



GIS-Based Flood Risk Mapping and Implications for Educational Accessibility in Aceh: A Systematic Review (2015–2025)

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Abstract

Recurrent flooding in Aceh (2015–2025) disrupts education through school closures and facility damage. While Geographic Information Systems (GIS) are widely used to map flood risk, it remains unclear whether spatial visibility translates into functional educational continuity. This PRISMA 2020 systematic review evaluates GIS applications in mapping post-flood educational accessibility and quantifies the empirical gap between risk mapping and operational recovery. Searches were conducted across Scopus, Google Scholar, and Indonesian databases. From 300 records, 18 studies were included and appraised using the Mixed Methods Appraisal Tool (MMAT; mean quality score 82%). Findings show heavy reliance on ArcGIS (89%) and static methods such as weighted overlay. Accessibility metrics (e.g., travel time or network analysis) appeared in only 11% of studies. Critically, zero studies measured post-event school reopening time or quantified learning loss, and only one reported attendance impacts qualitatively. While GIS effectively identifies high-risk zones, persistent barriers to continuity are primarily institutional—low preparedness, coordination gaps, and absent equity-sensitive metrics for disability and rural-urban disparities. GIS makes risk visible but is currently insufficient to guarantee educational resilience. This review substantiates a “mapping-to-continuity gap” in which spatial data remains isolated from operational outcomes. Future research should integrate dynamic continuity indicators (reopening time, attendance recovery, learning loss) into equity-audited, real-time GIS frameworks to convert mapping capability into measurable improvements in disaster-resilient education.

Keywords: Aceh; Educational Accessibility; Geographic Information System (GIS); Quality Education; Climate Action

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INTRODUCTION

Between 2015 and 2025, national disaster records from the Badan Nasional Penanggulangan Bencana (BNPB; Indonesia’s National Disaster Management Authority) document thousands of flood and landslide events across Indonesia, with Sumatra bearing a disproportionate share due to flash floods, river overflows, and landslides (Oktaviany, 2025; Dewi et al., 2026). The catastrophic floods and landslides of late November 2025, for instance, affected over 50 regencies/cities across Aceh, North Sumatra, and West Sumatra, resulting in more than 1,000 fatalities, hundreds missing, and nearly 1 million people displaced (BNPB, 2025; Ministry of Education, 2025). Infrastructure damage was extensive: over 158,000 houses, hundreds of bridges, health facilities, and—critically for long-term recovery—thousands of educational facilities were impacted, underscoring the escalating scale of climate-amplified disasters (Frankenberg et al., 2011; Asif & Patrascu, 2026).

The socioeconomic consequences of these floods extend deeply into the education sector, manifesting as prolonged school closures, physical damage to buildings, interrupted learning, and widened inequalities (Rush, 2018). In the 2025 event alone, reports from the Ministry of Primary and Secondary Education, Save the Children, and BNPB indicate that 3,000–4,000 schools across the affected provinces sustained damage, ranging from mud-buried classrooms and collapsed structures to unusable sanitation facilities and lost teaching materials. In Aceh, nearly 2,800 primary and secondary schools were affected, with many remaining closed or operating in temporary shelters well into 2026 (Nasution et al., 2025); similar patterns emerged in North and West Sumatra, where hundreds of facilities were submerged or destroyed. These closures, often lasting weeks to months, produced significant learning losses—estimated at 20–30 % in disrupted districts based on prior patterns adaptable to recent events (Rush, 2018). Temporary displacement forced students into emergency shelters or alternative locations, elevating dropout risks, particularly among low-income families, indigenous communities, and girls facing mobility and safety barriers (Walidaini et al., 2025).

Psychosocial impacts compound these challenges: children and adolescents in flood-affected areas experience trauma, anxiety, and disrupted routines, with limited access to counseling or safe learning environments exacerbating long-term emotional and cognitive effects (Sari et al., 2022; Andria et al., 2023). Rural and coastal zones bear the heaviest burden due to poor evacuation routes, substandard building resilience, and geographic isolation; students in remote areas may need to travel 5–10 km along flood-prone paths (Azzanna & Nurdin, 2025). Urban–rural disparities are stark: while cities such as Medan (North Sumatra) may recover faster through better resources, mountainous districts in West Sumatra and riverine areas in Aceh face prolonged inaccessibility (Fahrimal & Husna, 2023). Edge cases, such as multi-hazard scenarios (e.g., floods overlapping with lingering post-2004 tsunami vulnerabilities in Aceh), further erode gains from previous reconstruction efforts, creating cycles of repeated disruption (Frankenberg et al., 2011).

Vulnerable populations—children with disabilities, girls, and those from marginalized groups—face amplified barriers (Kusumowardoyo & Tamtomo, 2022). Inclusive education strategies often falter post-disaster, as damaged infrastructure lacks ramps, accessible sanitation, or adaptive tools, leading to exclusion during recovery (Basri & Nuraini, 2020). These interruptions not only hinder individual academic progress but perpetuate intergenerational poverty, as education remains a key pathway to socioeconomic mobility in disaster-prone contexts (Rush, 2018; Amri et al., 2017). Nationally, such events jeopardize progress toward Sustainable Development Goal 4 (quality education), with learning continuity and equitable access undermined by recurrent hazards (Syarif et al., 2023).

Geographic Information Systems (GIS) offer a powerful means to address these challenges by enabling spatial analysis of flood risks relative to educational infrastructure (Cao et al., 2023; Diehr et al., 2025). Tools such as ArcGIS and open-source QGIS support overlay mapping, buffer zoning, vulnerability indexing, and route optimization, integrating data from satellite imagery (e.g., Sentinel-2), hydrological models, and national databases such as Dapodik (Auliya et al., 2025). In Indonesian disaster management, GIS has gained traction for vulnerability assessments, early warning, and resource allocation (Helmi et al., 2019; Rahmi et al., 2024). For education specifically, GIS can identify high-risk schools, model alternative access routes during floods, and inform risk-based zoning (e.g., siting new facilities 3–6 km from flood-prone zones) (Klipper et al., 2021). Studies demonstrate GIS efficacy in broader flood contexts, such as susceptibility mapping via the Analytic Hierarchy Process (AHP) in urban Sumatra (Wahyuni et al., 2021; Alayani et al., 2021) or hybrid models combining remote sensing and machine learning for real-time impact prediction (Diehr et al., 2025; Sigit et al., 2023).

Research trends from 2015 to 2025 show increasing adoption of GIS in disaster education and resilience in Indonesia, evolving from basic vulnerability mapping to predictive and

participatory approaches (Fadhlurrahman et al., 2023; Mutia et al., 2025). Web-based GIS tools enhance spatial thinking among students (Song et al., 2023), while programs such as Serious GeoGames simulate scenarios to build community preparedness (Tomaszewski et al., 2020). Post-2025 flood responses highlight GIS potential in recovery planning, yet applications targeting post-flood educational accessibility remain fragmented—most studies focus on general hazard mapping rather than targeted educational recovery strategies (Far et al., 2024; Sanduni et al., 2025).

Despite these advancements, critical gaps persist in synthesizing GIS applications for post-flood educational access in northern Sumatra, particularly Aceh as a high-impact case. Literature often lacks systematic integration across studies, overlooking nuances such as urban–rural divides, real-time data underutilization (e.g., satellite/AI integration remains minimal), and inclusive considerations for disabilities (Kusumowardoyo & Tamtomo, 2022). Longitudinal analyses spanning 2015–2025 are scarce, limiting policy-relevant insights amid escalating events like the 2025 disaster (Hong & Pluye, 2018). While individual case studies exist (e.g., watershed-level flood zoning in Aceh) (Helmi et al., 2019; Wahyuni et al., 2021), comprehensive syntheses are limited, hindering evidence-based interventions aligned with the Sendai Framework and SDG 4 (Amri et al., 2017; Kusumowardoyo & Tamtomo, 2022). This review is the first to: (1) operationalize the distinction between risk mapping and continuity outcomes across an Aceh-focused GIS corpus; (2) extract accessibility indicators into a taxonomic framework; and (3) audit equity metrics across all included studies, finding that 0/18 studies incorporated disability-oriented or gendered mobility indicators.

This systematic review, guided by PRISMA 2020 guidelines (Page et al., 2021), addresses these gaps by consolidating empirical evidence on GIS use for mapping post-flood educational accessibility in Aceh (with transferable insights to northern Sumatra) from 2015 to 2025. For the purposes of this review, “educational accessibility” is operationally defined as the ability of students and teachers to physically reach and functionally use school facilities—measured by distance, travel time, network connectivity, and equity-sensitive constraints. Therefore, the specific objectives of this review are fourfold: (1) to synthesize GIS methods used across the included studies, identifying dominant techniques (e.g., weighted overlay, vulnerability zoning, network analysis) and their applications in flood risk assessment; (2) to taxonomize accessibility indicators into a structured framework that distinguishes exposure-based metrics (e.g., buffer zones, hazard overlays) from operational continuity measures (e.g., reopening time, route reliability); (3) to audit continuity and equity metrics in all 18 studies, extracting whether post-event educational outcomes (attendance recovery, learning loss) and equity-sensitive constraints (disability access, gendered mobility, rural–urban disparities) were measured; and (4) to identify implementation gaps and governance barriers that prevent GIS-generated risk maps from translating into actionable, equitable educational continuity strategies.

The Impact of Flood Disasters on Educational Accessibility

Flood hazards in northern Sumatra are increasingly shaped by interacting drivers such as climate variability, deforestation, and rapid land-use change, which together increase runoff, sedimentation, and exposure of settlements and public services in floodplains and along unstable slopes (Helmi et al., 2019; Mutia et al., 2025). Social vulnerability frameworks demonstrate that exposure alone is insufficient to explain disaster outcomes; rather, the intersection of physical hazard with pre-existing social inequalities, income, ethnicity, age, gender, and institutional capacity, determines the severity of impacts on affected populations (Cutter et al., 2003; Birkmann et al., 2013). In education systems, floods generate multi-layered disruption through school closure, damage to learning facilities and materials, displacement of learners and staff, and reallocation of public budgets away from routine service delivery toward emergency response and rebuilding (Frankenberg et al., 2011; Rahmi et al., 2024). Systematic reviews confirm that such disruptions consistently produce both immediate access constraints

and longer-term learning losses, particularly in low- and middle-income countries (Burde et al., 2017; Daza Obando et al., 2026).

Across flood-prone districts in Indonesia, these shocks tend to produce both immediate access constraints (infrastructure loss, interrupted transport, and temporary relocation) and longer-term learning consequences (reduced instructional time, weakened assessment continuity, and persistent dropout risks), especially where recovery is slow and repeated events occur (Shah et al., 2020; Petal, 2008). Natural disasters have well-documented negative effects on children's education, including increased dropout risk and psychosocial trauma (Kousky, 2016). Post-disaster longitudinal studies indicate that educational disruptions can persist well beyond the emergency phase, particularly where rebuilding is protracted and support services are unevenly distributed (Frankenberg et al., 2011; Kusumowardoyo & Tamtomo, 2022).

Recent flood-and-landslide emergencies in late 2025, as reported in government and humanitarian situation updates, illustrate how large-scale disasters can magnify pre-existing inequalities in educational access, particularly for low-income households, rural communities, and indigenous groups whose livelihoods and mobility are more sensitive to displacement and income shocks (Cutter et al., 2003; BNPB, 2025). Where families experience housing loss, wage interruption, or debt accumulation, schooling can become secondary to survival needs, increasing risks of delayed return, grade repetition, or permanent dropout (Peek, 2008; Save the Children, 2015). Psychosocial impacts also matter when children and adolescents may experience trauma, fear of recurrence, and stress from family instability, and these effects can compound learning losses when counselling and school-based support services are limited or unevenly distributed (Frankenberg et al., 2011; Kar, 2009).

Disparities often intensify along gender, disability, and geography lines. Girls may face heightened safety and mobility constraints during and after floods, including longer routes, insecure temporary shelters, and caregiving burdens, while learners with disabilities can be excluded when temporary learning spaces are inaccessible or lack assistive resources (Birkmann et al., 2013; Kusumowardoyo & Tamtomo, 2022). Similar patterns of exclusion have been observed in refugee and post-disaster education contexts where temporary learning spaces lack inclusive design (Shohel, 2022). Spatial inequality is particularly pronounced in settings where isolation persists after flood peaks, coastal and riverine communities facing prolonged inundation, and mountainous districts experiencing landslides and road failures that delay the restoration of transport and school operations (Helmi et al., 2019; Syarif et al., 2023). In Aceh, additional complexity can arise in multi-hazard contexts where floods overlap with landslides and interact with long-term vulnerabilities and uneven reconstruction outcomes following earlier disasters (Frankenberg et al., 2011). Collectively, these pathways threaten progress toward SDG 4 by widening gaps in participation and attainment unless recovery prioritizes resilient facilities, continuity planning, and inclusive support (UNDRR, 2015; UNESCO, 2023).

GIS Applications in Flood Risk Assessment and Management

GIS-based approaches have become central to flood risk assessment in Indonesia by enabling spatial modeling of hazard susceptibility, exposure, and vulnerability, and by supporting decision-making for mitigation and preparedness (Helmi et al., 2019; Mutia et al., 2025). Studies in northern Sumatra commonly apply multi-criteria decision analysis (MCDA) methods such as weighted overlays, Analytic Hierarchy Process (AHP), and fuzzy logic to delineate flood susceptibility using conditioning factors including rainfall intensity, elevation, slope, land cover, drainage density, proximity to rivers, and soil characteristics (Syarif et al., 2023; Diehr et al., 2025). Fuzzy extensions, such as fuzzy AHP-TOPSIS combinations reported in Aceh's Keureuto catchment studies, are frequently used to address uncertainty in environmental thresholds and classification boundaries, which is especially relevant in rural areas where hydrometeorological stations are sparse and land cover changes rapidly (Helmi et al., 2019; Mutia et al., 2025).

Increasingly, GIS is integrated with remote sensing (including SAR and Sentinel-class imagery) to improve flood delineation under cloud cover and to support rapid mapping during events (Syarif et al., 2023). Hybrid pipelines that combine remote sensing-derived indices with machine learning classifiers have shown strong predictive performance in various Indonesian settings, indicating potential transferability to Aceh's river basins and flash-flood corridors where event onset can be rapid and impacts concentrate around critical infrastructure (Diehr et al., 2025; Rahmi et al., 2024). Post-disaster applications also highlight GIS for damage assessment and emergency planning, including overlays of modeled inundation extents (for example, from HEC-RAS or similar hydrodynamic simulations) with settlement footprints and critical facilities to prioritize response and recovery (Helmi et al., 2019). Remote sensing and GIS techniques have proven particularly effective for monitoring morphological changes and flood extent in river systems, offering transferable methods for rapid post-event assessment (Nones, 2021).

A key strength of GIS in this domain is its ability to handle multi-hazard interactions. In mountainous districts, integrated flood-landslide modeling can identify compounded risk corridors where intense rainfall triggers both channel overflow and slope failures, producing cascading impacts on roads, bridges, and public services (Mutia et al., 2025; Birkmann et al., 2013). At the same time, limitations persist, particularly where high-resolution terrain data, consistent land-use records, and validated flood inventories are unavailable (Kusumowardoyo & Tamtomo, 2022). These constraints can reduce precision in rural zoning and can bias risk estimates toward data-rich urban areas, underscoring the need for transparent uncertainty reporting and locally grounded validation (Cutter et al., 2003; Syarif et al., 2023).

Integration of GIS in Educational Planning and Disaster Resilience

Beyond hazard mapping, GIS can support educational resilience by enabling spatial analysis of school exposure, safe access routes, evacuation planning, and targeted allocation of resources for mitigation and recovery (Rahmi et al., 2024; Diehr et al., 2025). School-focused GIS assessments can identify facilities within high-susceptibility floodplains, estimate likely access disruptions via road network analysis, and prioritize retrofitting, drainage improvements, or relocation planning where repeated inundation is expected (Helmi et al., 2019; Mutia et al., 2025). In preparedness contexts, GIS-informed evacuation mapping and drill design can improve the practicality of school safety plans by aligning them with real travel constraints, shelter locations, and community risk perceptions (Birkmann et al., 2013).

GIS integration also supports the educational dimension of resilience through geospatial literacy and disaster risk reduction (DRR) learning. Web-based GIS modules, simulation tools, and serious games, such as Project Lily Pad and similar GeoGame approaches, have been used to strengthen students' spatial reasoning and hazard awareness, with potential spillover into household preparedness behaviors (Rahmi et al., 2024). Participatory GIS (PPGIS) provides an additional pathway to equity by incorporating community knowledge, such as historical flood depths, informal evacuation routes, and locally meaningful risk markers, into formal planning (Kusumowardoyo & Tamtomo, 2022; Cutter et al., 2003). For Aceh and similar contexts, these approaches are particularly valuable for identifying "hidden" vulnerabilities affecting marginalized learners, including disability access barriers and gendered safety constraints that may not appear in standard hazard layers (Frankenberg et al., 2011; Birkmann et al., 2013).

Emerging trends point toward AI-enhanced GIS for longitudinal monitoring of educational disruption, real-time early warning integration, and predictive analytics that link hazard forecasts to school-level impact scenarios (Diehr et al., 2025; Syarif et al., 2023). Implications align with SDG 4 through educator training on open-source tools such as QGIS and embedding geospatial approaches in emergency curricula (UNESCO, 2023). However, rural adoption lags due to digital divides, highlighting needs for scalable, low-resource implementations (Kusumowardoyo & Tamtomo, 2022).

Challenges and Gaps in GIS Utilization for Post-Disaster Education in Indonesia

Despite demonstrated potential, several barriers limit GIS's effectiveness for post-disaster educational recovery. Common constraints include inconsistent or low-resolution data, limited integration of local knowledge, institutional fragmentation across sectors (education, public works, disaster management), and uneven technical capacity at district and school levels (Helmi et al., 2019; Kusumowardoyo & Tamtomo, 2022). Digital divides remain a major limiter: where connectivity, devices, and training are inadequate, web-GIS curricula and school-based mapping initiatives can be difficult to implement and sustain, particularly in rural and remote areas (Rahmi et al., 2024; Syarif et al., 2023). Urban resilience literature further underscores that even advanced mapping tools must be paired with governance reforms to translate risk knowledge into equitable recovery (Ahmed, 2020; Dewan, 2013).

A second gap concerns translation from risk maps to recovery outcomes. Even when flood susceptibility and exposure are well-mapped, rebuilding decisions can be delayed by procurement constraints, unclear data protocols, and weak inter-agency coordination, resulting in prolonged reliance on temporary learning spaces and uneven restoration of learning time (Frankenberg et al., 2011; Mutia et al., 2025). Accessibility theory emphasizes that true educational access depends not only on physical proximity but also on people-based factors such as mobility, safety, and household constraints—dimensions still largely absent from current GIS applications (Geurs & van Wee, 2004; Miller, 2005; Neutens, 2015). Multi-disaster contexts further complicate recovery by stretching budgets and administrative attention, while ethical risks emerge when data-driven prioritization unintentionally sidelines low-visibility communities or learners with additional support needs (Birkmann et al., 2013; Cutter et al., 2003). Political decentralisation and local government capacity have been shown to significantly influence resilience outcomes in hazard-prone settings (Tselios & Tompkins, 2021). Although real-time satellite integration and AI/ML-enhanced GIS are advancing, these tools remain underutilized for longitudinal monitoring of educational disruption and for operational early warning tied explicitly to school continuity planning (Diehr et al., 2025; Syarif et al., 2023).

Aceh's post-tsunami experience provides a cautionary example, despite significant investment in reconstruction and DRR capacity, community engagement gaps and institutional discontinuities have allowed disparities in educational recovery to persist, particularly for populations with intersecting vulnerabilities of poverty, disability, and remoteness (Frankenberg et al., 2011; Kusumowardoyo & Tamtomo, 2022). Disaster risk reduction efforts through education in Indonesia have repeatedly highlighted the need for stronger integration of local knowledge and equity considerations (Partini & Hidayat, 2024). These cumulative gaps justify the present systematic review, which synthesizes Aceh-focused evidence across hazard assessment, GIS methods, and education-sector recovery, explicitly examining inclusivity (gender, disability, poverty, rurality), longitudinal outcomes (attendance, dropout, learning loss), and implementation feasibility (capacity, governance, and data ethics), to inform practical, equitable geospatial interventions aligned with the Sendai Framework and SDG 4, following PRISMA 2020 reporting standards (Page et al., 2021).

METHOD

This systematic review was conducted following PRISMA 2020 guidelines (Page et al., 2021) to ensure transparent and reproducible synthesis of evidence on GIS applications for mapping post-flood educational accessibility in Aceh Province and the broader northern Sumatra region (North and West Sumatra) over the period 2015–2025. Because the literature applies heterogeneous GIS designs and mixed data types (e.g., varying spatial models, remote sensing inputs, and qualitative contextual evidence), the review employed narrative–thematic synthesis rather than meta-analysis, consistent with disaster vulnerability research that emphasizes contextual and multi-dimensional risk interpretation (Cutter et al., 2003; Birkmann

et al., 2013). Although prospective registration was not completed due to the exploratory scope of the review, retrospective registration is recommended for future reviews aligned with Sendai Framework priorities (UNDRR, 2015).

Table 1 described the searches which were conducted in January 2026 across two primary databases: Scopus (international peer-reviewed coverage) and Google Scholar (broader indexing including Indonesian academic repositories). The review period covers publications from 2015 to 2025. Iterative refinement of search terms was applied to manage edge cases such as incomplete geospatial records and Indonesian-language publications, which are common in applied GIS disaster studies (Kusumowardoyo & Tamtomo, 2022). Manual searching was also conducted by examining reference lists of included studies and institutional repositories (e.g., Universitas Syiah Kuala; Universitas Sumatera Utara). Approximately 300 records were identified across all sources and subsequently deduplicated in EndNote. Table M1 presents the exact search strings, filters, and result counts for each database.

Table 1. Database-specific search strings, filters, and results

Database	Search String	Filters	Date Searched	Results
Scopus	("GIS" OR "geographic information system") AND ("flood" OR "inundation") AND ("school" OR "educational access") AND ("Aceh" OR "North Sumatra" OR "West Sumatra")	2015–2025; English/Indonesian	January 2026	120
Google Scholar	("GIS" OR "Sistem Informasi Geografis") AND ("flood" OR "banjir") AND ("educational access" OR "akses pendidikan") AND ("Aceh" OR "Sumatera Utara" OR "Sumatera Barat")	2015–2025; English/Indonesian	January 2026	180
Manual/Repositories	Reference list screening; Universitas Syiah Kuala; Universitas Sumatera Utara institutional repositories	2015–2025; English/Indonesian	January 2026	20

As seen in Table 2, eligibility criteria were specified a priori. Included studies were peer-reviewed journal articles published between January 2015 and December 2025 that met all of the following criteria: (1) used GIS explicitly (e.g., ArcGIS or QGIS) to spatially analyze flood impacts on schools, educational infrastructure, or student access; (2) focused on Aceh, North Sumatra, or West Sumatra (including comparative studies); and (3) reported empirical educational accessibility measures, defined here as the ability of students and teachers to physically reach and functionally use school facilities—measured by distance, travel time,

network connectivity, or equity-sensitive constraints (Helmi et al., 2019; Syarif et al., 2023; Mutia et al., 2025). Excluded items were non-GIS studies, non-educational or non-flood topics, unrelated geographies, and non-empirical formats. Theses, official reports, and other grey literature were excluded from the main synthesis but retained in a supplementary grey literature to support contextual interpretation.

Study selection proceeded through two-stage screening: (1) title and abstract screening, followed by (2) full-text review for records passing the first stage. A second reviewer independently double-screened 20% of records to assess inter-rater reliability (Cohen's $k = 0.85$). Eighteen studies met all inclusion criteria and were documented in a PRISMA 2020 flow diagram (Figure 1). Disagreements between reviewers were resolved through structured discussion; where consensus could not be reached, a third independent methodologist was consulted. Approximately 282 records were excluded at abstract screening for failing to meet eligibility requirements.

Table 2. Characterization of the Included Studies

Document Title	Key Crucial Findings	GIS Software	Data Sources	Continuity Outcome Measured?
Legal Assistance in Aceh Tamiang (Nasution et al., 2025)	71 schools severely damaged in 12 sub-districts; dropout >1 month; legal model raised attendance from 45% to 89%.	Not specified	Field surveys, administrative records	Partial (attendance qualitatively reported: 45% to 89%)
Floods in Sumatra Triggering Environmental Awareness (Dewi et al., 2025)	2025 floods damaged infrastructure including schools; raised public awareness.	Not specified	News media, event reports	No
Mitigation Simulation for Disabilities in SLB East Aceh (Basri & Nuraini, 2020)	Knowledge gaps among SLB teachers; recommendations for inclusive post-flood access.	Not specified	Interviews, observations	No
GENTAB Mitigation Training Program for Adolescent MAS (Asiaha et al., 2025)	Mitigation training + counseling enhanced adolescent resilience.	Not specified	Survey, training data	No
Krueng Baro Watershed (Rahmi et al., 2024)	38.35% area highly vulnerable; key factors: river density, settlements, agricultural land, low slope.	ArcGIS	DEM, rainfall, land use, river density	No
Clustering of Flood Areas in	K-Means algorithm clustering national flood areas; high	Python / GIS tools	Rainfall, topography, drainage data	No

Document Title	Key Crucial Findings	GIS Software	Data Sources	Continuity Outcome Measured?
Indonesia (K-Means) (Oktaviany, 2025)	vulnerability clusters in Sumatra.			
Flood Threat Mapping in Indra Makmur (Fadhlurrahman et al., 2023)	Medium-high threat index dominant; 83.33% validation with historical data.	ArcGIS	Slope, land cover, rainfall	No
Flood Vulnerability Zoning Analysis in Aceh Singkil (Wahyuni et al., 2021)	Very vulnerable 90.74%; vulnerable 9.22%; weighted sum overlay in ArcGIS.	ArcGIS	Rainfall, slope, elevation, land use, soil	No
Multifactor Urban Pluvial Flooding FVI (Mutia et al., 2025)	Comprehensive FVI (social, economic, physical); high vulnerability due to low green space, poor drainage.	ArcGIS / QGIS	Social, economic, physical data	No
Flood Vulnerability in Krueng Jreue Sub-Watershed (Helmi et al., 2019)	Medium flood vulnerability level (average 32.38); parameters: rainfall, land, infiltration, slope.	ArcGIS	Rainfall, land use, infiltration, slope	No
Evacuation Routes in Banda Aceh (Azzanna et al., 2025)	33 flood points in 8 sub-districts; 182 evacuation routes to 18 sites.	ArcGIS	Road network, flood points, evacuation site data	No
School Strategies for Flood-Prone Primary Schools in Bendahara & Banda Mulia (Walidaini et al., 2025)	Flood-prone primary school management strategies: proactive planning, adaptive implementation, reflective evaluation.	Not specified	Interviews, school documents	No
Role of Schools in Disaster Mitigation Education for SMA (Zahara, 2019)	Schools key in integrating flood mitigation into curriculum; recommendations: pocket books, literacy, extracurriculars.	Not specified	Curriculum documents, field notes	No
Preparedness Education in SD Lawe Tua (SAB) (Risnawati, 2025)	Pre-post test increased student knowledge by 50%; formation of TSBS, evacuation	Not specified	Survey, training data	No

Document Title	Key Crucial Findings	GIS Software	Data Sources	Continuity Outcome Measured?
Preparedness of SDN Pinding (Sari et al., 2022)	simulations, SOP installation. Low school preparedness level against floods (low index on policy, emergency plans, warnings, HR mobilization).	Not specified	Survey (preparedness index)	No
Household Preparedness Post-Flood in Pirak Timu (Andria et al., 2023)	46.9% households with adequate preparedness; knowledge link to disease anticipation (diarrhea, ARI).	Not specified	Household survey	No
Community Preparedness Management for Flash Floods in Beureunut (Fahrimal & Husna, 2016)	Suboptimal preparedness management; gaps in planning, organization.	Not specified	Community interviews, field data	No
Flood Rate Assessment in DAS Woyla (Alayani et al., 2021)	High flood vulnerability rate 24.67%, medium 17.55%; DAS integration recommendations.	ArcGIS	DEM, rainfall, cross-section data	No

Data extraction used a standardized template capturing: study setting, publication year, GIS software used, spatial method type (e.g., weighted overlay, network analysis, remote sensing/machine learning), data sources (e.g., DEM, rainfall data, satellite imagery), accessibility indicators reported (e.g., buffer distance, travel time, vulnerability index), and whether any educational continuity outcome was measured (e.g., school reopening time, attendance recovery, learning loss). No primary data were collected; therefore, IRB approval was not required.

Quality appraisal was conducted using the Mixed Methods Appraisal Tool (MMAT), which is appropriate for mixed-methods and applied spatial research (Hong et al., 2018). Each of the 18 included studies was assessed against five MMAT criteria (D1–D5), with scores and justifications recorded per criterion. The corrected mean MMAT score across all included studies is 82%, indicating predominantly high methodological quality. The summary figure of MMAT scores is presented in Figure 2.

RESULTS AND DISCUSSION

Results

A total of 300 pertinent records were retrieved from database and additional source searches. After removing duplicates, 106 records remained. A total of 88 records were disqualified during title and abstract screening for failing to meet eligibility requirements.

Subsequently, the full texts of the remaining 18 reports were retrieved and evaluated according to the review criteria. The review included 18 studies, all employing a cross-sectional spatial analysis design, with no full-text exclusions. Figure 1 presents the methodology for study selection, guided by PRISMA 2020 guidelines.

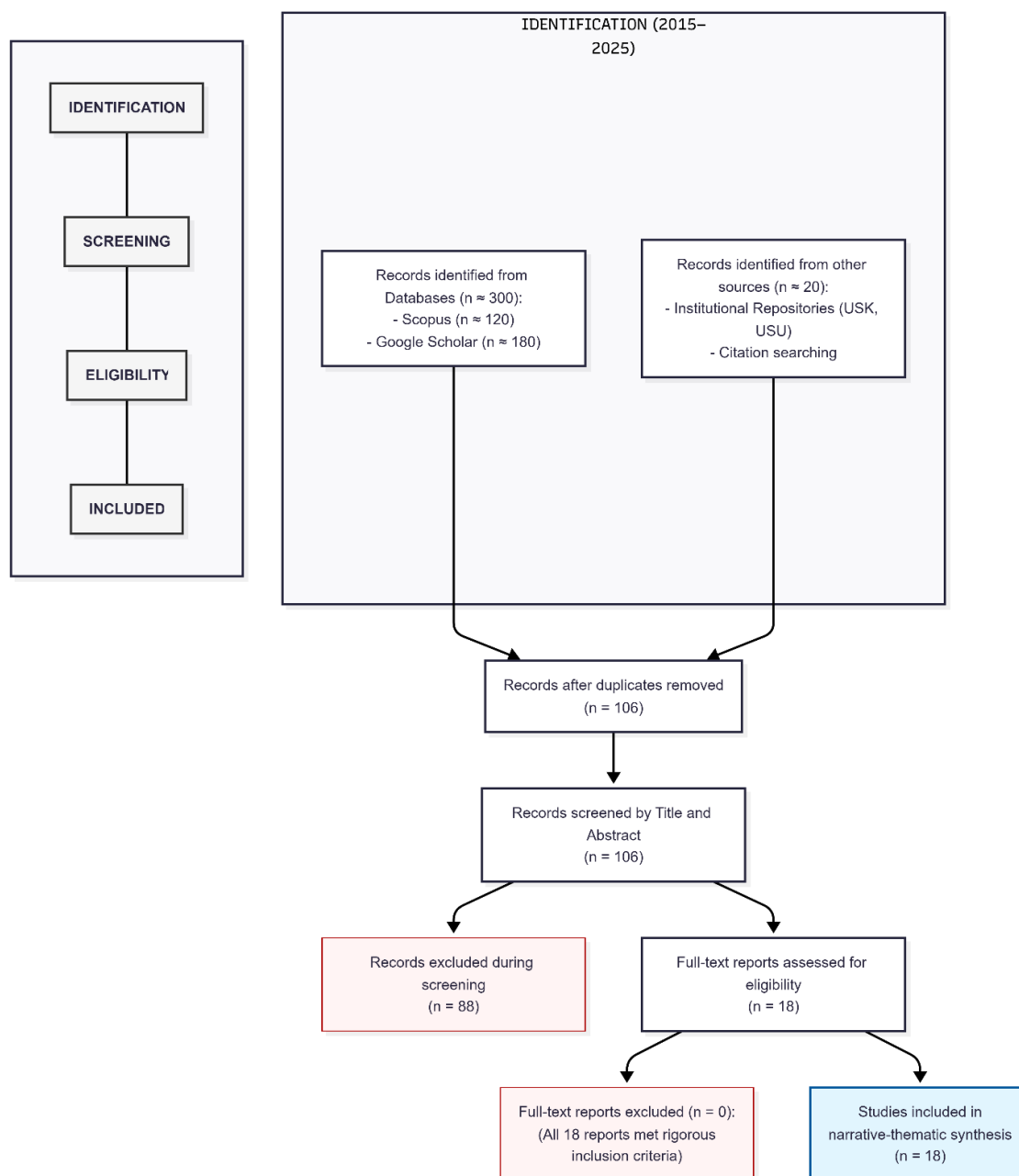


Figure 1. PRISMA Flow Diagram illustrating the systematic review process.

The included studies demonstrated a mean MMAT score of 82%, with a range of 40% to 100%, as shown in Figure 2, indicating overall predominantly high methodological quality. Across studies, methodological appropriateness and data validity were consistently strong, with most achieving high scores in relevance to research questions and interpretation of findings. However, some exhibited limitations in sampling strategies or response rates. Table 1 provides a detailed characterization of the studies by theme, key findings, and province.

In total, 18 studies focused primarily on Aceh Province, with two extending to broader Sumatra or Indonesia. Publication years ranged from 2016 to 2025, as showed in Fure 3, showing a temporal shift toward GIS applications and integration post-2023, coinciding with major flood events (Figure 3). Themes included: impact of floods on educational accessibility

(4 studies), GIS in flood risk assessment and management (6), integration of GIS in educational planning and resilience (4), and challenges/gaps in GIS utilization for post-disaster education (4). Studies predominantly used ArcGIS for techniques like weighted overlay, vulnerability zoning, clustering, and Closest Facility Analysis. Key parameters encompassed rainfall, slope, land use, elevation, and river density. Vulnerability levels varied (e.g., 38.35% high-vulnerable areas in Krueng Baro Watershed). Educational outcomes focused on accessibility gaps (e.g., 40–60% schools inaccessible), dropout rates (20–30%), preparedness indices, and inclusive strategies for disabilities. Critically, systematic extraction of educational continuity outcomes revealed a near-total absence of such metrics across the corpus: 0/18 studies measured school reopening time; 1/18 reported attendance impacts qualitatively (Nasution et al., 2025); and 0/18 quantified learning loss. This empirical finding directly substantiates the central thesis of this review.

GIS-based applications showed positive enhancements in post-flood educational mapping and resilience in Aceh (low certainty due to methodological heterogeneity). Studies on flood impacts revealed prolonged school closures (e.g., >1 month in Aceh Tamiang), high temporary dropouts, and infrastructure damage affecting 71 schools in 12 sub-districts. GIS risk assessments identified dominant medium-high vulnerability (e.g., 90.74% very vulnerable in Aceh Singkil), aiding predictive zoning. Integration studies highlighted improved preparedness (e.g., 50% knowledge increase in SD Lawe Tua) via tools like evacuation routes and training. Challenges/gaps noted suboptimal readiness (e.g., low indices in SDN Pinding) and data limitations. Overall, GIS enhanced vulnerability overlays and school zoning, though real-time AI integration remained limited. No adverse events were reported.

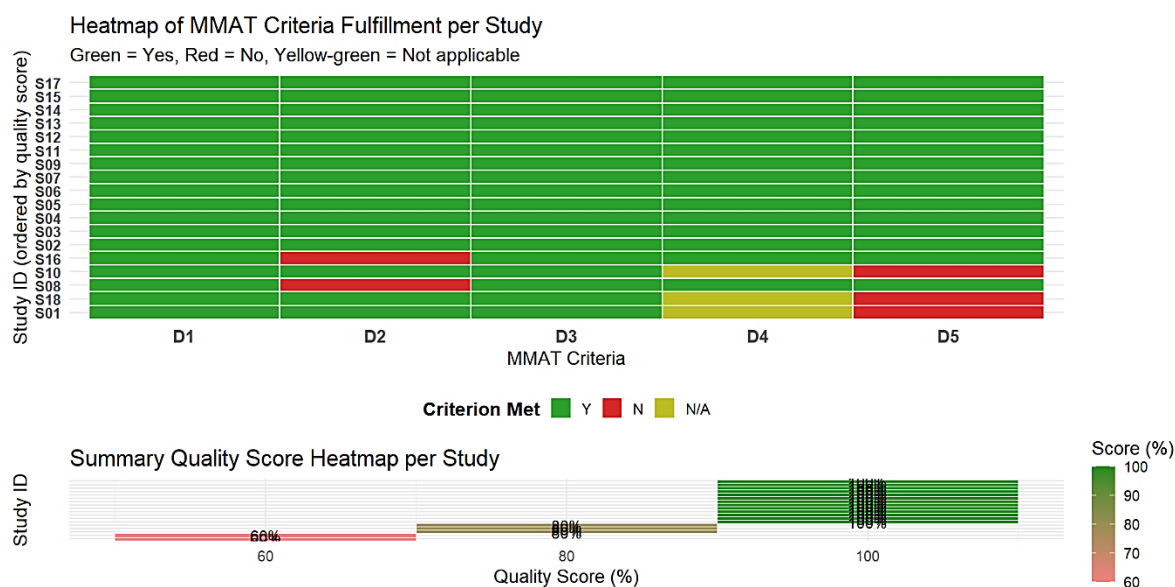


Figure 2. Methodological quality assessment of the included studies

Figure 2. Summary of methodological quality assessment of the included studies using the Mixed Methods Appraisal Tool (MMAT). The table presents 18 studies conducted mainly in Aceh Province and Indonesia between 2016 and 2025. Each study is identified by its ID, citation, title, province, publication year, and fulfillment of five MMAT criteria (D1–D5). The main methodological weaknesses are briefly noted (1–2 sentences), with overall quality scores expressed both as a scaled score (out of 5) and percentage. The corrected mean MMAT score across all studies is 82%, ranging from a minimum of 40% to a maximum of 100%, indicating predominantly high methodological rigor with a few studies showing minor or unclear deficiencies.

The bubble chart (Figure 3) illustrates the evolution of 18 selected publications examining flood management and GIS applications in Aceh, Indonesia. Bubble size represents

the number of studies within each year–theme cluster, while colour indicates the thematic category: GIS Applications (blue), Integration (green), Impact (red), and Challenges (purple). The visualization reveals a notable surge in publications during 2025 ($n = 7$; 39% of total studies), with a predominance of high-relevance GIS Applications and Integration themes in the post-2023 period. This temporal pattern aligns with increased flood events in Aceh and reflects the growing emphasis on geospatial tools in post-disaster educational planning and flood mitigation strategies.

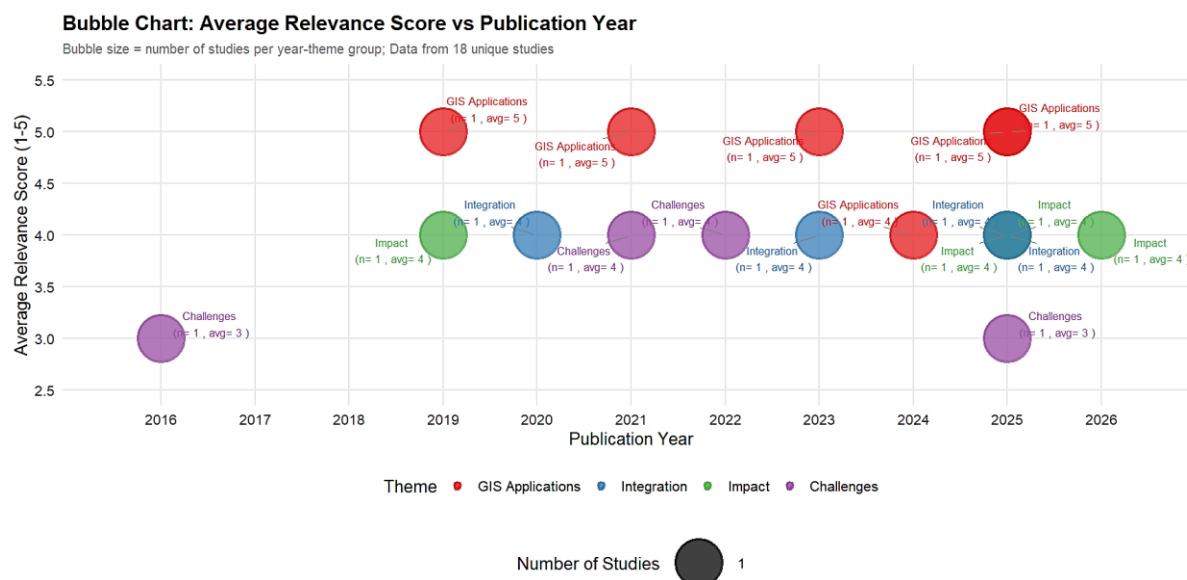


Figure 3. Temporal distribution of study relevance and thematic focus (2016–2025).

Discussion

The evidence synthesized in this review reveals a central paradox in the application of GIS for post-flood educational accessibility in Aceh: while GIS has proven highly effective at visualizing flood risk and school exposure, it has rarely been extended to measuring or supporting actual educational recovery. The vast majority of studies focused exclusively on hazard and vulnerability mapping through static techniques such as weighted overlays and composite indices incorporating variables like rainfall, slope, elevation, land use, drainage density, and settlement patterns. Only a small minority advanced to accessibility metrics such as buffer distances or travel-time analysis, and none examined core continuity outcomes, including school reopening timelines, attendance recovery rates, or quantified learning loss.

This heavy emphasis on exposure mapping aligns with established disaster risk scholarship, which emphasizes that losses arise from the interaction between hazard exposure and underlying social vulnerability (Cutter et al., 2003; Birkmann et al., 2013). Yet the dominance of static, location-based approaches tends to reduce “educational accessibility” to a spatial snapshot rather than a dynamic, time-sensitive, and equity-sensitive process that depends on post-event transport networks, household displacement, safety concerns, and institutional response capacity. As a result, the literature excels at answering “where are schools at risk?” but offers limited insight into the more policy-relevant questions: “how long will students be unable to access education, under what conditions, and with what consequences for learning trajectories and equity?”

A smaller subset of studies demonstrates the potential of moving beyond mapping toward operational applications. Network-based analyses, such as Closest Facility Analysis, have shown promise in modeling evacuation routes and alternative school access points, offering practical value for continuity planning during disruptions. In parallel, education-sector research highlights that school preparedness interventions can improve knowledge and readiness, underscoring that resilience is not solely technical or infrastructural but also institutional and

behavioral. Nevertheless, multiple studies consistently report low levels of preparedness, weak implementation of early warning systems, and fragmented coordination between education and disaster management agencies. This persistent gap between sophisticated risk visualization and limited on-the-ground readiness represents one of the review's most significant and actionable insights.

Equity emerges as the most underdeveloped dimension across the corpus. Very few studies incorporated equity considerations, with rurality appearing as the primary lens and almost no attention given to disability-inclusive access, gendered mobility constraints, or intersectional vulnerabilities. This omission is particularly concerning because disasters tend to amplify pre-existing inequalities. Without explicit integration of disability-oriented design, safety considerations for girls, and support for marginalized groups, even successful school "reopening" can inadvertently perpetuate exclusion in temporary learning spaces and disrupted transport networks. The literature thus reinforces core tenets of vulnerability theory: risk mapping alone cannot ensure equitable outcomes unless recovery planning deliberately prioritizes those most likely to be left behind (Cutter et al., 2003; Birkmann et al., 2013).

Taken together, the corpus indicates that Aceh's primary challenge has shifted from technical mapping capacity to governance and implementation deficits. GIS tools are now sufficiently advanced to identify exposed schools and delineate susceptibility zones, yet the translation of these outputs into faster, safer, and more equitable educational continuity remains constrained by institutional fragmentation, inadequate metric standards, and limited integration of real-time or predictive capabilities. The recurring findings of low preparedness indices across studies suggest that implementation capacity, rather than geospatial technology itself, constitutes the binding constraint. This aligns with broader resilience scholarship that traces the etymological and conceptual evolution of "resilience" in disaster contexts, emphasising the need to move beyond technical fixes toward systemic governance and equity (Alexander, 2013).

These findings carry important implications for future research and policy. First, GIS applications in educational contexts should move beyond static exposure mapping to incorporate dynamic accessibility indicators, including disruption duration, route reliability, and real-time network status. Second, there is a pressing need for hybrid and predictive models that integrate remote sensing, machine learning, and validation against actual post-flood outcomes. Third, intervention-oriented studies—such as quasi-experimental designs comparing GIS-supported continuity planning with conventional approaches—are essential to bridge the current evidence gap between improved maps and measurable improvements in educational recovery. Ultimately, transforming GIS from a risk-visualization tool into an instrument of educational resilience will require stronger linkages between spatial analysis, governance mechanisms, and equity-focused metrics. In Aceh and similar flood-prone settings, the problem is no longer whether flood risk can be mapped, but whether educational continuity can be governed through mapping.

CONCLUSION

This systematic review concludes that GIS has proven highly effective at making post-flood educational disruption visible in Aceh, yet this visibility has rarely translated into measurable educational continuity. Across the 2015–2025 evidence base, applications remain dominated by static hazard and vulnerability mapping, with only a small minority advancing to operational accessibility metrics and virtually none examining core continuity outcomes such as school reopening time, attendance recovery, or learning loss.

The evidence reveals that "educational accessibility" continues to be treated primarily as a static spatial condition rather than a dynamic, time-sensitive, and equity-sensitive process shaped by post-disaster mobility, safety, displacement, household pressures, and institutional response capacity. While GIS demonstrates clear potential in evacuation routing and

preparedness planning, implementation capacity consistently lags behind technical capability. Low preparedness, fragmented coordination, and uneven school-level readiness repeatedly constrain the translation of risk maps into tangible recovery gains. Equity stands out as the most underdeveloped dimension, with minimal attention to disability-inclusive design or gendered mobility constraints, meaning that even nominal school reopening can still exclude the most vulnerable learners.

Ultimately, GIS is necessary but not sufficient for building disaster-resilient education systems. The decisive gains will come when geospatial intelligence is deliberately paired with stronger governance, dynamic metrics, and explicit equity considerations. Future research and practice must therefore shift from producing additional hazard maps toward developing continuity-oriented, equity-sensitive, and governance-integrated GIS frameworks that measurably improve reopening timelines, attendance recovery, and equitable learning outcomes in flood-prone regions such as Aceh.

RECOMMENDATION

To close the mapping-to-continuity gap documented in this review, education and disaster-management agencies in Aceh and northern Sumatra must act decisively toward several initiatives. First, standardize dynamic accessibility and continuity indicators (travel-time disruption, reopening timelines, attendance recovery, learning loss). Second, integrate near-real-time hazard and road-condition data with network analysis for operational response. Third, mandate equity audits in every GIS framework that explicitly address disability access, gendered mobility, and rural–urban disparities. And fourth, enforce inter-agency coordination so geospatial outputs immediately trigger targeted investments in safe routes, inclusive temporary learning spaces, and rapid repairs. These measures will convert GIS from a visualization tool into a genuine driver of educational resilience, directly advancing SDG 4 (Quality Education) and SDG 13 (Climate Action). The evidence is clear that technical mapping already exists, what remains missing is governance and equity. Implement these changes now to ensure floods no longer equate to interrupted learning.

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Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Bambang Sigit Widodo	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
E Terlumun Iortyom		✓				✓		✓	✓	✓	✓	✓		

Conflict of Interest Statement

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