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Development of a Community Flood Risk Reduction Guideline Using Design and Development Research (DDR): A Case Study of the Kelantan River Floodplain, Malaysia

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ABSTRACT
Flood risk reduction at the community level requires more than technical hazard information; it requires locally relevant guidance that integrates spatial flood exposure, community preparedness, risk perception, and practical action. This study developed a Community Flood Risk Reduction Guideline for flood-prone communities within the downstream Kelantan River floodplain, Malaysia, using Design and Development Research (DDR). DDR was implemented through three interrelated phases: needs analysis, design and development, and evaluation. The needs-analysis phase integrated hydrological modelling, GIS-based flood mapping, field observation, and a questionnaire survey of 400 residents. Flood simulations were generated using HEC-RAS and processed spatially to delineate flood depth and village-level exposure across 20 communities. Approximately 4.334 km², or 43.39% of the combined 9.989 km² village area, was affected by flooding, with pronounced variation among settlements. In the design and development phase, empirical findings were synthesised with disaster risk reduction and disaster risk management principles, documentary evidence, and expert input to construct the guideline. In the evaluation phase, ten experts assessed 26 items using a seven-point scale converted to triangular fuzzy numbers. Expert consensus was evaluated through threshold distance ($d \leq 0.20$), percentage agreement (>75%), and defuzzified fuzzy scores (*Amax*). All evaluated items achieved high fuzzy scores (0.833-0.937), supporting overall acceptance of the developed guideline. The study demonstrates that DDR can provide a traceable methodology for transforming hydrological, spatial, social, and expert knowledge into a locally contextualised disaster-management product, while Fuzzy Delphi analysis provides a transparent mechanism for validating guideline content under conditions of linguistic uncertainty.
Keywords: community-based disaster risk management (CBDRM); Design and Development Research (DDR); HEC-RAS; GIS and Fuzzy Delphi

1. INTRODUCTION

Flooding is one of the most recurrent natural hazards affecting communities in Malaysia, especially settlements located on low-lying river floodplains. Repeated inundation can disrupt transportation, damage houses and household assets, interrupt livelihoods, affect access to essential services, and increase the need for evacuation and emergency assistance. Although structural measures such as levees, drainage improvement, river engineering, and retention facilities remain important components of flood management, structural interventions cannot completely remove residual risk. Community members therefore require accessible information and practical guidance to recognise flood risk, prepare for emergencies, respond to warnings, and undertake appropriate protective actions.

Contemporary disaster risk reduction places increasing emphasis on the role of communities as active participants in risk management rather than passive recipients of emergency assistance. Residents possess local knowledge of historical flood levels, the sequence of inundation, evacuation constraints, vulnerable household members, and locally used routes or safe areas. At the same time, hydrological analysis and geospatial modelling provide systematic evidence on the spatial distribution and severity of flood hazard. Integrating these two knowledge domains is important because technical flood information alone may be difficult for the public to interpret, while experience-based knowledge alone may not fully capture spatial variations in hazard.

Flood maps are particularly valuable for community risk communication because they can identify inundated locations, distinguish flood-depth categories, and illustrate differences in risk among neighbouring settlements. In the present study, flood mapping was not treated as an end product. Instead, it formed part of the evidence base for the development of a community-oriented guideline. The study therefore sought to translate flood modelling and community data into information that could support practical decisions before, during, and after a flood.

A further challenge is methodological. Many flood studies generate maps, vulnerability indices, or survey findings but stop before converting those findings into a systematically designed community product. Design and

Development Research (DDR) is suitable for addressing this gap because it explicitly links empirical investigation with the design, development, and evaluation of a product. DDR has been used to develop educational materials, modules, guidelines, and other practical interventions through a structured process of needs analysis, product development, and evaluation (Richey & Klein, 2007; Van den Akker, 1999).

This study applied DDR to develop a Community Flood Risk Reduction Guideline for communities within the downstream Kelantan River floodplain. The research combined hydrological modelling, GIS-based flood mapping, field observation, a community questionnaire survey, documentary analysis, and expert evaluation. The central contribution of the study lies not only in identifying flood-prone areas but in demonstrating how physical and social evidence can be systematically transformed into a validated community risk-reduction instrument.

The study had three objectives: (1) to identify local flood-risk conditions and community preparedness needs in selected floodplain settlements; (2) to design and develop a locally contextualised Community Flood Risk Reduction Guideline using evidence derived from the needs-analysis phase; and (3) to evaluate the developed guideline through structured expert consensus using the Fuzzy Delphi Method.

2. STUDY AREA

The study focused on the downstream Kelantan River floodplain, covering selected settlements within the Kota Bharu and Tumpat districts of Kelantan, Peninsular Malaysia. The study area contains communities located on both sides of the Kelantan River and includes settlements with different topographic positions, distances from the main channel, and levels of exposure to river flooding.

Figure 1. Kelantan Floodplain and Flood Risk Area

Twenty villages were included in the spatial analysis: Pulau Pisang, Teluk Katak, Pulau Besar, Sungai Pisang, Kampung Laut, Chabang Tiga Cherong, Palekbang, Morak, Paloh, Pasir Pekan, Kutan, Kampung Baru, Kijang, Sungai Keladi, Sungai Bodor, Pak Nik Ya, Gajah Mati, Tebing Tinggi, Kubur Kuda, and Lembah Sireh. These communities provided an appropriate empirical setting for assessing how flood exposure varies within a shared river-floodplain environment and for developing locally differentiated flood risk reduction guidance.

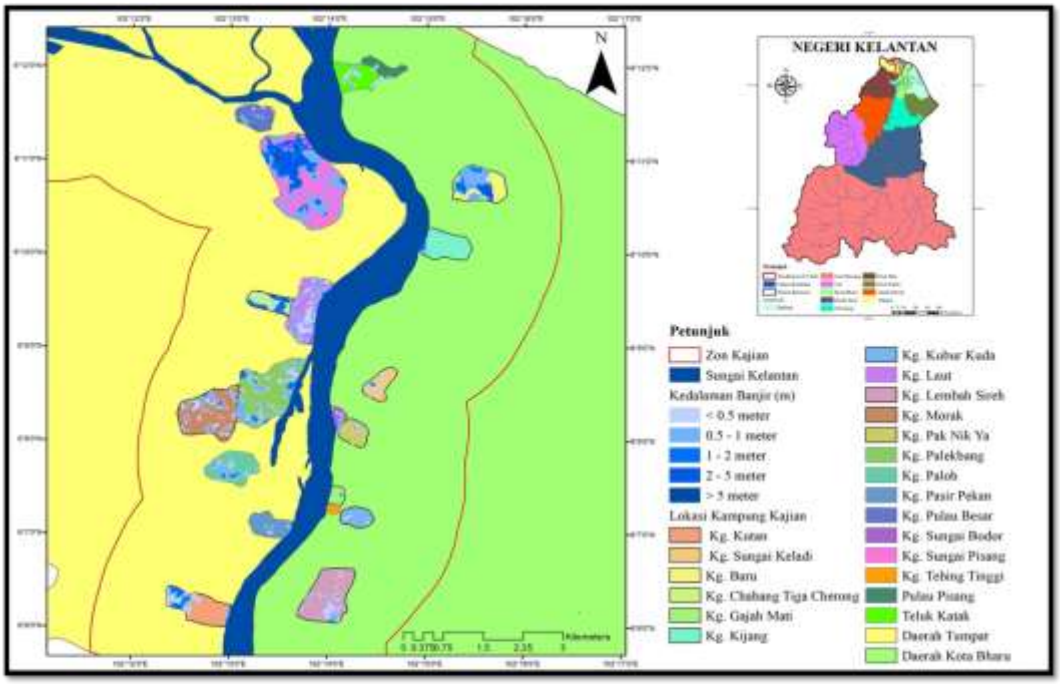

Figure 2. Study villages and simulated flood-depth distribution within the downstream Kelantan River floodplain.

3. MATERIALS AND METHODS

3.1 Design and Development Research Framework

The study adopted Design and Development Research (DDR) as the overarching methodological framework. DDR is a systematic form of inquiry concerned with the design, development, and evaluation of products, tools, models, modules, guidelines, and intervention processes. In contrast with research designs that primarily describe or explain a phenomenon, DDR is explicitly product-oriented: empirical evidence is first used to determine what should be developed, the product is then constructed through an explicit design logic, and its content and usability are subsequently evaluated. This orientation was appropriate for the present study because the intended research output was not only a flood-risk assessment, but a usable Community Flood Risk Reduction Guideline for residents living in the downstream Kelantan River floodplain (Richey & Klein, 2007; Richey et al., 2004).

The research was organised into three sequential but interdependent phases: Phase 1, needs analysis; Phase 2, design and development; and Phase 3, evaluation. Phase 1 determined the actual flood-risk conditions, information gaps, preparedness needs, and community requirements that should be represented in the guideline. Phase 2 transformed these findings into a structured prototype by combining empirical results with disaster risk reduction and disaster risk management principles. Phase 3 examined the content, presentation, local relevance, and practical suitability of the prototype through expert evaluation and Fuzzy Delphi analysis. The output of one phase therefore served as the input to the next, creating a traceable chain from risk evidence to guideline content and finally to validation.

3.1.1 Rationale for DDR in Disaster-Management Guideline Development

DDR is particularly suitable for disaster-management guideline development because disaster guidance is an applied decision-support product. A community guideline must translate multiple forms of evidence - hazard information, vulnerability conditions, local knowledge, institutional procedures, preparedness behaviour, and expert judgement - into instructions that can be understood and acted upon. A purely descriptive design may identify flood problems but does not by itself provide a systematic procedure for deciding which findings should become guideline elements, how those elements should be organised, or how the completed product should be evaluated. DDR provides this development pathway by linking evidence generation, product construction, and validation within one methodological framework.

In disaster risk reduction, this linkage is important because guideline quality depends on both scientific validity and contextual usability. Scientific validity requires that recommendations are grounded in observed or modelled risk conditions. Contextual usability requires that the same recommendations reflect the social, geographical, institutional, and communication realities of the intended users. In the present study, hydrological modelling and

GIS supplied spatial evidence on flood depth and extent, while the community survey supplied social evidence on awareness and preparedness. These two evidence streams were not treated as separate end products; they became design inputs for the guideline.

The DDR process also supports iterative refinement. Disaster-management products frequently contain elements that require judgement, such as the prioritisation of preparedness actions, the presentation of hazard maps, terminology for risk communication, and the suitability of recommended community actions. Through Delphi and Fuzzy Delphi procedures, specialists and community-informed evaluators can review these elements, identify ambiguity, and determine whether sufficient consensus has been achieved. DDR therefore creates a methodological audit trail showing why a guideline element was included, how it was derived, and whether it was accepted by the evaluation panel.

Conceptually, the three DDR phases correspond to three practical questions in disaster management: (i) What risks and community needs must be addressed? (needs analysis); (ii) What information, actions, and decision aids should be incorporated into the guideline, and how should they be organised? (design and development); and (iii) Is the resulting guideline sufficiently relevant, clear, locally appropriate, and technically acceptable for intended use? (evaluation). This alignment makes DDR useful for converting disaster research into an operational community resource rather than leaving risk information solely in technical reports.

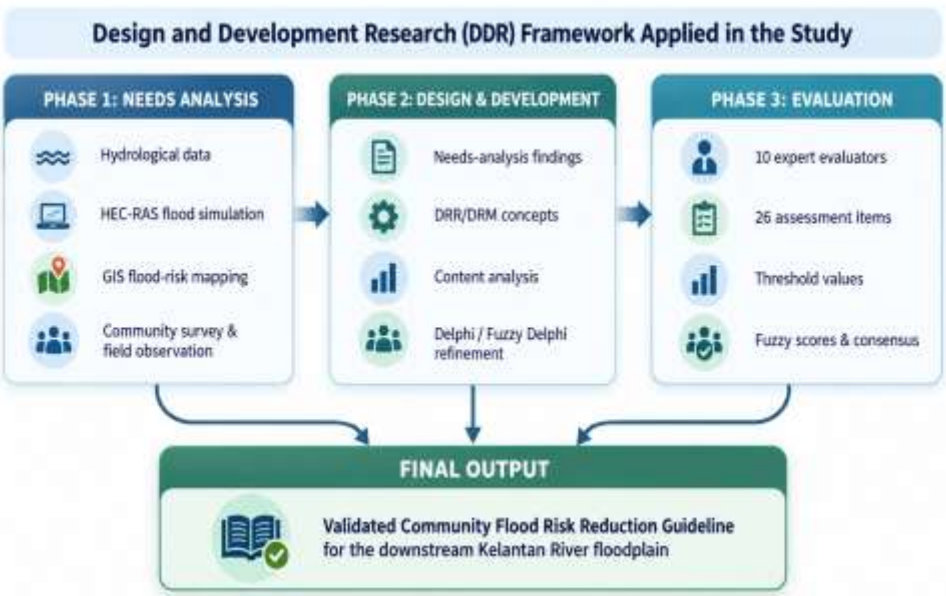

Figure 3. Design and Development Research framework applied in the study.

3.2 Phase 1: Needs Analysis

The needs-analysis phase was conducted to identify the gap between existing community conditions and the information, preparedness, and risk-reduction actions required for flood-prone settlements. Four principal methodological components were used: hydrological analysis, flood modelling and mapping, community survey, and field observation. Secondary data were combined with primary community information so that both physical flood conditions and social preparedness needs could inform guideline development.

3.2.1 Hydrological Data and Flood-Frequency Analysis

Secondary hydrological and spatial data included historical rainfall, river discharge, water level, flood frequency, river morphology, topographic information, land-use information, previous flood reports, and field-observed flood levels. Digital Elevation Model data with approximately 12.5 m spatial resolution were also used as a terrain input for hydraulic simulation and spatial analysis.

Flood-frequency analysis was undertaken to estimate discharge conditions for hydraulic modelling. The study applied Gumbel and Weibull techniques to historical discharge information. These analyses were used to derive discharge estimates associated with selected recurrence intervals and to provide hydraulic inputs for subsequent HEC-RAS simulation. The study considered multiple return periods, including 10-, 25-, 50-, 100-, and 200-year scenarios. The final flood-risk mapping process utilised the simulated flood outputs in combination with village boundaries and local field information.

3.2.2 HEC-RAS Flood Simulation and GIS Mapping

HEC-RAS was used to simulate flood inundation because the available hydrological and terrain datasets could be incorporated into a hydraulic modelling environment. The modelling workflow included preparation of terrain data, river geometry and cross-sectional information, insertion of analysed discharge values, simulation of flood conditions, and comparison of simulated water levels with field-observed flood information for calibration and validation.

The hydraulic outputs were subsequently processed in a GIS environment. Raster flood information was converted and classified so that inundation depth and extent could be spatially represented for the study villages. Flood depth was grouped into five categories: less than 0.5 m, 0.5-1 m, 1-2 m, 2-5 m, and greater than 5 m. Village polygons were overlaid with the inundation layer to calculate the area and percentage of each village affected by flooding.

3.2.3 Community Preparedness and Awareness Survey

A structured questionnaire was used to obtain information on community preparedness and awareness. The instrument comprised four components: respondent background, flood awareness, flood preparedness, and community recommendations for reducing flood risk. Questionnaire items were informed by existing disaster-management guidance and agency documents to maintain consistency with established preparedness recommendations.

A five-point Likert scale was used for major awareness and preparedness items. The target population comprised residents in the Kota Bharu and Tumpat districts. The study selected 400 respondents, with 20 respondents representing each of the 20 study villages. Before the main survey, the instrument was reviewed by a DDR expert and pilot-tested with 30 respondents. Following refinement, full field data collection was conducted across the selected floodplain communities.

Survey data were processed using SPSS. Descriptive frequency analysis was used to examine the distribution of preparedness and awareness responses, while correlation analysis was used to explore relationships between selected demographic characteristics and community preparedness or awareness variables. The survey findings formed part of the evidence base used to determine the content and emphasis of the guideline.

3.2.4 Flood Risk Assessment

The study integrated hazard and vulnerability information through a flood-risk assessment framework. Flood hazard was represented through indicators related to flood occurrence and severity, while vulnerability was assessed through exposure and resilience components. Exposure reflected residential, agricultural, and commercial land-use conditions, whereas resilience reflected structural and non-structural mitigation. The detailed construction of the Flood Vulnerability Index (FVI) is presented in Section 3.2.5. The overall Flood Risk Index was conceptualised from the combined hazard and vulnerability dimensions so that the guideline could distinguish communities with different risk profiles.

The purpose of this integration was to avoid treating every community as having the same level of risk. Instead, differentiated hazard and vulnerability information was used to support the selection of appropriate guideline content and to strengthen the local relevance of community risk-reduction recommendations.

For interpretation, the study framework uses the following interval bands: low vulnerability ($0 < FVI < 0.25$), moderate vulnerability ($0.25 < FVI < 0.50$), high vulnerability ($0.50 < FVI < 0.75$), and very high vulnerability ($0.75 < FVI < 1.00$). These bands are used as an interpretive aid for comparing village-level vulnerability, while the component scores for exposure and resilience remain important for understanding the specific basis of vulnerability in each community.

The equation expresses the conceptual relationship between exposure and resilience used in the study framework. In the results section, the village-level component scores and FVI values are reported as provided in the study dataset and are interpreted comparatively across the 20 communities.

$$FVI = [(KKn + PTn + KMn) / 3] - [(STRn + BSTRn) / 2] \quad \ldots (1)$$

where;

KKn is the residential-area interval score
PTn is the agricultural-area interval score
KMn is the commercial-area interval score
STRn is the structural-mitigation score
BSTRn is the non-structural-mitigation score

3.2.5 Construction of the Flood Vulnerability Index

The Flood Vulnerability Index (FVI) was specified as the difference between the mean exposure score and the mean resilience score. To operationalise vulnerability at village level, the study separated the assessment into two conceptual dimensions: exposure and resilience. Exposure was represented by interval scores for residential, agricultural, and commercial areas, whereas resilience was represented by structural and non-structural mitigation scores. This structure enabled the guideline-development process to distinguish places with substantial exposed assets from places where mitigation capacity could offset part of that exposure. In the DDR framework, the resulting village-level vulnerability information served as a needs-analysis input rather than as an isolated statistical endpoint; it was used to determine which risk-reduction messages and preparedness measures required greater emphasis in the guideline.

3.3 Phase 2: Design and Development of the Guideline

The second DDR phase translated the findings from needs analysis into the structure and content of the Community Flood Risk Reduction Guideline. The design logic was evidence-to-content: each major guideline domain had to be supported by either empirical findings from Phase 1, established disaster risk reduction/disaster risk management principles, existing institutional guidance, or expert judgement. This procedure reduced the risk of producing a generic handbook disconnected from the actual conditions of the Kelantan River floodplain. The guideline was organised around risk identification, preparedness, risk transfer, and mitigation, with local flood history, population and geographical context, river morphology, flood-risk zoning, household emergency planning, insurance or risk-transfer considerations, structural and non-structural mitigation, and roles of government and non-government actors incorporated as relevant subcomponents.

Three complementary procedures supported guideline development: content analysis, Delphi consultation, and Fuzzy Delphi-oriented refinement. Content analysis was used to identify relevant evidence and recommendations from books, official documents, agency guidance, and journal articles. These sources were compared with Phase 1 findings so that external recommendations could be localised rather than copied directly. Delphi consultation was used to obtain structured expert judgement on proposed elements and to refine areas in which professional interpretation was required. Fuzzy Delphi analysis was then applied during evaluation to convert linguistic expert judgements into triangular fuzzy numbers, quantify the degree of consensus, and support transparent decisions on whether guideline items should be retained, revised, or reconsidered.

The guideline was organised to help community users understand local flood conditions, identify risk zones, interpret flood-depth information, undertake household and community preparedness measures, respond to warnings, plan evacuation, reduce potential losses, support vulnerable residents, and review preparedness after flood events. Maps and infographics were incorporated as decision-support tools rather than as decorative elements.

3.4 Phase 3: Expert Evaluation Using the Fuzzy Delphi Method

The developed guideline was evaluated by ten experts using a 26-item assessment instrument. The items examined presentation and design, clarity of visual materials, content accuracy, suitability of flood-risk information, relevance to local conditions, community participation, use of maps and infographics, alignment with disaster risk reduction practice, and practical applicability. The use of a multi-expert evaluation was important because the guideline integrates technical, institutional, and community-facing information that cannot be judged adequately from a single disciplinary perspective.

3.4.1 Linguistic Scale and Triangular Fuzzy Numbers

Expert responses were collected using a seven-point Likert scale and converted into triangular fuzzy numbers. A triangular fuzzy number is expressed as $M = (m1, m2, m3)$, where m1 represents the minimum or lowest plausible value, m2 represents the most plausible value, and m3 represents the maximum plausible value. This transformation recognises that linguistic judgements such as 'agree' or 'strongly agree' are not perfectly precise points; instead, they represent a range of plausible membership values. Fuzzification therefore reduces the artificial precision associated with treating ordinal linguistic responses as exact numerical quantities.

Table 1. Conversion of the seven-point linguistic scale to triangular fuzzy numbers.

Likert	Linguistic response	Triangular fuzzy number (m1, m2, m3)
7	Extremely agree	(0.9, 1.0, 1.0)
6	Strongly agree	(0.7, 0.9, 1.0)
5	Agree	(0.5, 0.7, 0.9)
4	Moderately agree	(0.3, 0.5, 0.7)
3	Disagree	(0.1, 0.3, 0.5)
2	Strongly disagree	(0.0, 0.1, 0.3)
1	Extremely disagree	(0.0, 0.0, 0.1)

3.4.2 Aggregation of Expert Fuzzy Responses

For each item, the fuzzy response of expert i was represented as $M_i = (m_{1i}, m_{2i}, m_{3i})$. The group fuzzy value was obtained by averaging the corresponding lower, modal, and upper values across all n experts:

$\bar{m}_1 = (1/n) \Sigma m_{1i}$; $\bar{m}_2 = (1/n) \Sigma m_{2i}$; $\bar{m}_3 = (1/n) \Sigma m_{3i}$ … (2)

The aggregated fuzzy number for each item was therefore expressed as $\bar{M} = (\bar{m}_1, \bar{m}_2, \bar{m}_3)$. These average values provided the reference point for determining the distance between each individual expert judgement and the group judgement.

3.4.3 Threshold Value (d) and Expert Consensus

The threshold value d was calculated using the vertex-distance method between the triangular fuzzy number of each expert and the aggregated group fuzzy number. The distance for expert i was calculated as follows:

$d(M_i, \bar{M}) = \sqrt{(1/3)[(m_{1i} - \bar{m}_1)^2 + (m_{2i} - \bar{m}_2)^2 + (m_{3i} - \bar{m}_3)^2]}$ … (3)

Following the decision rule used in the study, an individual expert judgement was considered to be within the consensus range when $d \leq 0.20$. Values above 0.20 indicated greater divergence from the group position and signalled that the relevant item or expert response required closer review. This threshold criterion is widely used in Fuzzy Delphi applications based on the distance between fuzzy ratings (Chen, 2000; Cheng & Lin, 2002).

The percentage of expert consensus for each item was calculated from the number of experts whose threshold distance satisfied $d \leq 0.20$:

Expert consensus (%) = $[N(d \leq 0.20) / N_{total}] \times 100$ … (4)

The second acceptance criterion required overall group consensus greater than 75%. With ten experts in the present evaluation, this means that at least eight experts needed to fall within the defined consensus range for an item to exceed the 75% requirement. Items failing either the threshold-distance or group-consensus criterion would require revision or a further evaluation round. The >75% consensus rule is consistent with Delphi/Fuzzy Delphi applications that use group agreement as a minimum condition for retaining an item (Chu & Hwang, 2008).

3.4.4 Defuzzification and Fuzzy Score

After consensus was assessed, the aggregated triangular fuzzy number was converted to a single crisp value to indicate the strength of expert agreement and to rank the guideline items. The study used the simple average defuzzification procedure, expressed as A_{max}:

$A_{max} = (\bar{m}_1 + \bar{m}_2 + \bar{m}_3) / 3$ (4)

A_{max} ranges from 0 to 1, with values closer to 1 indicating stronger overall agreement with an item. In this study, A_{max} was primarily used to describe the strength of expert endorsement and to rank the 26 evaluation items after the threshold and group-consensus criteria had been examined.

$\alpha\text{-cut} = (0 + 1) / 2 = 0.50$ (5)

For completeness, the optional α-cut reference used in some Fuzzy Delphi applications is the midpoint of the 0-1 membership interval, equal to 0.50. The present study did not use this as a mandatory acceptance condition because its protocol specified threshold distance and percentage consensus as the two required validation criteria. The full evaluation sequence was therefore: (1) convert each Likert response to a triangular fuzzy number; (2) compute the aggregated group fuzzy values; (3) calculate the threshold distance d for each expert-item pair; (4) determine the percentage of experts satisfying $d \leq 0.20$; (5) retain items with group consensus >75% subject to review of the threshold pattern; and (6) calculate A_{max} to quantify and rank the strength of expert agreement. This sequence provides a transparent numerical basis for validating disaster-management guideline content while preserving the uncertainty inherent in linguistic expert judgement.

4. RESULTS

4.1 Spatial Distribution of Flood Exposure

The spatial analysis demonstrated substantial variation in flood exposure among the 20 study villages. The combined village area was 9.989 km^2, of which approximately 4.334 km^2 was affected by the mapped flood extent. This represented 43.39% of the total village area. The distribution of exposure was highly uneven, indicating that flood preparedness and risk communication should be spatially differentiated rather than uniform across the study area.

Table 2. Flooded area and proportional inundation by village.

Village	Village area (km²)	Flooded area (km²)	Flooded (%)
Pulau Pisang	0.171129	0.015868	9.27
Teluk Katak	0.394970	0.098660	24.98
Pulau Besar	0.310019	0.055038	17.75
Sungai Pisang	2.028888	1.207658	59.52
Kg. Laut	0.681223	0.372648	54.70
Chabang Tiga Cherong	0.259835	0.198795	76.51
Palekbang	1.149480	0.444440	38.66
Morak	0.899540	0.285519	31.74
Paloh	0.493645	0.150028	30.39
Pasir Pekan	0.310824	0.019515	6.28
Kutan	0.570751	0.197228	34.56
Baru	0.591133	0.419973	71.05
Kijang	0.446249	0.039261	8.80
Sungai Keladi	0.240476	0.063364	26.35
Sungai Bodor	0.088661	0.030745	34.68
Pak Nik Ya	0.226108	0.040232	17.79
Gajah Mati	0.097096	0.011587	11.93
Tebing Tinggi	0.045892	0.001545	3.37
Kubur Kuda	0.202958	0.000554	0.27
Lembah Sireh	0.780559	0.186470	23.89
Total	**9.989435**	**4.334470**	**43.39**

Chabang Tiga Cherong recorded the highest proportional inundation at 76.51%, followed by Kampung Baru at 71.05%, Sungai Pisang at 59.52%, and Kampung Laut at 54.70%. These villages therefore exhibited the greatest relative spatial exposure in the mapped scenario. By contrast, Kubur Kuda recorded only 0.27% inundation, while Tebing Tinggi (3.37%), Pasir Pekan (6.28%), Kijang (8.80%), and Pulau Pisang (9.27%) also showed comparatively low proportions of inundated village area.
The contrast between highly exposed and less exposed settlements supports the use of localised risk information in community preparedness materials. A single generic preparedness message would not reflect the different levels of spatial exposure shown by the flood map. The guideline therefore incorporated mapped risk information as part of the community decision-support content.

4.2 Village-Level Flood Vulnerability Index

The village-level vulnerability assessment complemented the inundation analysis by combining three exposure-related dimensions such as residential, agricultural, and commercial area interval scores with two resilience-related dimensions which is structural and non-structural mitigation. Table 3 presents the component scores and the FVI values reported for all 20 study villages. The results demonstrate considerable spatial variation in vulnerability across the Kelantan River floodplain and show that vulnerability cannot be inferred from inundated area alone.

Table 3. Exposure, resilience, and Flood Vulnerability Index (FVI) by village.

Village	Exposure			Resilience		FVI
	Residential area interval score	Agricultural area interval score	Commercial area interval score	Structural mitigation	Non-structural mitigation	
Kg. Pulau Pisang	0.43	0.01	0.09	0.02	0.10	0.21
Kg. Teluk Katak	0.20	0.08	0.03	0.20	0.05	0.03
Kg. Pulau Besar	0.09	0.02	0.02	0.19	0.15	0.08
Kg. Sungai Pisang	0.50	0.09	0.25	0.31	0.37	0.08
Kg. Laut	0.72	0.55	0.65	0.70	0.10	0.56
Kg. Chabang Tiga Cherong	0.52	0.75	0.45	0.25	0.25	0.61
Kg. Palekbang	0.67	0.24	0.33	0.18	0.33	0.37

Village	Exposure			Resilience		FVI
	Residential area interval score	Agricultural area interval score	Commercial area interval score	Structural mitigation	Non-structural mitigation	
Kg. Morak	0.68	0.45	0.17	0.23	0.10	0.49
Kg. Paloh	0.71	0.12	0.15	0.15	0.50	0.17
Kg. Pasir Pekan	0.73	0.09	0.78	0.09	0.70	0.41
Kg. Kutan	0.41	0.05	0.75	0.12	0.10	0.50
Kg. Baru	0.11	0.12	0.38	0.10	0.25	0.13
Kg. Kijang	0.19	0.04	0.21	0.05	0.10	0.15
Kg. Sungai Keladi	0.29	0.16	0.11	0.30	0.25	0.01
Kg. Sungai Bodor	0.10	0.14	0.09	0.25	0.10	0.03
Kg. Pak Nik Ya	0.31	0.03	0.13	0.05	0.50	0.08
Kg. Gajah Mati	0.18	0.01	0.81	0.15	0.65	0.10
Kg. Tebing Tinggi	0.10	0.03	0.68	0.75	0.25	0.19
Kg. Kubur Kuda	0.09	0.01	0.77	0.20	0.50	0.09
Kg. Lembah Sireh	0.63	0.50	0.53	0.75	0.50	0.21

Note: The exposure, resilience, and FVI values are reported from the study dataset.
The highest reported FVI was recorded in Kg. Chabang Tiga Cherong (0.61), followed by Kg. Laut (0.56), Kg. Kutan (0.50), Kg. Morak (0.49), Kg. Pasir Pekan (0.41), and Kg. Palekbang (0.37). Lower FVI values were reported in Kg. Sungai Keladi (0.01), Kg. Teluk Katak (0.03), Kg. Sungai Bodor (0.03), Kg. Sungai Pisang (0.08), Kg. Pak Nik Ya (0.08), and Kg. Pulau Besar (0.08). The spread of values indicates that community vulnerability differs substantially across the floodplain, reflecting the combined influence of land-use exposure and existing mitigation capacity.
Within the DDR needs-analysis phase, the village-level FVI values provide a structured evidence base for translating vulnerability conditions into guideline content. Villages with comparatively higher FVI values require stronger emphasis on risk identification, household preparedness, evacuation planning, loss-reduction measures, and locally appropriate mitigation. At the same time, the individual exposure and resilience components help identify whether vulnerability is associated primarily with residential, agricultural, or commercial exposure, or with limitations in structural and non-structural mitigation.

4.3 Translation of Needs-Analysis Findings into Guideline Content

The needs-analysis phase produced two broad groups of evidence for guideline development: physical flood-risk information and community-oriented preparedness information. Physical evidence consisted of flood extent, flood depth, spatial variation among villages, and risk indicators. Community evidence consisted of awareness, preparedness, local experience, and suggestions for reducing flood impacts. These findings were synthesised into a practical sequence of guideline topics.
The resulting guideline included introductory information on the local flood context; identification of flood-prone locations; interpretation of flood-depth maps; household preparedness before the monsoon or flood season; emergency items and document protection; warning and information sources; actions during rising water; evacuation decision-making; assistance for vulnerable persons; protection of property and livelihoods; community participation; and post-flood recovery and preparedness review.
A key design principle was the simplification of technical information without removing its meaning. Flood-depth classes and village-level risk maps were used to convert hydraulic modelling outputs into information that could be understood and applied by community members. Visual elements such as maps and infographics were therefore treated as integral components of risk communication.

4.4 Expert Evaluation of the Guideline

Expert evaluation indicated high overall acceptance of the developed guideline. Across the 26 items, the aggregated fuzzy scores (A*max*) ranged from 0.833 to 0.937, demonstrating consistently strong endorsement. Because A*max* is derived from the mean of the three aggregated fuzzy components, values approaching 1 indicate that the expert responses were concentrated toward the upper end of the seven-point agreement scale. The highest reported score was 0.937 for the item indicating that the proposed guideline elements were aligned with best practices derived from flood-risk-reduction research. The item on clear strategies for community participation, education, and engagement achieved 0.927, while the items concerning appropriate infographics and systematic maps for community decision-making achieved 0.920.

Table 4. Selected high-consensus items from the expert evaluation.

Evaluation aspect	Fuzzy score	Interpretation
Guideline elements aligned with research-based best practices	0.937	Highest reported expert agreement
Clear strategy for community participation, education and engagement	0.927	Very high agreement
Suitability of infographics	0.920	Very high agreement
Systematic maps for community flood-risk decision-making	0.920	Very high agreement
Comprehensive understanding of community flood-risk reduction	0.917	High agreement
Appropriateness to the local context	0.917	High agreement

Although some individual expert-item distances exceeded d = 0.20, the item-level consensus pattern remained high. The reported aggregate threshold values were generally within the acceptance range, and all 26 items achieved the required group-consensus level used in the study. This distinction is important: an isolated expert may diverge from the panel on a particular item without invalidating the item, provided that the consensus criteria remain satisfied. The combined interpretation of threshold distance, percentage consensus, and A_{max} therefore supported retention of the full guideline while still highlighting presentation, wording, font size, infographic treatment, and selected risk-related elements that could be refined during final editing.

5. DISCUSSION

5.1 DDR as a Bridge Between Flood Research and Community Practice

The principal methodological contribution of this study is the application of DDR to community flood risk reduction. Flood research frequently produces technically valuable outputs such as inundation maps, hazard indices, vulnerability assessments, and social survey findings, but those outputs do not automatically become usable resources for households or community organisations. DDR addresses this translation gap because it treats the guideline itself as a research product whose content must be derived, structured, tested, and refined systematically. In this study, the needs-analysis phase established the empirical basis of the product, the design and development phase converted that evidence into organised guidance, and the evaluation phase tested whether the resulting material was sufficiently acceptable and contextually appropriate.

This structure is especially valuable for disaster-management guidelines because such products sit at the interface between science, policy, and behaviour. A technically accurate flood map may still be ineffective if residents cannot interpret it, while a simple preparedness message may be inadequate if it ignores differences in local exposure. DDR requires these competing demands to be reconciled during product development. The guideline therefore becomes a synthesis layer: hazard modelling establishes where and how flooding may occur; community data reveal what residents know, do, and require; disaster risk reduction concepts organise the recommended actions; and expert evaluation tests whether these components have been combined coherently.

5.1.1 Methodological Value of DDR for Disaster-Management Products

For disaster-management research, DDR offers four methodological advantages. First, it is needs-driven. The product is justified by evidence of a real gap rather than by the assumption that another guideline is required. In this study, needs analysis combined hydrological, spatial, and community evidence, allowing the guideline to respond to both physical exposure and social preparedness. Second, DDR is traceable. Each major element can be linked back to a data source, theoretical principle, official recommendation, or expert decision. This traceability is important where guidance may influence safety-related behaviour.

Third, DDR is iterative and multidisciplinary. Disaster risk reduction is not a single-discipline problem; hydrology, geospatial analysis, social science, emergency management, communication, and local governance all contribute different forms of knowledge. The design and evaluation stages create a controlled process for reconciling these perspectives. Fuzzy Delphi analysis is particularly useful at this stage because it captures the imprecision of linguistic expert judgements while still producing quantitative indicators of consensus.

Fourth, DDR supports transferability without assuming direct generalisability. The three-phase logic can be reproduced in another floodplain, but the guideline content should be regenerated from the new location's hazard, vulnerability, institutional, and community evidence. This distinction is important for disaster management: the development process may be replicable even when the final product is context specific. DDR therefore provides a methodological template for locally grounded guideline development rather than a one-size-fits-all disaster manual.

5.2 Integrating Physical and Social Dimensions of Flood Risk

The mapped results demonstrate why a community guideline should not rely solely on generic flood-preparedness messages. The proportion of village area inundated ranged from 0.27% to 76.51%. Communities located within the same downstream floodplain therefore experience markedly different spatial exposure. For highly exposed settlements, preparedness messages may need to emphasise early evacuation, emergency access, protection of critical household items, and assistance for vulnerable residents. Communities with lower proportional exposure still require awareness and monitoring but may face different priorities.

The community survey complements this spatial evidence because flood risk is not determined by hazard alone. Preparedness, awareness, household capacity, information access, and previous experience affect how people interpret warnings and respond to rising water. Incorporating both physical and social dimensions strengthens the relevance of the resulting guideline and reflects the broader logic of disaster risk reduction, in which risk emerges from the interaction of hazard, exposure, vulnerability, and capacity.

The FVI analysis further demonstrates why DDR is useful for disaster-management guideline development. In a conventional hazard-mapping study, the analysis might end after flood extent and depth are quantified. In the present DDR process, the FVI and its exposure-resilience components are treated as design evidence: they inform what the guideline should communicate, which communities require greater emphasis on preparedness and mitigation, and what types of measures should be prioritised. This creates a traceable connection between empirical diagnosis and the design of the disaster-management product, which is central to the logic of DDR.

The divergence between inundation percentage and village-level FVI reinforces the multidimensional character of flood risk. A settlement may have a relatively large inundated area while also possessing stronger mitigation capacity, whereas another settlement may have lower inundation but weaker resilience or different patterns of land-use exposure. For community-facing disaster guidance, this distinction is important because recommendations should not be based on hazard intensity alone. The DDR approach therefore enables hydrological, spatial, social, and mitigation evidence to be translated into differentiated and locally relevant risk-reduction guidance.

5.3 Translating Technical Flood Information into Community Risk Communication

Flood maps and hydraulic model outputs are typically prepared for engineers, planners, and agencies. Their technical symbology, return-period terminology, and modelling assumptions may be difficult for non-specialists to interpret. The guideline development process therefore required translation rather than simple reproduction of technical results. Flood-depth categories, village boundaries, locally recognisable place names, and simplified visual explanations were used to improve accessibility.

The high expert support for infographics and systematic maps indicates that visual communication was an important strength of the developed product. Maps can help residents identify whether their homes, roads, or frequently used areas are located within zones of greater inundation. When linked with clear actions, such maps become decision-support tools rather than static illustrations.

5.4 Community Participation and Local Context

The expert evaluation also strongly supported the inclusion of strategies for community participation, education, and engagement. This is consistent with the principle that local residents should be involved in risk reduction before emergencies occur. Communities can contribute to identifying vulnerable households, disseminating official information, supporting evacuation, maintaining local preparedness networks, participating in drills, and reviewing lessons after flood events.

The local orientation of the guideline is equally important. A guideline designed for one floodplain should not be transferred uncritically to another location. Hydrology, settlement form, transportation access, warning arrangements, social characteristics, and institutional responsibilities differ among river basins. The DDR process offers a practical way to preserve a common development framework while allowing each locality to generate its own evidence-based content.

5.5 Practical and Research Implications

The approach has several implications for disaster-management agencies and researchers. First, community flood preparedness materials can be strengthened when local hazard maps and household-level guidance are developed together. Second, GIS and hydraulic modelling outputs should not remain only in technical reports; they can be simplified into community maps and decision aids. Third, the combination of DDR and Fuzzy Delphi provides a defensible quality-control mechanism before a guideline is disseminated. Rather than reporting that experts 'generally agreed,' the evaluation can show the fuzzy membership structure, threshold distance, percentage consensus, and defuzzified score for each item. This makes the validation process more transparent and allows future revisions to focus on items with relatively weaker consensus.

The framework may also support the digitalisation of flood-risk guidance. The same local risk layers and community-oriented content could be incorporated into a web or mobile application that allows users to identify their location, view risk categories, and access recommended preparedness actions. Such digital development should retain the DDR principle of iterative design and user-oriented evaluation.

Future research should therefore undertake field-based usability testing with residents and evaluate whether use of the guideline improves flood-risk knowledge, warning comprehension, household preparedness, evacuation readiness, participation in drills, and protective behaviour. Comparative studies could also test the DDR framework in other Malaysian river basins or in other flood-prone regions to determine which guideline components are transferable and which require local redesign.

6. CONCLUSION

This study demonstrates the usefulness of Design and Development Research for developing an evidence-based Community Flood Risk Reduction Guideline. The DDR framework enabled hydrological, geospatial, community, documentary, and expert information to be integrated within a single development process rather than treated as separate research outputs.

The needs-analysis phase identified pronounced differences in flood exposure across 20 villages in the downstream Kelantan River floodplain. Of the combined 9.989 km² village area, approximately 4.334 km², or 43.39%, was affected by the mapped flood extent. Proportional inundation ranged from 0.27% in Kubur Kuda to 76.51% in Chabang Tiga Cherong, demonstrating the need for locally differentiated risk information.

The design and development phase translated these empirical findings into a structured guideline that combined local flood maps, preparedness information, community participation, and practical risk-reduction actions. The evaluation phase, involving ten experts and 26 assessment items, showed high expert agreement, with reported fuzzy scores ranging from 0.833 to 0.937.

Overall, the study shows that DDR can provide a systematic bridge between flood-risk research and practical community application. The approach is potentially replicable for other hazard-prone communities, provided that local physical conditions, community needs, and institutional arrangements are incorporated into the needs-analysis and development process.

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