Evaluating the Effectiveness of Flood Early Warning Notifications in Mitigating Business Risk Losses Among Smes in Flood-Prone Areas

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ABSTRACT

Flood disasters remain recurring threats to business continuity and economic sustainability, particularly among Small and Medium Enterprises (SMEs) operating in vulnerable, low-lying areas of Malaysia. Although national disaster management agencies have deployed Flood Early Warning Systems (FEWS) as critical non-structural mitigation tools, their empirical effectiveness in safeguarding commercial enterprises from tangible and operational losses remains under-investigated. This study evaluates the effectiveness of flood alarm notification systems in mitigating business risk losses, specifically asset damage, operational disruption, and financial loss, among SMEs across Melaka, Negeri Sembilan, and Selangor. Drawing upon an adapted people-centered early warning framework, the research examines three core determinants: Awareness of FEWS, Trust in FEWS, and Timeliness & Communication. A quantitative survey design was employed using a self-administered questionnaire administered to SME owners and managers, stratified into enterprises with direct flood experience and those without prior flood exposure. The findings reveal that all three predictors have a strong, positive, and statistically significant relationship with early warning system effectiveness across both cohorts, with experiential exposure substantially reinforcing these associations. Timeliness and Communication emerged as the single most critical driver of system effectiveness for flood-experienced enterprises, demonstrating that actionable lead time and clear, multi-channel messaging are paramount for executing defensive asset transfers and minimizing operational downtime. In contrast, Trust serves as the primary behavioral anchor for non-experienced firms, indicating that anticipated effectiveness relies heavily on institutional credibility. A notable perception gap was identified: enterprises without flood exposure exhibit substantially lower awareness, proactive trust, and perceived utility. These results demonstrate that warning systems cannot rely solely on hydrological detection; disaster authorities must close the experience gap by implementing localized, business-focused communication strategies and proactive contingency drills to build long-term enterprise resilience.

Keywords— Flood Early Warning Systems (FEWS); Small and Medium Enterprises (SMEs); Business Risk Mitigation; Flood Awareness; Risk Communication; Business Continuity; Malaysia

INTRODUCTION

Flood disasters continue to threaten environmental, social, and economic stability across developing economies. Globally, floods are among the most frequent natural hazards, while in Malaysia the interaction of monsoon rainfall, rapid urbanisation, drainage limitations, and expanding development in low-lying areas has increased exposure to both seasonal and flash floods [1]-[3]. The December 2021 floods in Selangor illustrate the scale of

this exposure, resulting in multi-billion-ringgit losses, infrastructure damage, and disruptions to commercial activities [4], [5].

SMEs are especially vulnerable because they generally operate with smaller cash reserves, limited insurance coverage, constrained access to recovery finance, and less formalised business continuity planning than large firms [6]-[9]. Flood impacts are therefore not limited to physical damage. They also include the closure of premises, supply chain disruption, employee displacement, loss of sales, contractual delays, and recovery costs that can threaten business survival [7]-[9].

Malaysia has responded to flood risk through structural and non-structural interventions. Among the latter, FEWS operated through agencies such as the National Disaster Management Agency (NADMA), Department of Irrigation and Drainage (DID), and Malaysian Meteorological Department (MetMalaysia) are intended to provide early information that enables households and organisations to act before inundation occurs [10]-[12]. Effective warning, however, requires more than technical detection. The value of a warning depends on whether intended users know the system, trust the source, receive the message early enough, understand what it means, and can convert the message into protective action [12], [18], [19].

This human and organisational dimension is particularly important for SMEs. Previous studies indicate that warnings may fail to produce action when users have low awareness, limited confidence in issuing authorities, insufficient lead time, or messages that are too technical or poorly localised [14]-[17]. Existing disaster-risk studies also remain more developed for households and public infrastructure than for enterprise-level decision-making. Consequently, the extent to which FEWS attributes reduce perceived business risk losses among Malaysian SMEs remains insufficiently examined.

This study addresses that gap by examining three determinants: awareness of FEWS, trust in FEWS, and timeliness and communication, and their influence on the perceived effectiveness of FEWS in mitigating business risk losses. A second contribution is the comparison between SMEs with prior flood experience and those without, allowing the study to assess whether experiential exposure changes how firms perceive and respond to warning systems. Specifically, the study evaluates: (1) the level of FEWS-related awareness, trust, communication, and perceived effectiveness; (2) the relationships between the three determinants and FEWS effectiveness; and (3) the relative predictive contribution of each determinant within flood-experienced and non-experienced SME groups.

LITERATURE REVIEW

Flood Early Warning Systems and People-Centred Warning

The Sendai Framework for Disaster Risk Reduction 2015-2030 identifies multi-hazard early warning as a core component of disaster resilience [18]. People-centered early warning frameworks generally comprise four interconnected functions: risk knowledge; hazard detection, monitoring, and forecasting; warning dissemination and communication; and preparedness or response capability [12], [18], [19]. A technically accurate forecast is therefore only one part of an effective FEWS. If warning information is not trusted, understandable, timely, and actionable, its capacity to reduce losses is weakened.

In Malaysia, hydrological and meteorological monitoring is supported by DID and MetMalaysia, while warning information is disseminated through channels including official portals, broadcast media, SMS, sirens, and digital platforms [10]-[12]. For businesses, the critical issue is whether this information is sufficiently local and operational to trigger actions such as moving inventory, protecting machinery, backing up digital assets, shutting down electricity, rearranging logistics, and informing workers or suppliers.

SME Vulnerability and Business Risk Losses

Compared with large corporations, SMEs typically have lower financial reserves and fewer dedicated resources for disaster preparedness [7], [21]. Flood-related business risk can therefore be understood through three interrelated dimensions. First, asset and property damage includes damage to inventory, machinery, equipment,

premises, and information-technology infrastructure [7], [22]. Second, operational disruption includes inability to access premises, interrupted utilities, labour displacement, and supply-chain failure [4], [7]. Third, financial loss includes lost revenue, recovery expenditure, contractual default, and cash-flow pressure during business closure [6], [8]. Adequate warning lead time can reduce exposure across all three dimensions by enabling firms to act before water reaches critical assets [14], [22].

Determinants of FEWS Effectiveness

Awareness of FEWS

Awareness reflects whether business decision-makers know that FEWS exist, recognise official warning channels, understand warning meanings, and know which protective actions are expected [19], [23], [24]. When awareness is low, firms may overlook official alerts or rely on informal, potentially inaccurate sources, reducing the time available for action [15], [24].

Trust in FEWS

Trust refers to confidence in the accuracy of warnings, institutional credibility, and the transparency of the information provided [25], [26]. Repeated false alarms, inconsistent messages, or perceived delays in institutional response can produce warning fatigue. Conversely, trusted warning sources are more likely to trigger costly or disruptive protective decisions such as suspending operations, relocating stock, or changing delivery schedules.

Timeliness and Communication

Timeliness concerns whether alerts provide adequate lead time before flooding, while communication concerns clarity, frequency, localisation, and accessibility across multiple channels [27]-[29]. A warning received too late or expressed in technical language may have little operational value even when the underlying forecast is accurate. For SMEs, communication quality is therefore inseparable from the ability to translate hazard information into business-continuity actions.

Research Framework and Hypotheses

Drawing on the people-centered warning approach and prior FEWS research [12], [17]-[19], the study proposes that awareness, trust, and timeliness of communication positively influence the perceived effectiveness of FEWS in reducing business risk losses.

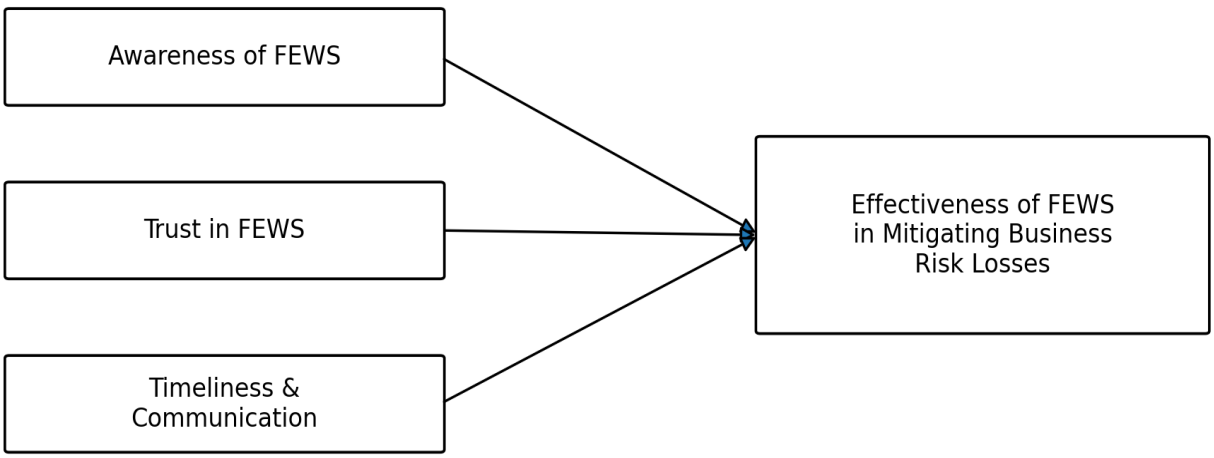


Figure 1 Conceptual Framework of the Study (adapted from Sa'adi et al. [17])

H1: Awareness of FEWS has a significant positive effect on the effectiveness of FEWS in mitigating business risk losses among SMEs.

H2: Trust in FEWS has a significant positive effect on the effectiveness of FEWS in mitigating business risk losses among SMEs.

H3: Timeliness and Communication have a significant positive effect on the effectiveness of FEWS in mitigating business risk losses among SMEs.

METHODOLOGY

Research Design

The study adopted a positivist, deductive, quantitative design based on the Research Onion framework [30]. A cross-sectional survey was used because the objective was to test predefined relationships among measurable constructs at a single point in time rather than to manipulate exposure or observe change longitudinally. Data were collected using a self-administered online questionnaire distributed through Google Forms.

Population, Sampling, and Data Collection

The target respondents were SME owners and senior managers operating in flood-prone districts in Melaka, Negeri Sembilan, and Selangor. Purposive sampling was used to reach businesses exposed to flood risk or located near flood-warning infrastructure [31]. The questionnaire was distributed through business networks, WhatsApp, Telegram, email, and social-media channels. Of 350 questionnaires distributed, 269 complete responses were retained, representing a valid response rate of 76.9%. The sample comprised 185 SMEs with prior flood experience (68.8%) and 84 without (31.2%).

Instrumentation and Measurement

The questionnaire was adapted from established disaster-risk, warning-system, and business-continuity literature. To reduce ambiguity across respondent groups, experienced SMEs answered retrospectively, with reference to actual flood events, while inexperienced SMEs responded prospectively to equivalent statements about how FEWS would support their firms. All perceptual items used a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Awareness of FEWS (5 items): knowledge of system existence, official warning receipt, system operation, training exposure, and protective intent [12], [19], [23], [24].

Trust in FEWS (5 items): confidence in warning accuracy, agency credibility, information transparency, and reliance on alerts for decision-making [12], [25], [26].

Timeliness and Communication (5 items): promptness, message clarity, multi-channel reach, sufficiency of reaction time, and update frequency [27]-[29].

Effectiveness of FEWS (5 items): perceived or anticipated ability of warnings to reduce asset damage, business downtime, financial loss, and overall business risk [18], [19], [23], [32].

A pilot study with 30 SME owners confirmed item readability and face validity; pilot reliability coefficients exceeded the conventional .70 threshold.

Data Analysis

Data were analysed using IBM SPSS Statistics Version 31. Frequencies, percentages, means, and standard deviations were used for respondent profiling and construct interpretation. Internal consistency was assessed using Cronbach's alpha, with $\alpha \geq .70$ treated as acceptable. Univariate normality was assessed using skewness and kurtosis, using ±2.0 as a practical screening range. Pearson correlation was used to assess bivariate relationships, followed by separate multiple linear regression models for flood-experienced and non-experienced SMEs to test H1-H3. Collinearity was evaluated using tolerance and variance inflation factor (VIF) statistics.

RESULTS AND DISCUSSION

Respondent Profile

Table I Demographic and Operational Profile of Participating SMEs (N = 269)

Variable	Category	Frequency	Percentage (%)
Business Sector	Services	139	51.7
	Retail	72	26.8
	Manufacturing	58	21.6
Years of Operation	< 1 year	30	11.2
	1-3 years	78	29.0
	4-6 years	105	39.0
	7-10 years	33	12.3
	> 10 years	23	8.6
Number of Employees	1-5	61	22.7
	6-10	109	40.5
	11-20	58	21.6
	21-50	25	9.3
	> 50	16	5.9
Geographic Location	Melaka	56	20.8
	Negeri Sembilan	83	30.9
	Selangor	130	48.3
Flood Exposure	Experienced flooding	185	68.8
	No previous flood experience	84	31.2

The sample was dominated by service firms (51.7%), followed by retail (26.8%) and manufacturing (21.6%). Most firms had operated for four to six years (39.0%), while 63.2% employed ten or fewer workers, indicating that the sample largely represented micro- to small operations. Selangor contributed 48.3% of responses, Negeri Sembilan 30.9%, and Melaka 20.8%. More than two-thirds of respondents (68.8%) had direct previous flood experience.

Reliability and Normality

Table II Construct Reliability Summary

Construct	Items	Flood-Experienced α	Non-Experienced α
Awareness of FEWS	5	.944	.861
Trust in FEWS	5	.951	.910
Timeliness & Communication	5	.954	.922
Effectiveness of FEWS	5	.952	.931
Overall instrument	20	.986	.944

All construct-level reliability coefficients exceeded .70. Among flood-experienced SMEs, α ranged from .944 to .954, with an overall 20-item alpha of .986. Among non-experienced SMEs, α ranged from .861 to .931, with an overall alpha of .944. These results indicate high internal consistency. Skewness and kurtosis were within the study's ±2 screening rule for the experienced group, while the non-experienced group showed positive skewness (1.240-1.610) and kurtosis up to 2.638. Accordingly, the non-experienced data are somewhat less symmetric, but the sample was retained for parametric analysis given the moderate sample size and the robustness of regression to modest departures from normality.

Descriptive Comparison across Flood-Experience Groups

Table III Descriptive Comparison between Flood-Experienced and Non-Experienced SMEs

Variable	Experienced Mean	SD	Non-Experienced Mean	SD
Awareness of FEWS	3.41	1.34	1.93	0.83
Trust in FEWS	3.43	1.33	1.97	0.88
Timeliness & Communication	3.39	1.32	1.96	0.89
Effectiveness of FEWS	3.43	1.34	1.95	0.94

Using the interpretation 1.00-2.33 = low, 2.34-3.66 = moderate, and 3.67-5.00 = high [33], flood-experienced SMEs recorded moderate mean scores for all four constructs (M = 3.39-3.43), whereas non-experienced SMEs recorded low means (M = 1.93-1.97). The difference is substantively important because it suggests that direct exposure may increase both awareness of warning systems and recognition of their operational value. However, because no independent-samples significance test was reported in the original analysis, the observed group differences should be described as descriptive rather than inferential.

Pearson Correlation Analysis

Table IV Pearson Correlation Matrix for Study Variables

Subgroup	Construct	Awareness	Trust	Timeliness & Comm.	Effectiveness
Experienced (n=185)	Awareness	1.000	.949**	.945**	.937**
	Trust	.949**	1.000	.967**	.953**
	Timeliness & Communication	.945**	.967**	1.000	.958**
	Effectiveness	.937**	.953**	.958**	1.000
Non-experienced (n=84)	Awareness	1.000	.812**	.805**	.766**
	Trust	.812**	1.000	.842**	.866**
	Timeliness & Communication	.805**	.842**	1.000	.865**
	Effectiveness	.766**	.866**	.865**	1.000

Note: ** $p < .001$ (2-tailed).

All three predictors were strongly and positively associated with FEWS effectiveness in both groups. Among flood-experienced SMEs, timeliness and communication showed the strongest bivariate association with effectiveness (r = .958), followed by trust (r = .953) and awareness (r = .937). Among non-experienced SMEs, trust (r = .866) and timeliness and communication (r = .865) were nearly equivalent, followed by awareness (r = .766). The consistently higher correlations among experienced SMEs suggest that direct flood exposure may strengthen the perceived connection between warning-system characteristics and business protection. At the same time, correlations among the predictors themselves were extremely high in the experienced group (r = .945-.967), foreshadowing a serious multicollinearity concern in the regression model.

Multiple Regression and Hypothesis Testing

Table V Multiple Linear Regression Models (Dependent Variable: Effectiveness of FEWS)

Group	Predictor	B	β	t	p	Tolerance	VIF
Experienced	Constant	.032	—	.453	.651	—	—
	Awareness	.256	.254	4.428	< .001	.109	9.213
	Trust	.302	.299	3.802	< .001	.058	17.358
	Timeliness & Communication	.439	.431	5.489	< .001	.058	17.285
Non-experienced	Constant	-.097	—	-.823	.413	—	—
	Awareness	.180	.159	2.097	.039	.387	2.584

	Trust	.452	.420	4.609	< .001	.268	3.736
	Timeliness & Communication	.415	.390	4.126	< .001	.248	4.027

For flood-experienced SMEs, the model explained 93.5% of the variance in perceived FEWS effectiveness, $R^2 = .935$, $F(3,181) = 874.76$, $p < .001$. Timeliness and communication had the largest standardised coefficient ($\beta = .431$, $p < .001$), followed by trust ($\beta = .299$, $p < .001$) and awareness ($\beta = .254$, $p < .001$). For inexperienced SMEs, the model explained 82.2% of the variance ($R^2 = .822$), $F(3,80) = 123.52$, $p < .001$. Trust was the strongest predictor ($\beta = .420$, $p < .001$), followed by timeliness and communication ($\beta = .390$, $p < .001$) and awareness ($\beta = .159$, $p = .039$).

The collinearity diagnostics require careful interpretation. In the non-experienced model, VIF values ranged from 2.584 to 4.027, indicating substantial but generally tolerable overlap among predictors. In contrast, the experienced model produced VIF values ranging from 9.213 to 17.358 and tolerance values as low as 0.058. These figures indicate severe multicollinearity, particularly between trust and timeliness and communication. The overall model fit and significance remain informative, but the individual beta coefficients for experienced SMEs should not be treated as fully stable estimates of independent importance. The high R^2 may also partly reflect the strong conceptual and measurement overlap among the three warning-system dimensions.

Table VI Summary of Hypothesis Testing

Hypothesis / Path	Flood-Experienced	Non-Experienced	Overall Verdict
H1: Awareness → FEWS Effectiveness	Supported*	Supported	Supported with caution
H2: Trust → FEWS Effectiveness	Supported*	Supported	Supported with caution
H3: Timeliness & Communication → FEWS Effectiveness	Supported*	Supported	Supported with caution

*Statistically significant in the experienced model, but coefficient magnitude should be interpreted cautiously because of severe multicollinearity.

DISCUSSION

The results demonstrate that FEWS effectiveness is fundamentally behavioural and communicative rather than purely technological. Across both respondent groups, awareness, trust, timeliness, and communication were strongly related to perceived mitigation of business risk. This is consistent with people-centered early warning frameworks in which monitoring must be connected to warning dissemination and response capability [12], [18], [19]. For SMEs, the business value of a warning lies in whether it triggers timely protective decisions before floodwater causes irreversible damage.

Timeliness and communication had the largest regression coefficients among flood-experienced firms. This finding is operationally plausible: businesses that have previously experienced flooding are likely to understand that even a technically accurate warning has limited value if it does not provide enough time to move inventory, isolate power, protect machinery, rearrange deliveries, or close premises safely. Multi-channel communication through SMS, mobile applications, WhatsApp or Telegram groups, and official portals may therefore reduce the gap between hazard detection and protective action [27]-[29].

Trust was also a strong predictor in both groups and was the largest coefficient among SMEs without previous flood experience. Firms may incur real costs when responding to alerts—for example, by suspending operations, moving assets, canceling appointments, or arranging alternative logistics. Managers are unlikely to take such actions unless they believe the warning is credible. This supports prior research showing that institutional trust and warning credibility shape preparedness behaviour [25], [26].

The descriptive results reveal an important experience gap. Flood-experienced SMEs reported moderate levels of awareness, trust, communication, and perceived effectiveness, whereas non-experienced SMEs reported low levels on all constructs. This pattern suggests that preparedness may be reactive: direct loss experience appears to make warning systems more salient. From a policy perspective, however, waiting for firms to experience a damaging flood before they recognise FEWS value is undesirable. Simulations, business continuity exercises, and targeted awareness programmes could provide a form of experiential learning before an actual disaster occurs.

The regression results for experienced SMEs also expose a measurement and modelling issue that should inform subsequent research. Correlations among awareness, trust, timeliness, and communication ranged from .945 to .967, resulting in VIF values above conventional thresholds. These constructs may therefore represent closely intertwined aspects of a broader latent warning-system effectiveness mechanism rather than fully distinct predictors in experienced populations. Future studies should test discriminant validity using confirmatory factor analysis or structural equation modelling, and should consider whether a higher-order FEWS readiness construct better represents the data.

CONCLUSION

This study evaluated the effectiveness of FEWS in mitigating business risk losses among 269 SMEs in Melaka, Negeri Sembilan, and Selangor. The evidence shows that business protection depends not only on the availability of hazard-monitoring technology but also on whether SMEs are aware of the warning system, trust the issuing source, and receive clear information with sufficient lead time. Flood-experienced SMEs placed the greatest relative emphasis on timeliness and communication, while trust was the strongest predictor among firms without previous flood experience. These findings reinforce the need for a people-centered, business-oriented approach to flood warning in which technical forecasting is translated into trusted and actionable operational guidance.

Managerial and Policy Implications

Business-specific warning protocols. NADMA, DID, MetMalaysia, SME Corp Malaysia, and local authorities should complement general flood warnings with business-relevant information, including affected commercial zones, expected timing, likely water levels, and recommended protective actions.

Multi-channel dissemination. FEWS communication should combine official portals with automated SMS, mobile push notifications, and verified local WhatsApp or Telegram networks so that warning messages reach decision-makers rapidly and repeatedly.

Preparedness before first exposure. SMEs without previous flood experience should be prioritised for simulation drills, FEWS orientation, and business continuity workshops. Exercises should explicitly demonstrate the lead time required to protect inventory, machinery, records, digital systems, workers, and suppliers.

Action-oriented message design. Warning messages should use plain language and clearly distinguish between monitoring information and actions expected from businesses. This can reduce ambiguity and improve trust in official alerts.

Limitations and Future Research

Several limitations qualify the findings. First, the study is cross-sectional and relies on self-reported perceptions, so the results cannot establish causal effects of FEWS on actual monetary loss reduction. Second, retrospective responses from experienced firms may be affected by recall bias, while prospective responses from non-experienced firms capture expectations rather than observed behaviour. Third, the sample was restricted to three western Peninsular Malaysian states and was obtained through purposive non-probability sampling, limiting national generalisability. Fourth, the very high correlations and VIF values in the experienced-SME model indicate severe multicollinearity and call into question the empirical distinctiveness of the predictor constructs. Fifth, because all constructs were collected in the same questionnaire, common method bias cannot be ruled out.

Future studies should use longitudinal designs to track receipt of warnings, protective actions, downtime, recovery expenditures, and insurance claims across multiple monsoon seasons. Objective business-loss measures should be combined with survey data to test whether positive perceptions translate into measurable reductions in damage. Geographic coverage should be extended to the East Coast states and East Malaysia, where flood patterns and access to warnings may differ. Mixed-methods research could also use interviews to examine why some SMEs disregard warnings despite awareness, while confirmatory factor analysis or structural equation modelling could assess discriminant validity and test a higher-order FEWS readiness construct. Experimental message-design studies could further compare lead times, message wording, communication channels, and source credibility to identify which combinations produce the strongest protective response.

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