research and cultivation, while AHP-02 focused on general agriculture and local farming conditions. Their professional perspectives differed, but both worked within the same institution; neither claimed institutional independence. The available records did not establish whether either assessor had also helped select the initial FMEA indicators. They compared three alternatives:

(1) routine water-quality monitoring combined with environmentally friendly organic fertilizer
(2) collaboration with experts and research institutions
(3) improved cultivation practices involving crop rotation and appropriate spacing.

Pairwise comparisons used the conventional 1–9 AHP scale. Priority vectors were derived from the normalized pairwise matrices, and judgment consistency was evaluated using the Consistency Index and Consistency Ratio (CR). A CR of 0.10 or lower was treated as internally consistent [17].

Priority weights and consistency ratios were reported for each assessor; the arithmetic means were used only to summarize their preferences. A CR below 0.10 indicates internally consistent judgments but does not establish expertise or mitigation effectiveness [17]. The original pairwise comparisons were not available in the study materials used for verification, so the reported weights and CRs could not be recalculated independently. FMEA priorities and AHP preferences were therefore presented separately, without a scored risk–intervention-effectiveness matrix, cost analysis, or an intervention trial.

Table 1. Study design and analytical sequence.

Component	***Operationalization***
Design	Exploratory cross-sectional case study
Setting	Babana Hamlet, Bulukumba Regency, South Sulawesi; March–June 2026
Farmer respondents	37: 33 active (R01-R33) + 4 experienced temporarily inactive (R34-R37)
FMEA evidence	5 factors × 37 respondents = 185 S–O–D assessments
FMEA outputs	Audited RPN; mean, median, maximum, SD, IQR; pooled and active-only rank sensitivity
AHP evidence	2 AHP assessors from Bulukumba agriculture office; seaweed vs general agriculture focus; 3 alternatives
AHP outputs	Assessor-specific weights and CR; descriptive mean weight
Analytical boundary	Sequential interpretation; no mathematical FMEA–AHP integration

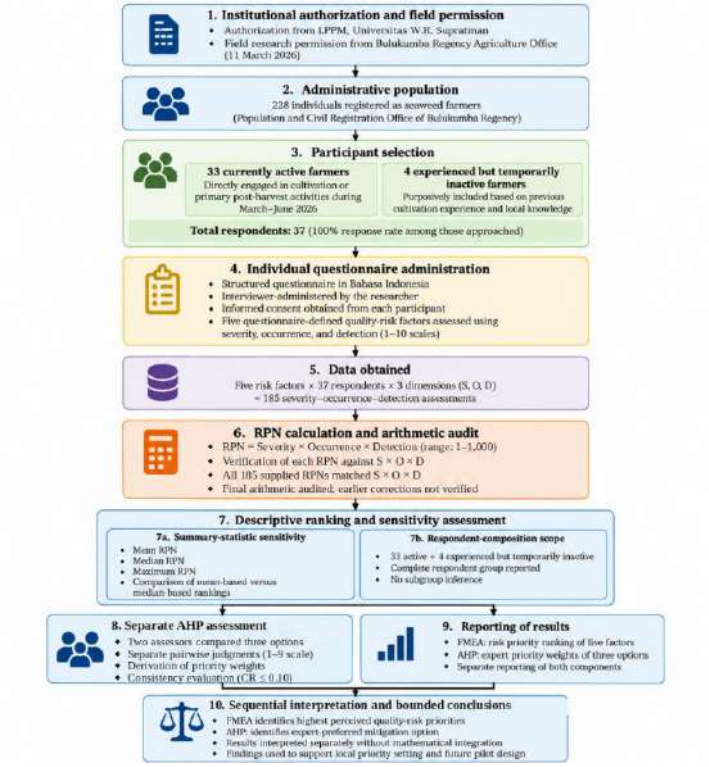

Figure 1. *Study sequence: farmer FMEA and assessor AHP produce separate descriptive priorities; the active-only sensitivity check does not link risks quantitatively to mitigation effectiveness.*

2.5 Authorization, consent, software, and evidence boundary

Before fieldwork, the study received institutional authorization from the Institute for Research and Community Service (LPPM) at Universitas W.R. Supratman Surabaya and administrative permission from the Bulukumba Regency Agriculture Office. Participants were informed about the study procedures, voluntary participation, and confidentiality, and written informed consent was obtained before questionnaire administration. These documents are reported as institutional and administrative authorizations; they are not described as formal research-ethics approval unless the competent body separately confirms that status.

Microsoft Excel 2021 was used for data entry, RPN checking, descriptive summaries, AHP calculations, and consistency assessment. The study did not collect objective measurements of salinity, nutrient concentration, temperature, dissolved oxygen, turbidity, disease prevalence, product moisture, contamination, rejected volume, processing yield, price, downstream loss, or realized risk reduction. These variables therefore fall outside the empirical evidence reported in this article.

3. RESULTS

3.1 Participant composition and arithmetic validation

Of the 37 respondents, 33 were active farmers (R01–R33; 89.19%), and four had temporarily stopped farming (R34–R37; 10.81%). Ages ranged from 18 to 61 years (mean 40.30, SD 12.38; median 42); 20 respondents were men, and 17 were women. All 185 S–O–D assessments were complete.

All 185 respondent–factor records in the final dataset were arithmetically consistent: each RPN equaled S × O × D, and factor totals reproduced the reported means, medians, and maxima. This confirms arithmetic consistency, not the validity of RPN as a cardinal risk measure. Because the underlying severity, occurrence, and detection ratings are ordinal, methodological research has questioned the interpretation of their products [15]. We therefore treated RPNs as local relative-priority indices rather than estimates of actual environmental or economic losses.

3.2 Perceived risk priorities and ranking sensitivity

Nutrient limitation led the pooled mean RPN ranking (304.62), followed by salinity instability (262.14) and weather changes during drying (133.70). Suspected disease symptoms (96.68) and turbidity (92.19) formed the lower pair. In that order, their IQRs were 441, 540, 234, 124, and 79. Every mean was higher than its median, and the top three ranks were identical under the two summaries. The two lower-ranked factors exchanged fourth and fifth places when medians rather than means were used.

Table 2. Audited RPN summaries and ranking sensitivity.

Questionnaire-defined quality-risk factor	*Mean RPN*	*Median RPN*	*Maximum RPN*	*IQR*	*Mean rank*	Median rank
Nutrient limitation	304.62	120	900	441	1	1
Salinity instability	262.14	48	1,000	540	2	2
Sudden weather change during drying	133.70	12	630	234	3	3
Suspected but undetected disease symptoms	96.68	1	800	124	4	5
Sediment resuspension-induced turbidity	92.19	2	1,000	79	5	4

Note. IQR = Q3 − Q1, calculated from the 37 respondent-level RPNs per factor using the inclusive quartile method (Excel QUARTILE.INC). Sample SD and all 185 recalculated RPNs are provided in the audit workbook.

Among active farmers alone (n = 33), mean RPNs were 306.45, 265.45, 130.55, 108.27, and 103.21 in the Table 2 factor order; all five mean-based ranks were unchanged. Median-based ranks differed: nutrient limitation remained first (120), suspected disease symptoms rose to second (48), salinity and weather tied for third (35 each), and turbidity ranked fifth (4). Nineteen of 37 pooled disease-related RPNs equaled 1, including all four inactive farmers; removing them left 15 such values among 33, shifting the median to 48. This compositional threshold effect does not demonstrate that inactive farmers misremembered conditions.

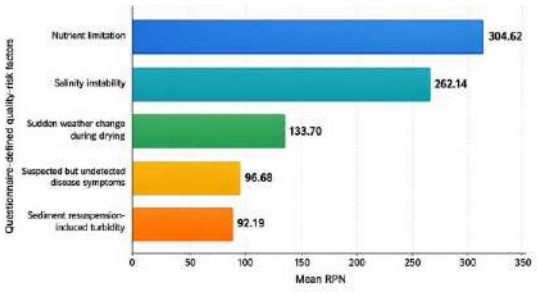

Figure 2. *Audited mean RPNs for the five questionnaire-defined seaweed quality-risk factors (n = 37). The bars summarize mean perceived priorities; dispersion is reported separately in Table 2.*

Nutrient limitation and salinity instability received the highest mean RPNs in Babana. Measurements from other Indonesian farming locations show variation in Kappaphycus alvarezii growth and product quality [18], and a study in South Sulawesi examined water conditions alongside growth and color during a monsoon shift [3]. Such field measurements make the farmers' concerns plausible topics for investigation, but they cannot verify local nutrient deficiency or unstable salinity: neither variable was measured in Babana. The RPNs establish perceived priorities, not environmental diagnoses.

Weather changes during drying ranked third among Babana farmers. Research on Indonesian smallholders treats the adoption of drying technology as an operational decision [4], whereas studies on solar drying evaluate drying performance and product attributes under specific equipment and conditions [19], [20]. These are different forms of evidence: neither an adoption analysis nor controlled dryer performance measures the losses experienced by respondents in this survey. The finding points to a potential need for post-harvest diagnostics, but drying time, moisture content, spoilage, and price penalties were not recorded here.

Suspected disease symptoms and turbidity ranked lower by mean RPN, although the disease median was sensitive to respondent composition. A study of farmers' ice-ice perceptions [21] and a review of its environmental and microbial dimensions [22] illustrate why perceived symptoms should not be treated as a laboratory diagnosis. Indonesian biosecurity research also considers disease management in the wider cultivation system [6], [23]. No pathogen testing or prevalence survey was undertaken in Babana, so the questionnaire item is interpreted only as suspected, undetected symptoms.

3.3 Expert mitigation preferences

The two AHP assessors ranked all three alternatives in the same order. Collaboration with experts and research institutions received the largest reported weights (0.75 for AHP-01 and 0.63 for AHP-02; descriptive mean 0.69). Water-quality monitoring with organic fertilizer followed (0.18 and 0.26; mean 0.22), ahead of cultivation improvements (0.07 and 0.11; mean 0.09). AHP-01 had reported $\lambda max = 3.029$, CI = 0.0145, and CR = 0.0250; the reported CR for AHP-02 was 0.0172. Both CR values were below 0.10, indicating internally consistent reported judgments and no demonstrated intervention effects.

These weights describe preferences, not measured reductions in risk. Multicriteria studies in agricultural and food supply chains compare proposed responses within their own decision structures [14], [24], [25]; they do not provide effectiveness estimates for the three Babana options. Because no local risk–alternative effectiveness matrix was elicited,

the top-ranked collaboration strategy cannot be called the most effective treatment for nutrient limitation or salinity instability.

Table 3. AHP priority weights and consistency results.

Mitigation alternative	*AHP-01*	*AHP-02*	*Descriptive mean*	*Priority*
Water-quality monitoring + organic fertilizer	0.18	0.26	0.22	2
Collaboration with experts and research institutions	0.75	0.63	0.69	1
Improved cultivation practices	0.07	0.11	0.09	3
Consistency Ratio	0.0250	0.0172	—	CR ≤ 0.10

4. DISCUSSION

4.1 Sequential interpretation and comparison with previous seaweed-risk studies

The Babana FMEA and AHP exercises address different decisions. The farmer-derived RPNs rank perceived quality-risk conditions; the two AHP assessors rank proposed responses. Fuzzy FMEA in Sabah [7] and House of Risk in Jeneponto [8] similarly work with seaweed-related risks. Still, their supply-chain units and models are not directly comparable to respondent-level RPNs. Sarinah and Djatna examined supply shortage and supplier selection in seaweed agro-industry [9], while a House of Risk–fuzzy AHP study addressed asymmetric information in the seaweed chain [10]. Those approaches illustrate alternative ways to structure decisions, not a basis for mathematically combining the two separate rankings collected here.

Earlier work in Babana specified desired characteristics of seaweed products [11]; a subsequent macroergonomic analysis highlighted rainy-season disruptions, including drying [12]. The present weather-related RPN is consistent with the local salience of post-harvest conditions, but its scale and construct differ from those earlier results. Likewise, evidence from Takalar farms [2], Bone cultivation [26], and seaweed processing businesses [27] concerns different units of analysis. None supplies a valid numerical benchmark for this single-hamlet five-factor RPN hierarchy. The findings should therefore inform local investigation rather than be generalized to South Sulawesi growers.

Farmers assigned the largest mean RPNs to nutrient limitation (304.62) and salinity instability (262.14), but AHP assessors preferred institutional collaboration (mean weight 0.69) to the monitoring-plus-organic-fertilizer option (0.22). This is not a disagreement over the same quantity: the farmers scored problem conditions, whereas the assessors compared response alternatives. Collaboration could, in principle, provide shared measurement equipment, interpretation support, and advice before technical action is selected.

Work on Indonesian smallholder drying technology shows that adoption involves operational and economic considerations [4]. Group model building in the national seaweed value chain emphasizes the value of building a shared understanding among stakeholders [28]. These studies provide context for the collaboration option but do not explain why the two assessors preferred it. The assessors' reasons, farmers' budgets, monitoring costs, and actual access to equipment were not measured. Moreover, collaboration is a broad enabling mechanism, whereas monitoring plus organic fertilizer is a specific intervention bundle. AHP weights alone cannot determine which would more effectively reduce nutrient or salinity risks.

4.2 Implications, contribution, and study boundaries

Excluding R34–R37 preserved the mean-based ranking of all five factors but changed their median-based ordering. This difference argues for reporting more than one summary statistic; it does not demonstrate that recall bias was absent. The stable leading mean priorities identify nutrient conditions, salinity variation, and drying exposure as reasonable targets for field diagnosis. Collaboration, the first-ranked AHP option, may help organize that work, although feasibility and actual effects were not assessed.

The main methodological contribution is transparency, not a new FMEA–AHP algorithm. All 185 final RPN products passed arithmetic checks, and reporting IQRs and active-only rankings exposes variation that a mean alone would obscure. This does not overcome the validity concerns associated with multiplying ordinal judgments [15], nor does it outperform alternative RPN models [16]. It shows how a smallholder case study can report both the utility and the limits of descriptive priorities when no intervention-effectiveness link is available.

These findings are limited to 37 nonprobability respondents in a single hamlet. Four were temporarily inactive; removing them preserved mean-based ranks but altered medians, so selection and recall bias remain possible. The five questionnaire factors were chosen by two agriculture office personnel without formal content validity testing and do not represent equivalent failure modes. Ordinal S–O–D ratings were multiplied into RPNs [15]. The AHP assessors had author-reported complementary expertise and provided separate judgments, but they came from the same office; formal credentials and their original pairwise matrices were not available for independent audit. The three mitigation alternatives differ in scope. No objective measurements of water quality, disease, product attributes, costs, or intervention effects were collected. These limits preclude causal claims, population generalization, and effectiveness comparisons.

5. CONCLUSION

In Babana, farmers gave the highest mean RPNs to nutrient limitation and salinity instability, followed by weather changes during drying. The leading IQRs (441 and 540) show that perceptions varied widely. Under the pooled data, mean- and median-based rankings agreed for the top three factors but reversed the bottom two. Excluding the four temporarily inactive respondents left all five mean-based ranks unchanged yet shifted the median-based positions, including suspected disease symptoms rising to second. The 185 supplied final RPNs were arithmetically consistent. These patterns support a cautious, descriptive priority assessment rather than estimates of measured environmental or production risk.

Both assessors preferred collaboration with experts and research institutions (AHP descriptive mean weight of 0.69) over monitoring of organic fertilizer (0.22) and improved cultivation practices (0.09). Their expertise covered different agricultural domains, but both belonged to the same office. The preference is not evidence of effectiveness, cost advantage, or farmer support. A sensible next test would be a joint pilot that measures nutrient and salinity conditions, checks the feasibility of shared monitoring, and compares proposed measures against baseline outcomes. Resource constraints may help explain the AHP pattern, but that explanation was not evaluated.

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