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Analysis of Disaster Management Systems in Tsunami Shelter Management in Padang City

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ABSTRACT

Padang City, Indonesia, faces near-field tsunami risk where evacuation time is severely limited, making vertical evacuation shelters critical life-safety infrastructure. This study analyzes the disaster management system underpinning tsunami shelter management in Padang using a qualitative case study design. Data were drawn from policy and planning documents, the BPBD Padang shelter inventory (2019), and the BPBD tsunami evacuation plan map (2025), and analyzed through thematic analysis with source triangulation. Results indicate four systemic issues: (1) fragmented shelter definitions and incomplete inventories that weaken capacity planning; (2) a pronounced readiness assurance gap, where large nominal capacity (~53,874 people) coexists with feasibility-testing status recorded as "not yet conducted" for key shelters; (3) partial operational integration between shelters, evacuation routes, warning devices, and routine drills; and (4) governance challenges arising from a multi-owner shelter portfolio requiring clear accountability, access guarantees, and sustainable maintenance. The study contributes a readiness assurance lens that distinguishes nominal shelter availability from verified operational readiness and offers actionable implications: establishing a unified shelter registry, institutionalizing feasibility evaluation and recertification, strengthening end-to-end integration with evacuation operations, and formalizing governance instruments for privately owned shelters. These findings highlight that effective tsunami shelter management depends on governing shelters as safety-critical socio-technical systems rather than static assets.

Keyword:
Tsunami evacuation shelter, Vertical evacuation, Disaster management system, Readiness assurance.

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INTRODUCTION

Near-field tsunamis are among the most unforgiving natural hazards because the window for life-saving action is measured in minutes, not hours. In such events, the effectiveness of risk reduction is ultimately tested at street level: whether people receive (or can infer) credible cues to evacuate, whether evacuation routes remain passable under post-earthquake disruption, and whether safe destinations can actually accommodate evacuees in the required time. Evidence from recent Indonesian tsunami experiences underscores this “last-mile” fragility. In the 2018 Sulawesi earthquake–tsunami, for example, residents in the impacted areas faced a situation in which an official warning did not function as the dominant trigger for evacuation; instead, social triggers and immediate cues played a significant role, while congestion and limited mitigation measures hampered rapid movement to safety (Harnantyari et al., 2020). This matters for cities exposed to near-field megathrust sources because evacuation performance depends not only on hazard knowledge, but also on the operational integrity of the entire evacuation ecosystem, warning dissemination, route capacity, and the governance of safe destinations.

One of the most consequential “safe destination” interventions in near-field tsunami contexts is the provision of tsunami evacuation shelters, including vertical evacuation in tsunami-resistant buildings when horizontal evacuation to high ground is not feasible within available time. Yet the presence of shelters on paper does not guarantee their use or their performance under real conditions. Research has shown that evacuees’ choices can be strongly shaped by trust, perceived credibility, and social influence; in the case of tsunami vertical evacuation buildings, whether people believe a structure will protect them can determine whether the intervention saves lives at all (McCaughey et al., 2017).

Moreover, evacuation outcomes are produced by the full chain from decision-to-evacuate through movement and arrival at a safe zone. Multi-method evacuation analyses have repeatedly highlighted that time, distance, and mode choice (e.g., walking vs. vehicle use) are critical, and that planning must capture the full evacuation process rather than a single component (Kubisch et al., 2020). Demographic vulnerabilities further complicate this landscape: older adults and single elderly households may face longer evacuation times and difficulties receiving warning alerts, implying that shelter siting, accessibility, and management must explicitly address heterogeneous capabilities (Saputra et al., 2025; Y. Sun & Sun, 2019). These findings collectively imply that “shelter management” is not a narrow facilities issue; it is a disaster management system problem that links infrastructure readiness, governance, information, and human behavior.

Kota Padang, a major coastal city on the west coast of Sumatra, provides an urgent and policy-relevant setting to examine this problem. Tsunami evacuation planning studies for Padang have estimated very short arrival times on the order of 20–30 minutes for credible tsunamigenic events, implying that vertical evacuation can be a decisive option for portions of the exposed population (Muhammad et al., 2017).

A comprehensive planning effort for Padang has integrated stochastic tsunami scenario modeling with evacuation mapping and included the assessment of temporary tsunami evacuation shelters (TES) alongside integrated horizontal–vertical evacuation time mapping.

However, translating plans into reliable, usable shelter systems requires more than hazard-and-time maps; it requires sustained, accountable management that ensures shelters remain structurally adequate, accessible, communicated, and governable during both routine periods and crisis conditions.

Preliminary empirical evidence suggests that this translation remains incomplete. A readiness assessment of 23 potential public buildings in Padang for use as temporary tsunami evacuation shelters found that none of the assessed buildings met readiness expectations under the study's criteria; even buildings that met main criteria still required significant improvements in supporting facilities and infrastructure (Ophiyandri et al., 2022).

This finding is consistent with a broader pattern visible in local documentation: the shelter system exhibits signs of "nominal availability but uncertain readiness." For example, local records indicate that data on the number of shelters are not consistent across sources, figures such as 7, 28, and 37 shelters appear, and the discrepancy is linked to definitional differences (e.g., whether buildings are designed specifically as tsunami shelters or merely designated public buildings) and the absence of an integrated, updated shelter database.

Beyond inventory ambiguity, several operational vulnerabilities are documented: maintenance is described as limited, permanent managers for shelters are often absent, and shelter planning is not well integrated with evacuation route planning, early warning, and community education, leaving residents insufficiently informed about which shelter is nearest or how to access it quickly.

These issues directly threaten the core logic of vertical evacuation: when minutes are scarce, any uncertainty about where to go, whether a shelter is accessible, or whether it is safe can translate into fatal delay or maladaptive route/mode choices. More concretely, local datasets also indicate a gap between constructed capacity and verified functionality. Government-built tsunami shelters in Padang are reported with capacities (e.g., 5,000; 5,000; and 1,344 people for three dedicated shelters), yet feasibility or eligibility testing is noted as not having been conducted for these shelters; and a total shelter capacity figure (53,874 people) is presented alongside the statement that shelters have not undergone feasibility testing. In a near-field tsunami context, this is not a minor administrative detail: shelter feasibility encompasses structural reliability under strong ground shaking, safe vertical refuge, access control, internal circulation, emergency supplies, signage, and operability under power/communication disruption. At the same time, warning components that should trigger timely movement may be compromised; local documentation notes that tsunami sirens are not maintained continuously, a particularly concerning issue given the already-short arrival-time estimates. Taken together, these patterns motivate a sharper analytical question: what disaster management system governs tsunami shelter management in Padang, and how do system-level weaknesses translate into readiness gaps at the shelter level?

International scholarship increasingly provides tools to examine such questions, but important gaps remain. Modeling and simulation studies have demonstrated the utility of evacuation simulations for assessing plan effectiveness, comparing pedestrian and vehicle scenarios, and identifying bottlenecks driven by capacity constraints and interaction effects (Fathianpour et al., 2023).

Yet simulation-driven insights can only improve real-world outcomes if they are embedded within governance and operational routines that keep shelters functional and trusted. Similarly, research on behavioral dimensions, such as trust in vertical evacuation buildings and vulnerability-driven differences in preparedness and evacuation time, points to the need for management approaches that build credibility, communicate clearly, and design for heterogeneous users (McCaughey et al., 2017; Y. Sun & Sun, 2019). Emerging methods such as virtual reality and GIS-based evaluation of potential vertical-evacuation practices further illustrate how planning can be stress-tested through experiential and spatial analytics, potentially improving decision-making and shelter use.

However, fewer studies explicitly connect these behavioral and analytical advances to the institutional architecture of shelter management, covering data governance, maintenance regimes, accountability, inter-agency coordination, community-facing communication, and continuous improvement cycles.

This study therefore positions tsunami shelter management in Kota Padang as a disaster management system problem and contributes an evidence-based diagnosis oriented to policy and practice. The article asks: (1) How is the tsunami shelter management system in Padang organized across actors, rules, and resources across the disaster management cycle (mitigation–preparedness–response–recovery)? (2) What are the critical gaps in governance, data/information management, maintenance readiness, and integration with evacuation routes and warning? and (3) How do these system-level gaps plausibly affect shelter usability under near-field time constraints? By answering these questions, the paper aims to move the discussion from "how many shelters exist" to "how shelter readiness is assured," bridging facility-level assessment with system-level management mechanisms. The remainder of the paper is structured as follows: the next section reviews relevant literature on tsunami evacuation, vertical evacuation, and shelter readiness; the methodology section details the analytical framework and data sources; results present system diagnostics across key management functions; and the discussion translates findings into actionable recommendations for strengthening tsunami shelter governance and readiness assurance in Padang.

LITERATURE REVIEW

Near-field tsunami risk and the "time-compression" problem in evacuation

Coastal cities exposed to near-field tsunamis face a distinctive operational constraint: the interval between strong ground shaking and wave arrival is often too short for purely horizontal evacuation to higher ground, particularly in flat coastal plains and dense urban fabrics. In Padang, empirical and scenario-based studies repeatedly frame the critical window as tens of minutes, not hours, commonly around 20–30 minutes, meaning that evacuation effectiveness is highly sensitive to walking speed, congestion, route continuity, and the availability of vertical refuge close to exposed populations (Muhammad et al., 2017; Ophiyandri et al., 2022).

This "time compression" shifts tsunami risk reduction away from generic disaster shelter thinking (post-impact displacement) toward pre-impact life-safety infrastructure and governance: shelters must be reachable fast, opened/accessible at all times, integrated with warnings and signage, and maintained as functioning assets rather than symbolic projects.

Recent tsunami-evacuation scholarship increasingly emphasizes that evaluating evacuation plans requires integrating hazard uncertainty, transportation-network realities, and evacuee interactions. For example, stochastic tsunami hazard scenarios for

Padang show that evacuation performance must be tested across a range of plausible sources and inundation patterns rather than a single deterministic scenario.

Beyond hazard uncertainty, researchers argue that the "safety" of an approach cannot be assumed from infrastructure presence alone; it must be demonstrated through integrated modelling and realistic behavioral assumptions (Mls et al., 2023; Muhammad et al., 2021).

In short, the literature converges on a core point directly relevant to this article: shelter management quality is inseparable from evacuation system performance, because the shelter is the target of a time-critical socio-technical process.

Shelter typologies, definitional ambiguity, and capacity–accessibility as performance criteria

Tsunami shelter systems generally include (i) purpose-built vertical evacuation structures (tower/building refuges), and (ii) multi-use public buildings that can function as temporary evacuation shelters (e.g., schools, mosques, government buildings) when they meet elevation/structural and access requirements. In many countries, the second category is attractive because it expands refuge supply faster than new construction, yet it introduces governance complexity: ownership, access control, liability, retrofitting standards, and operating procedures must be negotiated and institutionalized.

A persistent challenge, highly visible in the Padang case, is definitional ambiguity: different agencies and demonstrate different counts of what constitutes a "shelter," depending on whether they count only dedicated vertical evacuation buildings or also include all potentially usable public buildings. Your own baseline materials explicitly document those varying definitions, survey years, and study scopes produce inconsistent shelter inventories, which then distort capacity assessment and investment decisions.

This issue echoes a broader international literature warning: evacuation capacity is not simply "number of shelters," but the interaction of shelter location, effective vertical safety, usable floor area, and accessibility under time pressure.

Methodologically, contemporary studies operationalize shelter performance through two linked constructs: capacity (how many people can be protected, under realistic space standards) and accessibility (whether exposed people can reach a shelter within the available time window). Accessibility research increasingly uses network-based travel-time analysis and spatial optimization to determine coverage gaps and prioritize new shelter placement. A relevant example from Japan shows that increasing tsunami shelter accessibility can enhance adaptive capacity in coastal port cities, highlighting that spatial accessibility is a governance-relevant metric: it tells decision-makers where investments and policy coordination should concentrate (Zhang et al., 2019).

In Indonesia, building-readiness studies in Padang similarly stress that public buildings' suitability as temporary evacuation shelters must be assessed against criteria tied to near-field tsunami timing and structural/functional readiness (Ophiyandri et al., 2022). Importantly, the shelter-performance discussion is no longer purely physical. Under recent multi-hazard and public-health considerations, researchers propose capacity models that incorporate minimum living/spacing requirements and operational constraints, showing that "capacity" is a policy variable shaped by management rules, not just geometry. For instance, evacuation placement modelling in Japan explicitly integrates living-space constraints into capacity calculations for tsunami evacuation centers (Nakai et al., 2021).

This line of work is crucial for Padang because it underlines a key point for disaster management systems: the shelter's protective function depends on both engineering adequacy and governance decisions about operation and use.

Integrating shelters with evacuation networks: modelling, congestion, and uncertainty

A large portion of high-impact tsunami scholarship focuses on evacuation modelling, agent-based models (ABM), microsimulation, and network optimization, to quantify expected casualties, identify bottlenecks, and compare mitigation options. Systematic reviews of agent-based tsunami evacuation models find that ABMs enable large-scale scenario testing (including rare/high-consequence combinations), but they also highlight variability in modelling practices and limited standardization in representing behavioral rules and validation (Mls et al., 2023).

This matters for shelter management research because it clarifies what modelling can and cannot do: models can identify where shelters should be and how flows might behave, but they do not guarantee that shelters will be open, maintained, signposted, or socially trusted when the event occurs, these are management and governance problems.

Recent ABM work explicitly incorporates vertical evacuation decision-making, emphasizing that evacuees may choose between horizontal routes and vertical refuge depending on distance, perceived safety, and congestion. For example, an agent-based vertical evacuation model for near-field tsunami contexts demonstrates how vertical-shelter location choice shapes community outcomes (Mostafizi et al., 2019).

Complementary studies propose allocation methods that jointly assign refuges and evacuation routes, acknowledging that the "shortest path" can be unsafe under inundation and congestion; careful allocation can improve survivability (Kitamura et al., 2020).

Location/placement research also raises policy-relevant questions about where vertical evacuation structures should be built to maximize effectiveness under hazard and access constraints (M.-C. Sun et al., 2022).

A key evolution in this literature is the move toward risk-informed, uncertainty-aware evaluation of evacuation strategies. Wang and Jia propose comparing infrastructural (e.g., vertical shelters, route widening, retrofits) and non-structural strategies (e.g., preparedness education, drills) using evacuation-risk metrics under uncertainty, enabling prioritization of robust strategies rather than those that perform only under "average" assumptions (Wang & Jia, 2021, 2022).

This is directly aligned with disaster management system analysis: it legitimizes combining structural shelter provision and preparedness governance in a single evaluative frame. Similarly, new modelling paradigms explore advanced decision support (e.g., reinforcement learning for routing under congestion) to enhance evacuation performance, underscoring that "evacuation success" is increasingly treated as a dynamic system problem (Mas et al., 2024).

For Padang specifically, stochastic scenario-based evacuation planning work illustrates why shelter management cannot rely on a single map or static assumption: inundation patterns and performance outcomes vary, and thus shelter systems must be adaptable and redundantly integrated with routes and warning practices.

Yet, modelling-centric papers often assume shelters are operationally ready (open, maintained, accessible). The managerial reality, who holds keys, who funds maintenance, what SOPs exist, tends to be treated as exogenous, even though it is decisive for real-world effectiveness.

Governance, early warning "last mile," and behavioral readiness around shelters

Disaster governance research consistently shows that policies and infrastructure fail when local implementation is weak, fragmented, or under-resourced. A recent IJDRR study on governance alignment highlights a recurring gap: disaster risk management is frequently strong at the level of formal plans but inconsistent in local operationalization, precisely the space where shelter management sits (maintenance routines, responsible units, budget continuity, and compliance monitoring).

For tsunami contexts, this governance challenge is tightly coupled with the early-warning "last mile." Reviews of tsunami early warning at the local level emphasize remaining challenges in dissemination pathways, key actor coordination, and practical barriers that shape whether warnings translate into timely, correct protective action (Dias et al., 2024).

Risk communication scholarship similarly points to persistent gaps and the need for integrated stakeholder engagement, critical because people's willingness to evacuate vertically (to a shelter) depends on trust, perceived credibility of warnings, and prior preparedness experiences (Rafliana et al., 2022).

Empirical studies using evacuation drills further demonstrate that real movement data can recalibrate assumptions about travel speed, route choice, and compliance, providing an evidence base for both modelling and management decisions (e.g., where signage is needed, which routes bottleneck, how long it takes specific groups to reach shelters) (Chen et al., 2022).

This connects to a key operational insight: preparedness activities are not "soft add-ons"; they function as system tests that reveal whether shelter networks and evacuation guidance actually work under realistic conditions.

Operational management of evacuation centers (including protocols, staffing, and coordination) becomes even more complex during compound emergencies. Research on evacuation center operation during COVID-19 in Japan, for instance, identifies management issues and necessary measures, reinforcing that shelter effectiveness is shaped by governance and operational planning, not simply building existence.

While this study is not tsunami-specific in all aspects, it illustrates a transferable lesson: evacuation facilities require detailed operational governance (SOPs, resource planning, rules for access and use) that must be institutionalized before disasters occur.

Synthesis and research gap: from "shelter as building" to "shelter as managed socio-technical system"

When synthesizing the last decade of literature, a clear pattern emerges:

1. Engineering and spatial studies provide increasingly sophisticated tools to site shelters, estimate coverage, and simulate evacuation under uncertainty (ABM, allocation methods, risk-informed assessment, and emerging AI-based routing).
2. Accessibility and capacity studies show that shelter effectiveness is a function of reachability under time constraints and operational rules for usable space, not merely the number of structures.
3. Governance and risk communication studies emphasize that local implementation, actor coordination, and trust-mediated behavior strongly condition whether warnings lead to

protective action and whether shelter networks are used properly.

However, the managerial "middle layer" remains under-examined, especially in contexts like Padang: how shelters are inventoried and standardized, how responsibilities are assigned, how maintenance and access are guaranteed, and how shelters are integrated with evacuation routes, sirens, signage, drills, and public education as a continuous system. In your empirical base, this gap is already visible: limited facility maintenance, absence of permanent managers, and weak integration with evacuation routes and early warning are identified as recurring problems; communities may not know the nearest shelter or rarely join drills, while SOPs and sustained maintenance mechanisms remain unclear. Moreover, even basic feasibility testing ("uji kelayakan") appears as "Belum" for multiple listed shelters, signaling a governance and assurance deficit rather than an engineering one alone.

Therefore, the literature supports a reframing that this article can claim as its positioning: tsunami shelter management should be analyzed as a socio-technical disaster management subsystem across the disaster cycle, mitigation (asset provision and standards), preparedness (integration with routes, signage, drills, education, and warning), response (activation, access, crowd management, interoperability), and recovery (inspection, repair, learning loops, and budget continuity). This framing directly responds to what modelling-heavy studies often treat as external assumptions, while still leveraging their performance logic (capacity, accessibility, uncertainty, risk-informed prioritization) to make management analysis policy-relevant and internationally legible.

METHODS

Study design and case boundary

This research adopts a qualitative descriptive case study to generate an in-depth account of the disaster management system governing tsunami-shelter management in Padang City, Indonesia. The qualitative approach is appropriate because the study investigates policy dynamics, implementation gaps, institutional coordination, preparedness practices, and the operational readiness of shelter assets through narrative and documentary evidence rather than relying solely on numerical measurement.

The case is bounded (i) spatially to Padang's tsunami-prone coastal/lowland areas where evacuation demand is concentrated and (ii) analytically to governance arrangements that connect shelter assets to evacuation planning, warning, and community preparedness. The unit of analysis includes: (1) policy and planning instruments, (2) institutional roles and coordination mechanisms, (3) shelter assets (purpose-built shelters and potential buildings used as temporary evacuation shelters), and (4) preparedness practices (routes, signage, drills/simulations). Case study logic is used to preserve contextual complexity and to connect institutional arrangements with real-world readiness outcomes (K Robert, 2018).

Data sources and document corpus

Data were collected through literature review, policy/planning document analysis, and secondary data from BPBD Kota Padang. The policy and planning corpus includes core national and local instruments that shape tsunami risk governance and the provisioning/management of shelters, such as Law No. 24/2007 on Disaster Management, technical guidance/regulations relevant to vertical evacuation buildings, and local planning documents (RTRW, RPJMD, and local disaster risk assessment/Kajian Risiko Bencana). Policy documents were treated as empirical data that encode institutional priorities, standards, responsibilities, and implementation logic, consistent with qualitative document analysis principles (Bowen, 2009). Secondary data from BPBD were used to capture the "operational reality" of shelter provisioning and preparedness, including: shelter/bangunan potensial inventories, stated capacities, feasibility/eligibility status, and official hazard/evacuation mapping and drill documentation. In particular, the study draws on BPBD's 2019 inventory table and the 2025 evacuation plan map as key operational references (see Section 3.3).

Shelter classification and BPBD dataset handling

Given the known definitional variation in Padang regarding what "counts" as a shelter (purpose-built vertical evacuation shelters vs. public/private buildings designated as temporary shelters), the analysis applies an explicit classification rule: (i) purpose-built shelters (dedicated tsunami evacuation structures) and (ii) potential buildings (schools, offices, hospitals, malls, hotels, places of worship, and other multi-storey facilities listed as evacuation options). This classification is aligned with the BPBD 2019 dataset structure, which distinguishes building function categories (e.g., shelter, office, school, hospital, commercial) and records key readiness attributes.

The BPBD 2019 inventory provides a structured dataset with variables including location, address, building function, number of floors, estimated capacity, feasibility-testing status (uji kelayakan), and ownership. The dataset lists three major purpose-built shelters with large nominal capacities and a wider set of potential buildings; it also indicates that feasibility testing was largely "Belum" (not yet conducted) at the time of the inventory.

To support consistent interpretation, entries were standardized (e.g., harmonizing naming conventions and building-function labels) and used analytically as evidence for readiness assurance themes, not merely as descriptive statistics. The analysis also uses BPBD's aggregate statement on total nominal capacity (≈53,874) as contextual evidence while interpreting readiness constraints (e.g., feasibility status and governance arrangements).

Data extraction procedure

All documents and BPBD materials were logged in an extraction matrix capturing: source identity, issuing institution, year, document type, and relevant text segments linked to (i) shelter standards and definitions, (ii) asset readiness and feasibility verification, (iii) governance arrangements (roles, SOPs, maintenance responsibilities), (iv) integration with evacuation routes/signage and early warning systems, and (v) preparedness practices (education and drills). This structured extraction follows recommendations that document analysis should be systematic and iterative, enabling transparency and traceability of interpretations (Bowen, 2009).

Analytical framework and thematic analysis

Data were analyzed using thematic analysis as stated in the draft. The analysis combined (a) a disaster management cycle lens (mitigation–preparedness–response–recovery) to organize evidence across phases, and (b) a readiness assurance lens to distinguish nominal shelter availability from mechanisms that ensure operability (e.g., feasibility testing, maintenance routines, access/SOP, integration with evacuation systems, and community preparedness). Thematic analysis proceeded through iterative familiarization, coding, and theme development, using a hybrid deductive–inductive strategy: an initial codebook was derived from the analytical framework, while allowing additional codes to emerge from recurrent patterns in the materials. This aligns with contemporary guidance on reflexive thematic analysis and quality practice (e.g., transparency in how themes are constructed and refined) (Braun & Clarke, 2021; Nowell et al., 2017).

Consistent with the draft manuscript, codes were consolidated into higher-order themes: (1) disaster governance and regulatory alignment, (2) technical readiness of shelter assets, (3) inter-agency coordination and operational procedures, and (4) community preparedness.

Themes were then examined to identify explanatory linkages, e.g., how governance clarity and readiness assurance mechanisms condition whether shelters can function effectively during very short tsunami response windows.

Trustworthiness, triangulation, and reporting quality

Rigor was strengthened through triangulation of sources and methods, comparing policy/planning documents, peer-reviewed research, and BPBD operational datasets/maps to validate and contextualize interpretations. This follows established triangulation guidance as a strategy for quality management in qualitative research (Flick, 2018).

An audit trail was maintained (document log, extraction matrix, codebook iterations, and theme refinement notes). To enhance credibility and confirmability, interpretations were checked across convergent and divergent evidence (including attention to inconsistencies in shelter counts/definitions and feasibility-status reporting). Trustworthiness considerations draw on practical guidance emphasizing credibility, dependability, confirmability, and reflexivity in qualitative publication (Korstjens & Moser, 2018).

Reporting of design, data handling, analysis steps, and limitations was aligned with SRQR recommendations to improve transparency and reproducibility of qualitative reporting (O'Brien et al., 2014).

RESULTS AND DISCUSSION

Central claim: readiness assurance gap in Padang's tsunami-shelter system

This section synthesizes evidence from (i) the BPBD 2019 inventory of Temporary Evacuation Shelters (TES) and potential shelter buildings and (ii) the BPBD 2025 Tsunami Evacuation Plan Map to argue a central claim: Padang has accumulated a sizable nominal vertical-evacuation capacity, but lacks "readiness assurance" mechanisms to credibly guarantee that capacity will translate into life safety during a near-field tsunami. "Readiness assurance" here refers to an auditable chain of conditions, (a) trusted and updated shelter data, (b) verified structural performance, (c) operable access and integration with routes–warnings–drills, and (d) clear governance and sustainable financing, that collectively enable shelters to function as intended under extreme time constraints.

The BPBD 2025 evacuation map shows that the city already frames tsunami risk as a spatially managed problem: hazard zones concentrated along the coastline, evacuation routes directing residents toward higher ground or vertical evacuation buildings, and designated assembly points and support facilities.

However, as the 2019 inventory demonstrates, the "system" behind that map, particularly data reliability, building readiness verification, and operational governance, still exhibits major gaps that weaken end-to-end evacuation performance.

Inventory and spatial coverage: numbers exist, but definitions and data completeness undermine planning

The draft itself notes persistent disagreement about "how many shelters Padang has," driven by definitional differences (dedicated VES vs. all public buildings that could be used), different survey years, and partial study coverage.

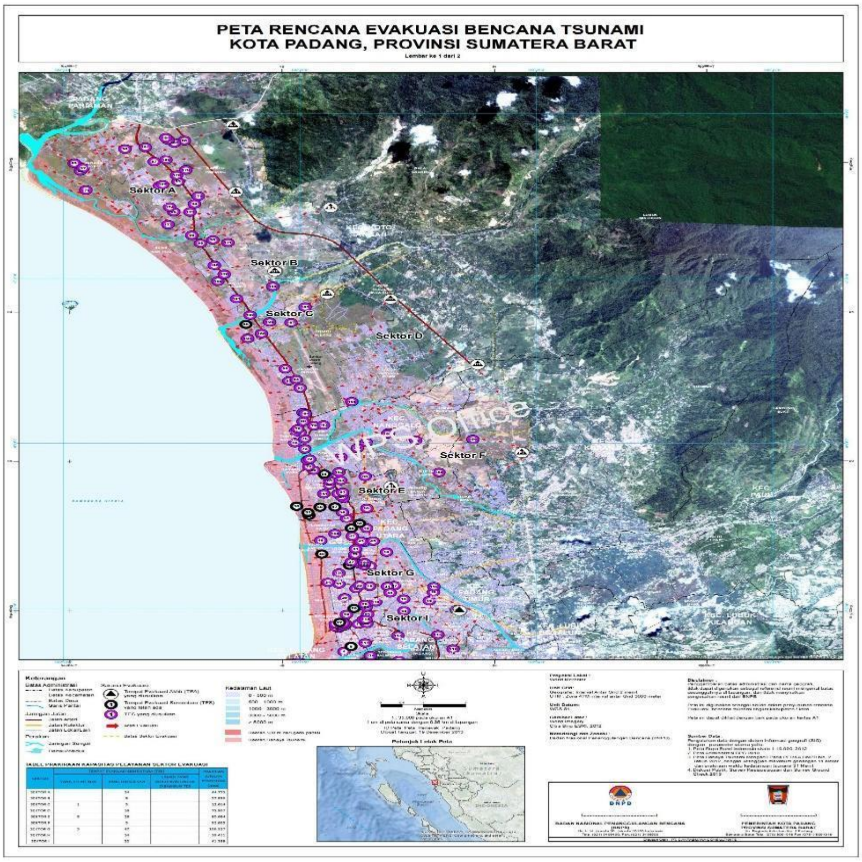

Figure 1. Padang City Tsunami Disaster Evacuation Plan Map

The BPBD 2019 dataset clarifies the scope: it lists 62 locations spanning 4 dedicated shelters and 58 potential buildings (offices, schools, campuses, hotels, worship places, markets, etc.). From Table 1, the candidate stock is functionally diverse: government/ administrative buildings (e.g., banks, agencies), education facilities, commercial buildings, and hospitality assets. This diversity can be an advantage, vertical evacuation is often a pragmatic solution where high ground is limited or warning time is short, but it also raises a planning requirement: a unified data standard for (i) "shelter designation," (ii) minimum operational conditions (24/7 access, signage, stair capacity), and (iii) "capacity" calculation rules that are consistent with engineering and crowd-safety assumptions.

Critically, data completeness is uneven. In Table 1, only 28 of 62 sites have explicit capacity figures, leaving more than half without quantified sheltering capacity (and several also missing floor counts or feasibility test status).

This is not a minor documentation problem: evacuation modelling and route assignment are highly sensitive to capacity distribution. For Padang specifically, the stochastic scenario evacuation-planning work by Muhammad et al. (2017) underscores that reliable inputs (hazard scenarios, exposure, and feasible refuge destinations) are essential for evacuation design. Without a complete, harmonized inventory, the BPBD 2025 map may remain a strong communication artifact but a weaker operational instrument, especially when population growth, new buildings, or building deterioration outpace database updates.

Implication for readiness assurance: Padang's shelter system needs a single authoritative geodatabase with standardized definitions and mandatory fields (location, floor-elevation of refuge level, structural system, capacity method, access constraints, maintenance logs). Otherwise, "coverage" cannot be confidently verified, and preparedness investments may target the wrong gaps.

Structural readiness: large nominal capacity, but feasibility certification is missing or undocumented

Table 1 indicates that Padang's nominal vertical-evacuation capacity reaches ~53,874 people when summing the listed capacities across shelters and potential buildings. Three dedicated shelters dominate the "purpose-built" category: Shelter Darussalam (5,000), Shelter Nurul Haq (5,000), and Wisma Indah Warta Bunda (1,344). Yet the same paragraph emphasizes the most consequential finding: all are recorded as "Belum" (not yet) undergoing structural feasibility testing, meaning their performance under tsunami and strong ground motion has not been formally verified in the dataset.

This matters because vertical evacuation is not simply "going upstairs." FEMA's guidance on vertical evacuation structures stresses performance objectives, siting and design loads, and the need for technically defensible safety margins under tsunami actions and earthquake shaking. The ITIC/NOAA-aligned vertical evacuation guidance similarly frames vertical evacuation as requiring structures with sufficient strength and resilience to resist tsunami effects. In other words, a building can be tall but still not be an evacuation refuge if its structural detailing, load path, foundation behavior, or non-structural safety (stairs, egress bottlenecks, façade hazards) is not assured.

The Table 1 pattern aligns with local engineering evidence: Ophiyandri et al. (2022) assessed candidate public buildings in Padang using multi-criteria readiness indicators and found none met readiness as tsunami evacuation shelters, implying that designation without verification can produce a false sense of security.

This external finding reinforces the internal BPBD 2019 signal: the city's challenge is no longer "finding tall buildings," but institutionalizing a certification and recertification pipeline, engineering review, retrofit prioritization, and periodic re-inspection.

Implication for readiness assurance: readiness must be demonstrated through documented feasibility tests (structural evaluation, refuge-floor elevation relative to inundation/run-up assumptions, and safe egress capacity). Nominal capacity should be treated as conditional until verified.

Operational integration: routes exist on maps, but access, warning reliability, and drills are inconsistent

The BPBD 2025 evacuation map explicitly depicts coastal hazard zones and planned evacuation routes guiding residents toward higher ground or vertical evacuation buildings, with supporting facilities and assembly points. This is a crucial backbone for evacuation governance. However, the draft also documents operational weaknesses: some residents do not know the nearest shelter, drills are not routine, and warning infrastructure (sirens, coordination chain) experiences maintenance shortfalls.

These gaps are acute in near-field settings where the effective window for evacuation can be short; the draft references an estimated 20–30 minutes post-earthquake context, where decision and movement time are decisive. Evidence from Padang-focused readiness work also highlights similar near-field constraints.

International literature consistently shows that drill experience improves evacuation behavior. For example, a study of post-event behavior after the Great East Japan Earthquake reported significantly higher evacuation among those with prior drill participation.

Meanwhile, tsunami risk-perception research synthesizes that hazard understanding, trust, and perception shape whether people act quickly and comply with warnings—factors that can lengthen decision time if weak. This directly connects to Padang's "readiness assurance" problem: even a structurally adequate shelter will underperform if people cannot reach it quickly, if access is blocked (locked gates, unclear entry points), or if warning and routing cues are ambiguous.

The draft's own recommendations are operationally precise—integrate BPBD TES maps into schools and community services, schedule drills, maintain signage and routes, and assign shelter managers at the kelurahan level. These are not "soft" add-ons; they are control points that determine whether the planned network behaves like a system under stress.

Implication for readiness assurance: the city needs an end-to-end evacuation performance standard (route reachability time, door/entry availability, stair throughput, signage legibility, siren uptime, drill frequency) and routine audits that link the map to real-world access.

Governance, ownership, and sustainability: multi-owner assets require clear accountability and recurring budgets

Table 1 shows a near-even ownership split across the candidate stock: 29 government-owned and 33 privately owned buildings (including hotels, malls, schools, and worship facilities). This matters because vertical evacuation in existing buildings requires agreements about public access during emergencies, liability, maintenance responsibilities, and continuity (e.g., renovations, change of ownership, or functional repurposing). The draft explicitly observes that some buildings are counted as shelters but remain multi-use facilities without permanent evacuation management, creating both physical readiness issues (access, stairs, sanitation) and administrative readiness issues (who operates the shelter during crisis). The sustainability problem is also budgetary. The draft argues that shelter effectiveness erodes without integration into routine operational financing and land-use governance; "maintenance as a recurring cost" rather than a one-off capital project is highlighted as essential.

Table 1. Temporary Evacuation Shelters (TES) and Potential Shelter Buildings, Padang City (BPBD 2019)

No	Location	Function	Number of Floors	Capacity	Feasibility test	Ownership
1	Wisma Indah Warta Bunda	Shelter	4	1.344	Not yet	Government
2	Shelter Darussalam	Shelter	6	5	Not yet	Government
3	Shelter Nurul Haq	Shelter	6	5	Not yet	Government
4	Shelter Air Tawar Timur	Shelter	4	—	Not yet	Government
5	Bank Indonesia	Office	4	—	Not yet	Government
6	Bank Nagari	Office	6	1	Not yet	Government
7	BPK	Office	3–4	800	Not yet	Government
8	Bappeda Prov. Sumbar	Office	4	—	Not yet	Government
9	Dinas Peternakan Prov. Sumbar	Office	3	—	Not yet	Government
10	Dinas PU & Permukiman Prov. Sumbar	Office	3	—	Not yet	Government

11	PSDA Prov. Sumbar	Office	3	200	Not yet	Government
12	DPRD Sumatera Barat	Office	4	100	Not yet	Government
13	Escape Building Kantor Gubernur	Office	—	—	—	Government
14	Pustaka Daerah	Office	5	—	—	Government
15	Polda Sumbar	Office	8	1.5	Not yet	Government
16	Telkom	Office	7	300	Not yet	Government
17	PT Sutan Kasim	Office	4	800	Not yet	Private
18	PT AMP	Office	4	1	Not yet	Private
19	Daihatsu & ACC Finance	Office/Showroom	3	30	Not yet	Private
20	RS M. Jamil	Hospital	6	—	Not yet	Government
21	RS Yos Sudarso	Hospital	5	300	Not yet	Private
22	Pasar Inpres	Market	4	4	Not yet	Government
23	Damar Plaza	Supermarket	5	1	Not yet	Private
24	Villa Hadis	Housing area	Rangka Baja	—	Not yet	Private
25	Sekolah Al Azhar 32	School	3	1	Not yet	Private
26	SD 03, 04, 21 Purus	School	4	—	—	Government
27	SD Agnes	School	3	—	—	Private
28	SD Percobaan	School	3	—	—	Private
29	SDN 23 & 24 Ujung Gurun	School	4	—	—	Government
30	SMP Frater	School	4	—	—	Private
31	SMP Maria	School	3	—	—	Private
32	SMPN 7 Padang	School	3–4	2	Not yet	Government
33	SMPN 25 Padang	School	3	—	Not yet	Government
34	SMAN 1 Padang	School	4	2	Not yet	Government
35	SMKN 5 Padang	School	4	2	Not yet	Government
36	FIP UNP	Campus	5	1.5	Not yet	Government
37	Pascasarjana UNP	Campus	6	1	Not yet	Government
38	Perpustakaan UNP	Campus	6	1	Not yet	Government
39	Universitas Muhammadiyah Sumbar	Campus	3	1.5	Not yet	Private
40	AMIK Indonesia	Campus	3	—	Not yet	Private
41	Universitas Bung Hatta	Campus	4	600	Not yet	Private
42	Universitas Ekasakti–AAI	Campus	6	800	Not yet	Private
43	STBA Prayoga	School	5	—	—	Private
44	SPR Plaza	Plaza	—	—	—	Private
45	Plaza Andalas	Plaza	—	—	—	Private
46	Hotel Pangeran Beach	Hotel	7	—	Not yet	Private
47	Basko Hotel & Plaza	Hotel & Mall	8	—	Not yet	Private
48	Hotel Ibis	Hotel	12	—	Not yet	Private
49	Hotel Daima	Hotel	6	—	Not yet	Private
50	Hotel Grand Zuri	Hotel	8	—	Not yet	Private
51	Hotel Rocky	Hotel	—	—	Not yet	Private
52	Axana Hotel	Hotel	—	—	—	Private
53	Bumi Minang Hotel	Hotel	8	—	—	Private
54	Hotel HW	Hotel	—	—	—	Private

55	Hotel Inna Muara	Hotel	6	—	—	Private
56	Hotel Mercure	Hotel	—	—	—	Private
57	Budha Tzu Chi	Social media	4	—	—	Private
58	Rusunawa	Residence	5	—	—	Government
59	Masjid Al Wustha	Worship place	4	—	—	Private
60	Masjid Muhajirin	Worship place	3	600	Not yet	Private
61	Masjid Raya Sumbar	Worship place	2	15	Not yet	Government
62	Masjid Taqwa Muhammadiyah	Worship place	4	2.5	Not yet	Private

This resonates with best practice: readiness is not static. Buildings age; stairwells degrade; signage fades; drills lapse; and warning components fail. A readiness assurance regime must therefore include monitoring and evaluation tied to measurable indicators and periodic recertification.

Implication for readiness assurance: Padang should treat shelters as a managed portfolio with (i) formal MOUs for private assets, (ii) designated site managers, (iii) SOPs for opening/access and crowd control, and (iv) a protected recurring budget line for inspection, maintenance, and drills. Without these, capacity remains "on paper."

Taken together, the BPBD 2019 inventory and BPBD 2025 map indicate that Padang is not starting from zero: it has an identified set of vertical refuge candidates and a spatial evacuation concept.

Yet the system currently behaves like a catalogue plus map, not an assured life-safety system. The decisive missing element is assurance, verification and governance that convert candidate buildings into dependable refuges. This is consistent with technical guidance that treats vertical evacuation as a safety-critical engineering and emergency-management function, not simply a designation exercise.

It also aligns with Padang-specific research showing that candidate buildings frequently fail readiness criteria when assessed rigorously.

CONCLUSION

This study set out to assess tsunami-shelter management in Padang City as a disaster management system, and the findings support a clear central conclusion: Padang's vertical-evacuation portfolio is substantial in nominal terms, but it is not yet "assured" as an operational life-safety system. The evidence indicates that the city has moved beyond the "absence of shelters" problem toward a more difficult governance challenge, how to verify, maintain, and operate shelters so that they reliably function within near-field time constraints.

First, the analysis reveals a data governance deficit: even the basic question of "how many shelters exist" is unstable because shelter counts differ across sources due to definitional variation (dedicated shelters vs. potential buildings), different survey years, and partial study scopes. The BPBD 2019 inventory clarifies that the operational shelter universe includes 62 sites (4 shelters and 58 potential buildings), but data completeness is uneven and capacity information is missing for many sites, undermining risk-informed capacity planning and evacuation assignment. Second, the most consequential gap is readiness assurance. Although BPBD reports an aggregate nominal capacity of ~53,874 people, the inventory records that key dedicated shelters, including major high-capacity sites, had not yet undergone feasibility testing ("Not yet").

In near-field tsunami settings, this lack of documented structural/functional verification is not a technicality: vertical evacuation depends on defensible safety performance under both strong ground shaking and tsunami loading, as emphasized in international technical guidance on tsunami vertical evacuation structures. The Padang case therefore demonstrates a recurring risk-governance trap: capacity and designation are often treated as proxies for readiness, even though life-safety performance requires certification, periodic inspection, and recertification.

Third, the BPBD 2025 evacuation plan map shows that Padang has developed a spatial evacuation concept, hazard zones, evacuation routes, and evacuation points, yet the end-to-end chain remains fragile when operational elements are weak. The supporting evidence in the manuscript highlights persistent issues such as limited siren maintenance, uneven integration of shelters with routes and public education, and low routine participation in drills, conditions that directly reduce effective evacuation time and increase uncertainty during an event.

Fourth, the shelter portfolio is multi-owner, with many potential shelter buildings in private ownership, which amplifies governance requirements (public access, liability, operational control, and continuity). Without formalized agreements, designated site managers, and operational SOPs, a shelter network may exist on maps but fail at the point of use (e.g., unclear access, locked entries, absent crowd-flow control).

POLICY AND MANAGERIAL IMPLICATIONS

The findings suggest that Padang should shift from "inventory-and-map provision" toward a readiness assurance regime, consisting of four actionable pillars:

1. Unified shelter registry and standards: a single authoritative geodatabase with standardized definitions, mandatory fields (capacity method, refuge-level elevation, ownership, access constraints), and scheduled updates to resolve definitional conflicts.
2. Feasibility testing and recertification: prioritize structural evaluation and retrofit/recertification for high-capacity sites recorded as not yet tested, and publish assurance status transparently.
3. Operational integration: link the BPBD 2025 route plan to shelter activation SOPs, signage maintenance, siren uptime targets, and routine community drills so the planned network behaves like a tested system under time pressure.
4. Multi-owner governance instruments: implement MOUs and role assignments for privately owned buildings designated as shelters, including access guarantees and responsibilities for maintenance and drills.

LIMITATIONS AND FUTURE RESEARCH

This study relies primarily on policy documents, official inventories, and mapping products; therefore, it may not fully capture real-time operational behaviors (e.g., whether doors are consistently accessible, stair throughput, or on-the-day crowd management). Future work should strengthen external validity through (i) field verification of a prioritized subset of shelters, (ii) key-informant interviews (BPBD, building owners/managers, community leaders), and (iii) drill-based observational data to quantify actual travel times and shelter-entry performance under realistic conditions.

Overall, the Padang case demonstrates that the most urgent task is no longer "building more shelters" in isolation, but governing shelters as safety-critical infrastructure, where availability is meaningful only when backed by verified performance, operational procedures, and sustained integration with evacuation and warning systems.

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