

Reactivated slope, perched channel, and protective-action capacity: an integrated analysis of the 2025 Matai'an landslide-dam disaster, Taiwan

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Abstract

On 21 July 2025 the largest landslide recorded in Taiwan impounded the Matai'an Stream in eastern Taiwan; sixty-four days later the barrier overtopped and breached, and nineteen residents of Guangfu Township died after nineteen official alerts. We ask why a dense warning sequence did not convert into survivable protective action for an identifiable group, treating physical preconditioning, channel geometry and warning practice as one causal chain and not as separate literatures. Using documentary analysis with historical topographic maps, satellite imagery and an earthquake catalogue, read through a terrain-explicit extension of Cutter's Hazards-of-Place model coupled to the Protective Action Decision Model, we establish three results. The failure reactivated ground mapped as unstable since 1924 and seismically loaded by 198 earthquakes of local magnitude 5.0 or above within 50 km between 2018 and failure. A century of dike construction left the channel perched above the plain, so the flood was delivered through a single dike aperture to the lowest, most densely settled ground, while the pre-1904 Amis settlement on higher ground was largely spared. Vertical evacuation, the mode recorded for 61.5 per cent of residents, carried a reinforced-concrete two-storey condition never matched to individual addresses, and the fatalities concentrated on the lowest streets. We derive a reproducible vertical-evacuation screening threshold and argue that a protective-action instruction carries an evidentiary burden the issuing authority must discharge before an event.

1. Introduction

Landslide dams concentrate several forms of uncertainty in one landform. Their formation is abrupt, their internal structure is unknown at the moment of formation, their failure mode is difficult to forecast, and the interval between the onset of overtopping and the arrival of the flood wave downstream is frequently shorter than the time an administrative system needs to convert a measurement into an evacuation that has actually happened (Fan et al. 2020; Costa and Schuster 1988). The 2025 Matai'an event in Hualien County, Taiwan, compressed all of these into sixty-four days. A slope failure of approximately 308 million m³, the largest recorded in Taiwan, occurred on 21 July 2025 and impounded the Matai'an Stream behind a dam some 200 m high and 2,780 m wide (Chao and Yang 2026). Rainfall from Typhoon Ragasa filled the impoundment, overtopping began at 14:50 on 23 September, and approximately 15.4 million m³ of water left the lake within about thirty minutes. Two flood waves reached Guangfu Township by 16:30. Nineteen people died, five were reported missing and 157 were injured (Central News Agency 2025d; Chao and Yang 2026).

Events of this kind are usually written up twice and separately. A geoscientific literature reconstructs the failure mechanism, the breach hydrograph and the sediment budget; a social-science literature examines warning communication, vulnerability and recovery. Each is weakened by the separation. A breach hydrograph without a settlement history cannot explain why one neighbourhood filled to the eaves while another two hundred metres away stayed dry. An analysis of warning failure that treats the hazard as given cannot assess whether the protective action the state instructed was physically available to the

households instructed to take it. The five-fold repetition of the alert sequence at Matai'an, nineteen alerts followed by nineteen deaths, is legible only when the two accounts are placed in the same frame.

This paper supplies that frame and asks three questions. What preconditioned the slope, and how long had the evidence of instability been in the public record? What determined the distribution of inundation once the flood entered the plain, and what does the spatial pattern of survival say about how the settlement came to be where it is? And why did an alert sequence of unusual density fail to convert into protective action for a specific and identifiable group of residents? The answers are assembled from historical topographic maps, satellite imagery, an earthquake catalogue, agency situation reports and post-event documentary sources, and read through an extension of Cutter's (2003) Hazards-of-Place model coupled to Lindell and Perry's (2012) Protective Action Decision Model.

The case is used to advance three claims that reach beyond it. The first is analytical: that the distribution of harm in a landslide-dam breach is decided at the intersection of engineered terrain and administrative practice, so that neither a breach hydrograph nor a communication audit can locate the fatal link on its own, and the two must be modelled together. The second is conceptual: that terrain configuration and infrastructure equity are preconditions of protective action and belong inside the vulnerability model as measured variables, on the same footing as the social attributes it already contains, which we formalise as a terrain-explicit and digitally augmented extension of the Hazards-of-Place model. The third is a transferable proposition and a tool to operationalise it: that a protective-action instruction carries an evidentiary burden, discharged in advance through a building inventory and a depth threshold, and that vertical-evacuation capacity can be screened before an event by a reproducible rule stated in Section 3. The Matai'an event is treated as a critical case that tests these claims where the interval between hazard onset and impact is too short for real-time correction.

2. Study area and hazard setting

2.1 Physiographic and tectonic context

Guangfu Township occupies the floor of the Huatung Longitudinal Valley in Hualien County, 35 to 40 km south of Hualien City. The valley marks the suture between the Eurasian Plate to the west and the Philippine Sea Plate to the east, one of the most rapidly deforming terrestrial plate boundaries on Earth (Shyu et al. 2005). The Longitudinal Valley Fault bounds the valley on its eastern side and the Central Range on its western side; the Matai'an Stream drains the eastern flank of the Central Range into the valley floor. Uplift, weak and highly fractured metamorphic lithologies, high seismicity and typhoon rainfall of the order of 1,000 mm in a single event combine to give the catchment an exceptionally high sediment yield. The compound character of the site is not incidental: seismic weakening over years, episodic saturation over hours, and a channel whose conveyance a century of engineering had reduced, coincided in the disaster.

2.2 The community and its social composition

Guangfu Township had 11,683 residents as of February 2024, of whom close to half are Indigenous, predominantly Amis (Pangcah). The Fataan and Tafalong communities are among the oldest continuously occupied Amis settlements in the valley. Baseline conditions include modest household incomes, high proportions of residents aged 65 and above and of single-storey dwellings. National digital inclusion profiling documents pronounced age-cohort gaps in internet use and application familiarity, concentrated in the rural, older and Indigenous demographics that predominate in the township (Ministry of Digital Affairs 2023; Taiwan Network Information Center 2022). For Indigenous communities in Taiwan, disaster vulnerability is historically constituted through colonial dispossession, forced migration and exclusion from land governance (Huang 2018; Lin 2025), and this history bears on where people live and therefore on what depth of water reaches their floor, a relationship Section 4.2 examines directly.

3. Materials and methods

3.1 Design and sources

The study is a single-case, mixed-evidence reconstruction. Documentary analysis (Bowen 2009) supplies the institutional and social record; historical cartography and satellite imagery supply the physical record; a published seismological and remote-sensing study of the failure supplies the mechanical account that this paper does not duplicate (Chao and Yang 2026). Historical topographic evidence was drawn from the Taiwan Historical Map Overlay System of the Center for Geographic Information Science, RCHSS, Academia Sinica (2026), which georeferences the Japanese colonial survey series against contemporary imagery: the 1:20,000 Taiwan Bau-Tu series of 1904, the 1:300,000 topographic map of 1924, and the 1:50,000 topographic map of 1954. Satellite evidence of pre-failure deformation was drawn from the 2025 natural disaster yearbook of the National Science and Technology Center for Disaster Reduction (2026). Post-event imagery and the earthquake catalogue were obtained from BigGIS, the geospatial platform of the Agency of Rural Development and Soil and Water Conservation, Ministry of Agriculture (2026). Institutional sources comprise situation reports of the Central Emergency Operations Center, technical bulletins of the Forestry and Nature Conservation Agency, and notices of the Ninth River Management Bureau. Official written reviews of monitoring, warning and evacuation submitted to the Legislative Yuan were consulted for the institutional response (Ministry of the Interior 2025), and independent geoscientific assessments of the failure and dam were used to corroborate the physical record (Chao and Yang 2026; Lai et al. 2026). Documentary sources on warning delivery, evacuation and mortality comprise reporting from July 2025 to March 2026 by Central News Agency, Public Television Service and The Reporter, together with the Tzu Chi Foundation's published operational materials. Verbatim meeting transcripts and audio recordings were excluded, and no oral testimony was used as evidence. Documents were retained where they reported a quantitative parameter, recorded an institutional decision, or provided a timeline or after-action account; opinion pieces and unverified social media content were excluded. The documentary-source register (corpus manifest) is provided as Supplementary Table S7 and the construct codebook as Supplementary Table S8, while the event

chronology, hydro-geomorphic metrics, exposure and impacts, the alert-and-evacuation record and the community response are compiled in Supplementary Tables S1–S5; a claim–evidence matrix links each core claim to its supporting records. Where sources conflicted, the later-dated technical agency figure was preferred and the discrepancy retained in an audit trail. All times are local (UTC + 8).

3.2 Analytical framework

Cutter's (2003) Hazards-of-Place model structured the coding around hazard potential, geographic context and social fabric, with two extensions. The geographic context domain was made terrain-explicit, so that channel elevation relative to the settlement, dike configuration and neighbourhood elevation enter the model as measured quantities. The social fabric domain was extended with a digital access and practices subdomain covering device access, channel familiarity, modality trust, connectivity reliability, language accessibility and the presence of digitally fluent co-residents. The extended model was coupled to Lindell and Perry's (2012) Protective Action Decision Model, which locates three sequential nodes at which compliance can be arrested: threat perception, stakeholder guidance and protective action search. The coupling disaggregates a single distributional outcome into discrete points at which an identifiable authority decision shaped the information environment or the physical options available; every node is read as a property of provision. Warning fatigue was approached through three documentary proxies: alert cadence over the roughly seventy-two hours before overtopping; post-event clarification and rumour-correction counts; and any documented change in evacuation uptake across successive notices. No household-level response data were available, so warning fatigue is treated throughout as a hypothesis consistent with the cadence and not as a measured effect.

3.3 Vertical-evacuation screening protocol

Vertical evacuation requires that a building offer a floor above the water with enough freeboard to remain habitable while the flood passes. The protocol provides a first-stage screening threshold, not an engineering certification. Let d be the expected peak flow depth at the building, c a freeboard allowance in metres, and h the local storey height; the refuge floor must lie above d plus c , so the minimum number of storeys screened is $n = \text{ceil}((d + c) / h) + 1$. With the storey height of 3.0 m typical of reinforced-concrete residential construction in rural eastern Taiwan and a freeboard allowance of 1.0 m, a design depth of 2 m screens to two storeys, 4 m to three, and 6 m to four. A complete suitability assessment also requires evidence on peak water level, flow velocity, debris impact, scour, structural integrity, access and occupancy capacity, and the values of d , c and h should be varied across a plausible range in sensitivity analysis. Three operations complete the protocol before an event: assign an expected depth to each block from the inundation model already used for evacuation planning; classify every building in the exposed area by storey count, using cadastral or house-tax records where available and high-resolution imagery and street-level photography where they are not; and compute, for each residential parcel, the walking distance and time to the nearest building meeting the threshold. The protocol was applied to Matai'an at the level at which verifiable data exist. The building-by-building inventory could not be completed for this paper: national house-tax dwelling statistics disaggregated by storey are published only at township level, and building-level attributes for Guangfu were not retrievable within the study

period. The inventory is therefore presented as a specified and reproducible operation, and the finding in Section 4.5 concerns the documented absence of any such inventory at the time the instruction was issued.

3.4 Ethics

The study analysed publicly available documents and platform records. No human participants were recruited, no interviews were conducted, and no personally identifiable data were collected or processed; formal institutional ethical review was therefore not required. The authors followed the ethical principles for research on disaster-affected communities, including respect for the dignity of the Amis residents whose experiences are described, accurate reporting of available data, and explicit acknowledgement of the limits of secondary documentary analysis for capturing lived experience.

4. Findings

4.1 Hazard genesis: an old landslide, reactivated

The physical mechanism of the Matai'an failure has been established elsewhere through seismic source inversion, and this section does not reconstruct that mechanism; it assembles the antecedent record that bears on warning practice (Chao and Yang 2026). The failure occurred on ground already identified as unstable in the cartographic record. The 1:300,000 topographic map of 1924 records an arcuate crack close to the western boundary of the 2025 failure surface, and the 1:50,000 topographic map of 1954 shows the contour pattern characteristic of a landslide at the same location (Center for Geographic Information Science 2026). The site had been drawn as a landslide for a century before it became one on the scale of 2025, a reading the seismological reconstruction reaches independently in noting long-term gully erosion and local failure in the subcatchment over at least seventy years (Chao and Yang 2026).

Evidence of contemporary movement predates the failure by close to eight years. Sentinel-2 scenes of 28 October 2017 and 16 January 2018 show slope failures and rock-mass deformation in the source area (National Science and Technology Center for Disaster Reduction 2026), and from April 2024 tension cracks widened progressively over approximately fourteen months, traceable in successive Sentinel-2 scenes to April 2025 (Chao and Yang 2026).

The seismic loading of that interval was substantial. Between 16 January 2018 and the day of failure on 21 July 2025, 198 earthquakes of magnitude 5.0 or greater were recorded with epicentres within 50 km of the site: 179 in the range 5.0 to 6.0, eighteen in the range 6.0 to 7.0, and one of magnitude 7.0 or above, as Table 1 summarises (Agency of Rural Development and Soil and Water Conservation 2026). The last of these, the Hualien earthquake of 3 April 2024, produced a peak ground acceleration of 216.4 gal at the site and initiated the crack development that the satellite record then tracked (Chao and Yang 2026); an independent assessment attributes 779 landslides across 433.93 ha in the wider area to that earthquake (Lai et al. 2026). Two implications follow for warning practice. The assessment of August 2025 described the impoundment as relatively stable, a judgement made about a dam whose

stratification, produced by two failure stages with different mechanics, was not then known. And a hazard with a documented antecedent history spanning a century, and observable deformation spanning eight years, offered a preparation window measured in years, whereas the window the population was eventually given was measured in minutes.

4.2 Terrain control on inundation: a perched channel and an open dike

The distribution of damage in Guangfu was determined by elevation, and the elevations in question are the product of a century of channel management. The Matai'an Stream's active corridor was approximately 2,690 m wide in 1948; successive dike construction reduced it to roughly 400 m, and continuous sediment accumulation within that confined corridor has raised the bed until the channel now runs above the surrounding plain, a configuration termed a perched or suspended river (Public Television Service 2026). At the time of the breach, midstream deposits amounted to some 51 million m³ and downstream deposits to some 18 million m³ (Public Television Service 2026).

The stream exits its gorge near Guangfu and spreads onto a large alluvial fan of braided channels before joining the Hualien River, so the town sits on the depositional surface the channel has built (Ninth River Management Branch 2025). Local relief compounds the effect. The southern embankment is an open-dike design, in which a deliberate gap permits drainage and temporary flood retention (Public Television Service 2025b). When the flood stage rose, that aperture functioned as an intake, and flow entered the built-up area on the lower ground to the south of the channel before further streams closed the remaining escape routes (Public Television Service 2025b 2026). The flood did not spread outward from the channel as an undiked floodplain would predict; it was delivered through a single aperture to the lowest and most densely settled ground in the township, so that terrain concentrated exposure on that ground. Precise elevation differentials between the perched bed, the embankment segments and individual neighbourhoods await confirmation against a national digital elevation model and river-authority survey data (Section 5.5).

Against that pattern, the 1904 cartographic overlay is instructive. The extent of the Fataan community recorded on the 1:20,000 Taiwan Bau-Tu sheet of 1904 sits on locally higher ground close to the Matai'an Stream, and Fig. 1 overlays that footprint on the September 2025 imagery and shows that the pre-colonial settlement lay largely outside the zone of deepest inundation and sediment burial, notwithstanding its proximity to the channel (Agency of Rural Development and Soil and Water Conservation 2026; Center for Geographic Information Science 2026). Much of the housing that flooded was built after 1945 as the settlement expanded into the low ground to the south and east. The pattern is consistent with scholarship documenting how Indigenous settlement siting encodes accumulated hazard experience, and with the finding that dispossession and land-use change progressively displaced communities from the ground their siting logic had selected (Hsu et al. 2015; Huang 2018; Lin 2025). The claim is bounded: the overlay establishes a spatial relationship between an older settlement

footprint, local elevation and inundation extent, and it does not by itself establish the reasoning by which the site was chosen, for which oral-historical work would be required (Section 5.5).

4.3 The alert sequence and the ninety-minute window

The impoundment formed on 21 July 2025 and was assessed as relatively stable that August. Typhoon Yangliu prompted an orange alert on 11 and 12 August, under which 697 residents were evacuated. A revised assessment on 19 September placed 275 people in the affected zone; on 21 September the assessment was revised upward twice within three hours, and by 18:00 the Central Emergency Operations Center had designated 1,837 households and 8,524 people for mandatory evacuation. A red alert followed at 07:00 on 22 September, and nineteen official alerts were issued between 20 and 23 September; the full sequence and the evacuation mediators are compiled in Supplementary Tables S1 and S4 (Public Television Service 2025b; Central News Agency 2025a). The county government's tally at the eighth central working meeting recorded, as of 13:30 on 23 September, 8,524 residents accounted for in the affected zone across the 1,837 designated households (6,843 registered residents, the difference reflecting residents registered but not present). By protective-action mode the 8,524 comprise 185 in shelters, 3,100 with family or friends and 5,239 in vertical evacuation, three mutually exclusive categories that sum to the total (Ministry of the Interior 2025). Overtopping began at 14:50; peak outflow of approximately $8,800 \text{ m}^3 \text{ s}^{-1}$ occurred within thirty minutes and was around four times the anticipated value; the Matai'an Bridge on Provincial Highway 9 failed at approximately 15:30; and two flood waves reached Guangfu by 16:00 and 16:30 (Central Emergency Operations Center 2025a 2025b; Petley 2025a; Supplementary Table S2). The interval from overtopping to the second wave was ninety minutes, the operational envelope within which every remaining protective action had to be selected, communicated, understood and completed.

4.4 Differentiated compliance failure

Four mechanisms are traceable in the documentary record, and each connects to a decision taken by an authority before the event; Table 2 sets out the four mechanisms alongside their administrative origins and the corrective standard each implies.

Channel-access gaps. National digital inclusion profiles document substantially lower smartphone and application use among adults aged 65 and above in rural eastern Taiwan, concentrated in the demographic most prevalent in Guangfu's low-lying neighbourhoods (Ministry of Digital Affairs 2023; Taiwan Network Information Center 2022). Cell broadcast alerts and Disaster Prevention Information Service app notifications, the primary state-issued digital channels, did not reach these residents with equal effectiveness. Non-digital channels carried the warning for this population, and documented impairment of the local public broadcast system reduced the redundancy the multi-channel architecture was designed to supply (Yahoo News Taiwan 2025; Supplementary Table S4).

Message-semantic ambiguity. The instruction to conduct vertical evacuation is appropriate for shallow, short-duration floods in robust multi-storey buildings. In the high-depth, high-velocity, debris-laden flow documented at Matai'an, an upper floor offers inadequate protection in single-storey and structurally

weak dwellings, which predominate in Guangfu's low-income and Indigenous residential areas. The central instruction did carry a building-type condition: reinforced-concrete buildings of two storeys or more were identified as candidates for moving to the second floor or above according to terrain (Ministry of the Interior 2025). Two gaps separated that condition from protective action. The condition was generic and was never converted into a per-address determination; the evacuation was designated by overlaying household-registration data to produce door-numbered addresses, classified by household and not by building height, so which of the 1,837 designated addresses actually met the reinforced-concrete two-storey condition was not established (Ministry of the Interior 2025). And the two-storey threshold left little margin for the depths that occurred: the sediment deposit later recorded on the worst-affected street reached 2.6 m, which already exceeds one storey, and the peak flow depth that governs the true requirement is not established, so a two-storey refuge cannot be assumed to have stood clear of a debris-laden flow. No depth tier and no timing rule accompanied the instruction, and the appropriateness of upper-floor shelter became a matter of public dispute (Central News Agency 2025b; The Reporter 2025).

Alert cadence and warning-fatigue hypothesis. The nineteen alerts issued across roughly seventy-two hours followed earlier overflow notices for lower-magnitude incidents that had produced limited harm. The warning literature reports that such a cadence can raise household action thresholds, as prior non-catastrophic alerts lower the subjective probability of a catastrophic outcome even as the objective probability rises (Sadiq et al. 2023; Villarreal et al. 2025). No household-level response data exist for Matai'an, so this mechanism is advanced as a hypothesis consistent with the documented cadence and not as a measured effect; a rumoured third wave that required official clarification during the response phase is recorded as a further strain on channel credibility (Central News Agency 2025c).

Governance-communication gap. Nineteen alerts represent vigorous issuance at the centre. The record of the local delivery interface documents siren patterns that residents could not interpret, uncoordinated loudspeaker scripts, absent evacuation transport for residents with limited mobility, and incomplete door-to-door coverage in the deepest-flooding zones (Central News Agency 2025c; Public Television Service 2025a). This gap is a structural property of Taiwan's disaster-governance architecture, in which the centre issues alerts and standards while local government carries implementation without mandated minimum standards for multi-channel delivery (Tso and McEntire 2011).

4.5 Vertical evacuation: an instruction issued into an uninventoried building stock

Vertical evacuation was the mode recorded for the largest single share of residents under the order at Matai'an: 5,239 of 8,524, or 61.5 per cent, sheltered in place on an upper floor (Ministry of the Interior 2025). The reported fatalities fell within this vertical-evacuation group, although household-level linkage between warning receipt, chosen action, building form and cause of death is not established. Fozu Street in the low-lying urban area was the worst-affected location, a severity confirmed in the central government's field survey (Ministry of the Interior 2025; Supplementary Table S3), and documentary

reporting associates the deceased with single-storey dwellings (Public Television Service 2025b 2026); the demographic detail rests on documentary journalism and awaits household-level confirmation (Section 5.5).

Applying the screening threshold from Section 3.3 to the documented conditions makes the mismatch explicit while marking its uncertainty. The sediment deposit on Fozu Street reached 2.6 m, a documented lower bound on the water that passed; the peak flow depth, which governs the requirement, is not established. Treating the 2.6 m deposit as a conservative design depth, the screen returns three storeys, and no refuge above the water existed at all below two storeys. A single-storey dwelling offered no screened option, and its occupants were nevertheless included in an instruction whose safe execution presupposed one.

The decisive finding is administrative and rests on the contents of the documentary record. The evacuation was designated by overlaying household-registration data to produce door-numbered addresses, classified by household and evacuation mode (Ministry of the Interior 2025). No published evacuation record disaggregates the exposed dwellings by building height, so the reinforced-concrete two-storey condition attached to the vertical-evacuation instruction was never resolved into a determination of which designated addresses met it, and the households for whom vertical evacuation was invalid were neither separately identified nor offered transport to a horizontal destination. That single-storey and timber-framed dwellings were present in the exposed stock is confirmed by the post-event structural-safety assessments, which recorded timber-framed houses among those requiring demolition (Ministry of the Interior 2025). Table 3 sets out the requirement schedule this implies and the pre-event operations needed to satisfy it.

4.6 Substitution at the recovery stage

The Buddhist Tzu Chi Foundation deployed from 24 September an analogue-to-digital intake workflow: residents registered at stations, by QR-code check-in or door-to-door canvassing, and needs were geocoded into work orders for volunteer dispatch (Buddhist Tzu Chi Charity Foundation 2025a 2025b). By converting offline household reports into a spatially referenced dispatch system, the foundation bridged at the recovery stage the same access gap that had contributed to uneven warning compliance during the evacuation. Its significance for the present argument is as a feasibility signal: a geocoded, multi-modal intake spine was assembled within twenty-four hours of the flood by an organisation outside the statutory chain. Whether an equivalent spine standing before the event could identify single-storey dwellings and residents with limited mobility across the exposed area would require verification, since pre-event statutory data access, privacy protection, maintenance responsibility and coverage testing differ from post-event registration. Across the 921 earthquake, Typhoon Morakot and Matai'an, the same foundations have repeatedly supplied the delivery, intake and recovery functions that the statutory design assigns to no one (Tsai et al. 2022), and the durability of that arrangement is what makes it a governance question.

5. Discussion

5.1 Preconditioning, and the limits of a stability assessment

The Matai'an record shows a hazard whose evidence base was long, public and distributed across archives that no single agency was required to consult. A crack on a 1924 map, a landslide contour on a 1954 map, deformation in 2017 and 2018 imagery, 198 earthquakes of M 5.0 or greater within 50 km over 7.5 years, and fourteen months of widening cracks after April 2024 together constitute a coherent signal legible only to an analysis that crosses the boundary between historical cartography, satellite monitoring and the seismic catalogue (Agency of Rural Development and Soil and Water Conservation 2026; Center for Geographic Information Science 2026; Chao and Yang 2026; National Science and Technology Center for Disaster Reduction 2026). Landslide-dam assessment in seismically active mountain regions would be strengthened by a standing obligation to interrogate the historical map series and the multi-decadal seismic record for any newly formed impoundment before a stability judgement is issued. The subsequent history bears this out: a further breach on 21 October 2025 caused no fatalities after pre-emptive evacuation, and works completed in January 2026 reduced the impoundment to under 30,000 m³ (Petley 2025b; Public Television Service 2026). The central government has since opened a revision of the evacuation-and-response plan for the site, including tabletop and live exercises and a review of accountability (Ministry of the Interior 2025).

5.2 Terrain as a vulnerability variable

Cutter's Hazards-of-Place model incorporates geographic context, usually operationalised as proximity to the hazard source. The Matai'an case shows the limits of proximity as a proxy. The pre-1904 Fataan footprint is closer to the channel than much of the housing that flooded, and it was largely spared; the determining variable was elevation relative to the perched bed and position relative to the dike aperture. A terrain-explicit specification of geographic context, carrying bed elevation relative to the settlement, dike configuration and neighbourhood elevation as measured quantities, would have distinguished the two. The settlement history adds a second layer: the ground that proved safe was occupied first, and the ground that flooded was occupied later, under conditions in which the older siting logic no longer determined where people could live, a sequence documented across Taiwan's Indigenous communities as an outcome of land alienation and administrative resettlement (Hsu et al. 2015; Huang 2018; Lin 2025). Reading the 1904 sheet against the 2025 inundation therefore offers a method as well as an illustration: the historical cadastral and topographic series records which ground was selected under accumulated hazard experience, and can inform contemporary land-use and resettlement planning.

5.3 Why an alert sequence of unusual density did not convert into action

The Protective Action Decision Model locates three nodes at which compliance can be arrested, and each was disrupted at Matai'an by a decision that can be named. Threat perception was blunted by cadence: absent a graduated semantic-escalation protocol, with distinct markers separating routine

overflow notices from imminent-failure alerts, the nineteenth alert in a long sequence of low-consequence notices carried no greater perceived urgency than the first, and a standing requirement for cadence management across compound events would address this at source. Stakeholder guidance was undermined by an instruction whose validity conditions were unstated: vertical evacuation was directed at a population containing many single-storey households, without depth thresholds, building-type conditions or timing rules, and without any inventory that would have permitted those households to be identified, so that the corrective is a conditional messaging standard tied to depth tier and building height, which requires the inventory to exist before the message is drafted. Protective action search was constrained by channel design, and the recovery-stage assembly of a geocoded intake spine in a day shows the constraint was removable.

5.4 Designing for the hour without power or network

A warning system is one component of a preparedness architecture that has to function when the electrical and telecommunications systems it presupposes are unavailable. The principle is operational: for each critical function in a community's preparedness plan, an assessor can ask what completes that function with no electricity, and record the answer. An electric well pump yields no water when the line is down even where the pipework survives, whereas a hand pump serves for as long as people can work it, and solar charging addresses the phone but not drinking water, sanitation or washing. The Matai'an evacuation zone lost mains power and its public broadcast system as the typhoon approached (Yahoo News Taiwan 2025), placing this consideration inside the case.

5.5 An integrated indicator set, and limitations

The analytical yield of the case is a proposition that travels: where warning lead time is shorter than the administrative cycle needed to convert a measurement into completed protective action, survival is governed by preconditions fixed before the event, namely the terrain that sets inundation depth and the building stock and channels that set the feasibility of the instructed action. The boundary conditions are equally explicit; the proposition applies to rapid-onset impoundment failures in settled valleys and weakens where lead times are long or where exposure is uniform. Table 4, from the indicator set in Supplementary Table S6, sets out the extension of the Hazards-of-Place model proposed here, in which terrain configuration and infrastructure equity enter as preconditions of protective action, moving the unit of measurement from community resilience after an event to the conditions for protective action before one. Three indicators are directly operational: a vertical-evacuation capacity index reporting, for each exposed block, the proportion of dwellings meeting the storey threshold at the design depth and the maximum walking time to a compliant building; a warning-reach equity index reporting the proportion of exposed households with at least one confirmed functional non-digital channel; and a mechanical-fallback index reporting the proportion of critical functions with a documented no-power completion path. Each is computable from data local authorities already hold or can assemble, and each converts a general commitment under Sendai Priorities 2 and 4 into an auditable quantity (United Nations Office for Disaster Risk Reduction 2015).

Four limitations bound the analysis. It relies on secondary documentary sources, and triangulation against technical agency reports mitigates measurement uncertainty without eliminating it. The elevation relationships in Section 4.2 derive partly from journalistic reconstruction and require verification against a national digital elevation model and river-authority survey data before they are used quantitatively. The building-height inventory specified in Section 3.3 was not completed, so the vertical-evacuation finding concerns the documented absence of an inventory and the mismatch between instruction and building stock, and does not rest on a count of compliant buildings. The survival of the pre-1904 Fataan footprint is established as a spatial relationship and not as a demonstrated siting rationale; community-led oral-historical work with Fataan knowledge holders, conducted on the community's terms and with its prior agreement on data use, collaborative interpretation and return of findings, is the appropriate next step and would also allow the mortality pattern to be examined at household level. Any cultural siting interpretation must be community-led or co-verified. Two further limits qualify the analysis: warning fatigue is a hypothesis and not a measured effect, since no individual response data exist, and the three operational indicators of Table 4 are proposed measures that have not yet been computed for this case.

6. Conclusions

The 2025 Matai'an disaster is legible as a success and as a failure, and both readings are supported by the same figures. Nineteen alerts were issued, more than 8,500 residents were accounted for under a protective-action mode, and the great majority of those in the hazard zone survived; nineteen people died, and the reported fatalities fell within the group that had complied with the instruction the state gave them, in a setting where the building condition attached to that instruction was neither matched to individual households nor calibrated to the depths that occurred, on the lowest ground the dike aperture fed. Household-level linkage between warning, action and death remains for future research to establish.

Three conclusions follow. The physical evidence of hazard at this site was a century old and publicly archived, and its assembly required only that historical cartography, satellite monitoring and the seismic catalogue be read together, so landslide-dam assessment protocols should require that reading. The distribution of harm was set by terrain that a century of channel engineering had produced, and by a settlement pattern that had moved off the ground earlier occupants selected, so terrain configuration and settlement history belong inside the vulnerability model as measured variables. And a protective-action instruction carries an evidentiary burden: an authority that directs a population to move upward asserts that upward movement is available to them, and that assertion is verifiable in advance through a building inventory and a depth threshold that any local government can compute. At Matai'an the assertion was made and the verification was absent, and closing that gap is the paper's central practical claim. Compound hazards of this kind will recur across the seismically active, typhoon-exposed mountain fronts of the Asia Pacific, and the interval they allow will remain short; what can be extended is the interval before the event, during which the archives can be read, the buildings counted, the channels tested and the mechanical fallbacks installed, at a cost far below the relief and reconstruction expenditure that followed this event.

Table 1
Earthquakes of local magnitude (ML) 5.0 and above with epicentres within 50 km of the Matai'an landslide site, 16 January 2018 to 21 July 2025

Magnitude range	Number of events
$M \geq 7.0$	1
$7.0 > M \geq 6.0$	18
$6.0 > M \geq 5.0$	179
Total	198

Note: compiled from the BigGIS earthquake catalogue (Agency of Rural Development and Soil and Water Conservation 2026).

Table 2
Warning compliance failure mechanisms and their administrative origins

Mechanism	Documentary evidence	Administrative origin	Corrective standard
Channel-access gap	Lower smartphone and application use among residents aged 65 and above in rural eastern Taiwan; impaired public broadcast system during the typhoon approach	Primary alert channels designed as digital, with analogue redundancy unmandated and unmaintained	Mandated multi-channel redundancy with pre-event functional testing of every non-digital channel
Message-semantic ambiguity	Vertical-evacuation instruction issued without depth threshold, building-type condition or timing rule; subsequent official acknowledgement of confusion	No conditional messaging standard tying instruction to flow depth and building height	Depth-tiered, building-conditioned message templates, contingent on a building-height inventory
Warning fatigue	Nineteen alerts in seventy-two hours following earlier low-consequence overflow notices; rumour requiring official correction during response	No cadence-management or semantic-escalation protocol for compound events extending over weeks	Graduated escalation markers distinguishing routine notices from imminent-failure alerts
Last-mile delivery gap	Uninterpretable siren patterns, uncoordinated loudspeaker scripts, absent transport for residents with limited mobility, incomplete door-to-door coverage	Central alert production with delivery devolved to local government without minimum service standards	Mandated minimum delivery standards with a named responsible officer and an auditable sweep record

Table 3

Vertical-evacuation screening schedule at a storey height of 3.0 m (illustrative scenario), with the pre-event operations required to satisfy it

Design flow depth d (m)	Minimum storeys $n = \text{ceil}((d + c)/h) + 1$, $c = 1.0 \text{ m}$, $h = 3.0 \text{ m}$	Status of single-storey dwelling	Pre-event operation required
2.0	2	Non-compliant	Assign expected depth to every exposed block from the inundation model already used for evacuation planning
2.6 (documented deposition, Fozu Street)	3	Non-compliant	Classify every building by storey count from house-tax or cadastral records, imagery and street-level photography
4.0	3	Non-compliant	Compute walking distance and time from every residential parcel to the nearest compliant building
6.0	4	Non-compliant	Identify households with no compliant building within the warning time and assign them horizontal evacuation with transport

Table 4

Terrain-explicit and digitally augmented extension of the Hazards-of-Place model: indicators of protective-action capacity (proposed measures; not yet computed for this case)

Domain	Indicator	Measurement	Data source
Terrain configuration	Channel-to-settlement elevation differential	Bed elevation minus neighbourhood elevation, by block	National digital elevation model; river-authority survey
Terrain configuration	Dike aperture exposure	Elevation and width of every dike opening relative to design flood stage	River management bureau design records
Terrain configuration	Historical settlement concordance	Overlay of pre-industrial settlement footprint on modelled inundation extent	Historical topographic map series
Built environment	Vertical-evacuation capacity index	Proportion of dwellings meeting the storey threshold at design depth; maximum walking time to a compliant building	House-tax dwelling records; imagery; street-level photography
Warning infrastructure	Warning-reach equity index	Proportion of exposed households with at least one confirmed functional non-digital channel	Local government channel audit; household register
Preparedness architecture	Mechanical-fallback index	Proportion of critical functions with a documented completion path requiring no electricity	Community preparedness plan audit
Social fabric	Assisted-evacuation register	Proportion of residents with limited mobility assigned a named responder and a transport plan	Long-term care register; village welfare record

Declarations

Author contributions

I-Chun Chen: data curation, methodology, visualisation, writing – original draft. Hsin-Tzu Lin: conceptualisation, investigation, writing – original draft. Jui Jen Peng: conceptualisation, investigation, writing – original draft. Jennifer Liu: conceptualisation, data curation, investigation. Yi-Chen Wu: writing – review and editing. Hsin-Hung Ho: methodology, data curation, writing – original draft. Jian-Hong Wu: resources, data curation (earthquake catalogue, historical topographic maps, terrain and slope analysis), formal analysis (geomorphological and geotechnical), validation, writing – review and editing.

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Figures

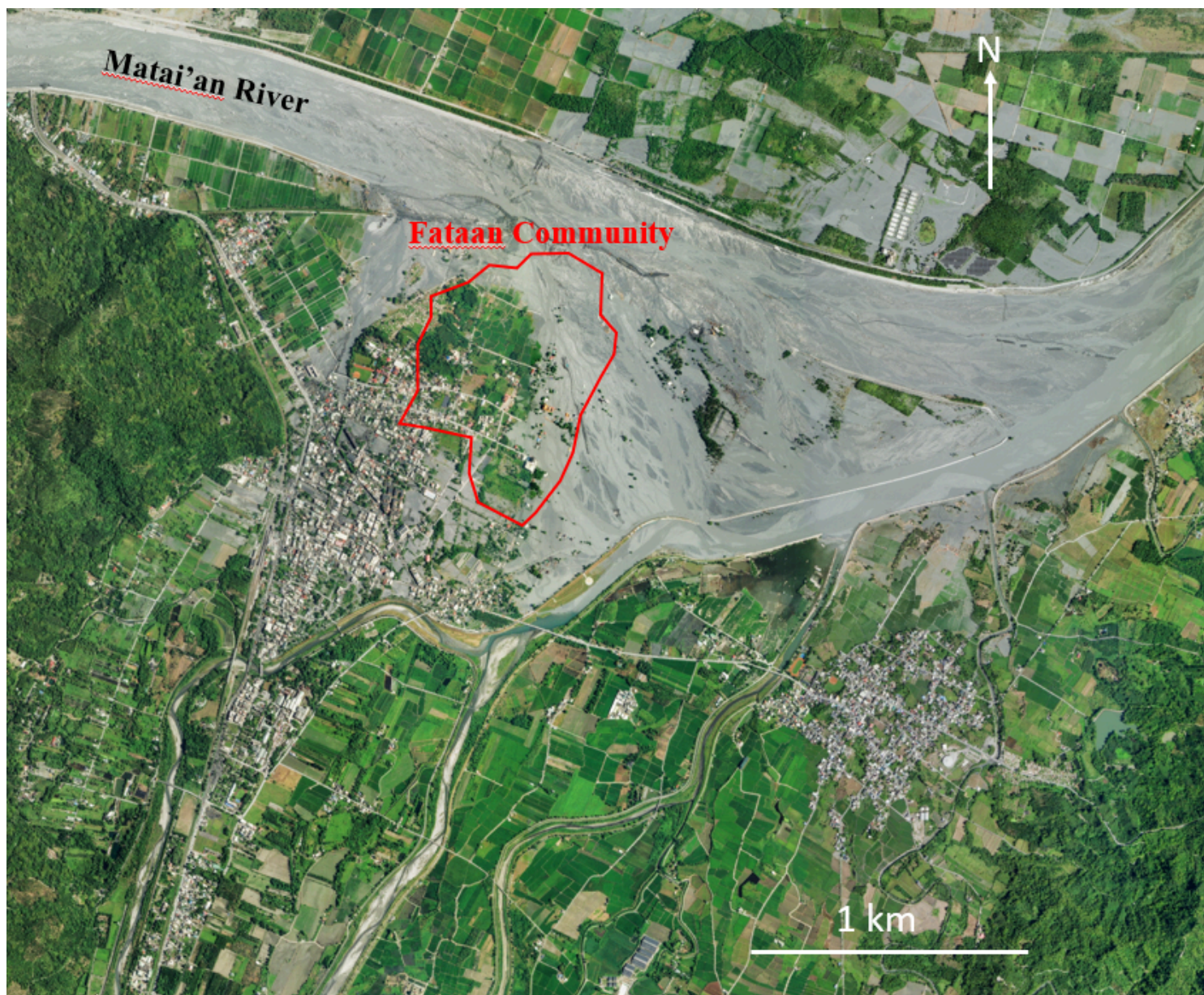


Figure 1

The pre-1904 Fataan community footprint, digitised from the 1:20,000 Taiwan Bau-Tu topographic map of 1904, overlaid on SkySat imagery of the inundated area at Guangfu, 28 September 2025. Grid north; georeferencing, coordinate system and registration error are reported in the Supplementary GIS protocol. Imagery © Planet Labs PBC, reproduced under academic licence [licence to be confirmed]. Sources: Center for Geographic Information Science, RCHSS, Academia Sinica (2026); Agency of Rural Development and Soil and Water Conservation, Ministry of Agriculture (2026)

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