

# WebGIS-Based Flood Hazard Map Learning Improves Spatial Literacy and Evacuation Preparedness in Luwu Raya High Schools

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| ARTICLE INFO                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
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| <p><b>Article History:</b><br/>Received: 2026-06-07<br/>Accepted: 2026-09-15<br/>Published: 2026-09-30</p> <p><b>Keywords:</b><br/>Evacuation preparedness;<br/>Flood;<br/>Luwu raya;<br/>Spatial literacy;<br/>Webgis</p> <p><b>Corresponding author:</b><br/>Andi Jumardi<br/>Email: <a href="mailto:ajmr44@uncp.ac.id">ajmr44@uncp.ac.id</a><br/>DOI: 10.37905/jgej.v7i2.39553</p> <p>Copyright © 2026 The Authors</p>  <p>This open access article is distributed under a Creative Commons Attribution-NonCommercial (CC-BY-NC) 4.0 International License</p> | <p>The Luwu Raya region, South Sulawesi, is one of the most flash flood-prone areas in Indonesia. Recent bibliometric reviews indicate a lack of experimental research examining the effectiveness of WebGIS-based educational interventions in this region. This study evaluates the impact of WebGIS-based flood hazard map learning on flood spatial literacy and evacuation preparedness, tests the mediating role of spatial literacy, and examines the influence of residential spatial proximity. Using a quasi-experimental pretest-posttest nonequivalent control group design, this study included 120 eleventh-grade students (<math>n = 60</math> per group) were selected from four hazard-zone schools (two schools assigned to the experimental group and two to the control group). The experimental group completed six WebGIS sessions using authentic data (inaRISK, DEMNAS, and DIBI). The results indicated that WebGIS significantly improved both spatial literacy (<math>d = 2.72</math>) and evacuation preparedness (<math>d = 3.07</math>). Path analysis revealed that spatial literacy did not mediate this relationship (<math>p = 0.430</math>). Instead, WebGIS exerted a direct and dominant effect on preparedness. Furthermore, ANCOVA indicated that the intervention effect on preparedness remained robust after controlling for students' baseline ability and residential proximity to the hazard source. These findings suggest that WebGIS may operate through visual risk immersion, offering a robust and inclusive pedagogical model for disaster risk reduction education.</p> |

**How to Cite:** Jumardi, A., Iriansa, I., Muis, I., Putri, I. K., & Busrah, Z. (2026). WebGIS-Based Flood Hazard Map Learning Improves Spatial Literacy and Evacuation Preparedness in Luwu Raya High Schools. *Jambura Geo Education Journal*, 7(2), 262–277. <https://doi.org/10.37905/jgej.v7i2.39553>

## 1. Introduction

Floods are the most frequent natural disasters globally, causing disproportionate loss of life and economic damage in developing countries (UNDRR, 2023). Globally, floods account for approximately 44% of all disaster events, affecting an average of 80 million people annually (Tellman et al., 2021). In Indonesia, the National Disaster Management Agency (BNPB) recorded 750 flood events from January to September 2024, out of a total of 1,200 natural disasters. Hydrometeorological disasters accounted for 98.92% of all events, including damage to 444 educational facilities (BNPB, 2024a). The impact on educational facilities positions school communities as frontline stakeholders in flood disaster risk reduction.

The Luwu Raya region, encompassing Luwu Regency, North Luwu Regency, East Luwu Regency, and Palopo City in South Sulawesi, is one of the most persistent flood corridors in Indonesia. The topographical configuration of this region, featuring the Latimojong Mountains that descend steeply toward the coastal lowlands of the Gulf of Bone, generates intense flash flood conditions through major river networks such as the Masamba, Salu Balease, and Salu Rongkong Rivers. Post-disaster sedimentological studies confirmed that the July 2020 flash floods in the Masamba, Radda, and Binuang Rivers occurred simultaneously, claiming 38 lives, injuring 58 people, displacing 14,483 individuals, and destroying nine schools (BNPB, 2020; Maulana et al., 2023). In May 2024, floods and landslides again struck 13 districts in Luwu Regency, resulting in 14 fatalities and submerging 1,867 houses with water levels reaching 1–3 meters (BNPB, 2024a). Qualitative and watershed-scale studies elsewhere in Sulawesi have linked upstream land-cover conversion to intensified flooding (Kelley & Prabowo, 2019; Ramadhan et al., 2023).

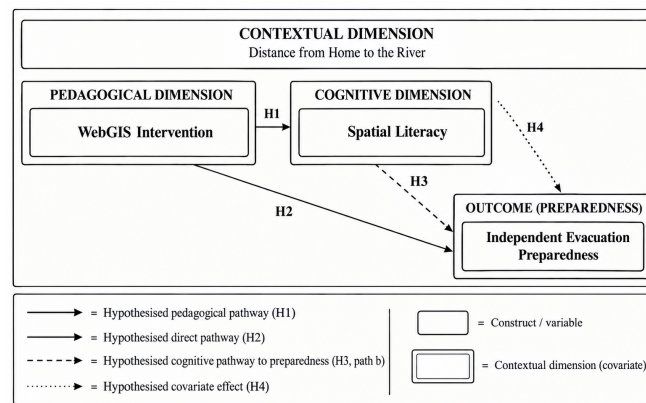
The 2015–2030 Disaster Risk Reduction framework positions schools as strategic entities in the national disaster resilience chain, including through the strengthening of local risk-based education (Aitsi-Selmi et al., 2015; UNDRR, 2015). Nevertheless, the integration of disaster risk reduction (DRR)

education into the Indonesian school curriculum remains highly uneven and heavily dependent on individual teacher initiatives (Desilia et al., 2023; Gokmenoglu et al., 2021). A bibliometric study of 659 publications on Indonesian school disaster management between 2010 and 2024 identified the dominance of studies from Java Island and a severe lack of representation from high-risk regions outside Java, including the Luwu Raya area (Amri et al., 2025). At the cognitive level, independent evacuation capability heavily relies on spatial literacy, which is the ability to read, analyze, and make decisions based on spatial representations (Jo et al., 2016; McLaughlin & Bailey, 2023). A study by Kamil et al. (2020) demonstrated that geographic literacy serves as a critical cognitive bridge between disaster knowledge and the actual preparedness capacity of Indonesian high school students.

Consequently, fostering disaster resilience in schools is not solely a general disaster education issue but also a geography learning challenge that must be addressed through the advancement of spatial thinking, spatial literacy, and geospatial pedagogy. However, the geography curriculum in Indonesian high schools still predominantly treats disasters as declarative knowledge to be memorized rather than spatial problems to be analyzed (Ridha et al., 2019). International studies confirm that effective DRR education requires more than mere knowledge transmission; it must build analytical skills and foster preparedness attitudes. In this context, Web-based Geographic Information Systems (WebGIS) offer a promising pedagogical pathway. While traditional GIS implementation in education often faces significant technical and pedagogical barriers (Bernhäuserová et al., 2022), WebGIS mitigates these challenges by allowing students to interact directly with authentic spatial data through accessible, standard school devices (Fargher, 2018). A study based on ArcGIS Online in Turkey involving 172 students demonstrated a significant improvement in spatial thinking abilities and positive attitudes compared to conventional learning (Kara & Özdemir, 2021). In Indonesia, Handoyo et al. (2024) demonstrated that the Spatial Disaster Learning-GeoTech (SDL-GeoTech) model significantly enhanced the disaster preparedness of junior high school students. Furthermore, a study by Song et al. (2023) in Natural Hazards and Earth System Sciences confirmed that WebGIS improved students' DRR understanding through interactive hazard maps implemented in Chinese and Japanese high schools. Song et al. (2022) also found that web-based hazard maps are more effective than printed maps in the context of DRR education.

Despite the accumulating evidence of WebGIS's effectiveness, several research gaps remain. First, methodologically, the majority of disaster education research still uses single-group designs with generic data simulations, limiting causal inference and ecological validity (Handoyo et al., 2024; Nyokro et al., 2023; Adipranata et al., 2026). Second, theoretically, the mediating role of spatial literacy has not been tested as a cognitive linking mechanism between WebGIS interventions and actual preparedness (Kamil et al., 2020). Third, geographically, despite the high vulnerability of the Luwu Raya region to flash floods (Amri et al., 2025; Maulana et al., 2023), experimental research has not examined the spatial proximity of students' residences. Literature asserts that this geographical factor forms the foundation of individual vigilance against threats (Sultan et al., 2024), making its examination necessary to ascertain the intervention's effect.

To address these gaps, this study proposes the Spatial-Cognitive and Contextual Preparedness (SCCP) evaluation framework. This comprehensive framework encompasses the pedagogical dimensions of WebGIS, spatial cognition, and local spatiality (Figure 1). The framework serves an organizing and evaluative function rather than a structural-estimation one: it specifies which constructs are examined and how they are hypothesized to relate, but it was not fitted as a structural equation model, and residential proximity is treated throughout as a covariate rather than a moderator. It is conceptually broader than the specific statistical mediation diagram tested in this study; while the mediation diagram strictly evaluates the cognitive pathway, the overarching SCCP model also integrates the spatial context of the learners. The framework hypothesizes that WebGIS interaction may bypass traditional theoretical cognitive loads and directly foster risk-informed evacuation preparedness. This study aims to: (1) examine the significance of the improvement in flood spatial literacy among high school students in Luwu Raya through WebGIS learning compared to conventional methods; (2) measure the intervention's impact on independent evacuation preparedness; (3) test the mediating role of spatial literacy in the relationship between WebGIS and evacuation preparedness; and (4) analyze the influence of spatial proximity (the Euclidean distance of residence to the nearest river) on student preparedness to isolate the treatment effect.



**Figure 1.** The proposed Spatial-Cognitive and Contextual Preparedness (SCCP) evaluation framework.

The figure organizes the constructs examined in this study and the hypothesized relations among them (H1–H4), with residential spatial proximity entering the analysis as a covariate. The framework is conceptual and was not estimated as a structural equation model; the statistical mediation model actually tested is presented separately in Figure 3. To systematically address these objectives, the following formal hypotheses were formulated and tested: (H1) WebGIS-based learning significantly improves students' flood spatial literacy compared to conventional learning; (H2) WebGIS learning significantly enhances independent evacuation preparedness compared to conventional learning; (H3) Spatial literacy significantly mediates the relationship between the WebGIS intervention and evacuation preparedness; and (H4) The WebGIS intervention maintains a significant main effect on evacuation preparedness when statistically controlling for variations in students' initial abilities and spatial proximity to the river.

## 2. Method

### 2.1 Research Design

This study employed a quasi-experimental pretest-posttest nonequivalent control-group design, as summarized in Table 1 (Gopalan et al., 2020; Kim & Steiner, 2016). This design was selected because random assignment of students to different classes is ethically and practically infeasible in a school context. Measurement of pretest and posttest scores in both groups enabled the assessment of baseline equivalence and treatment effects (Kim & Steiner, 2016). Randomization was applied at the school level rather than the student level. The four schools were first arranged into two matched pairs on the basis of their hazard-zone classification and comparable ICT infrastructure; within each pair, a single coin toss determined which school was assigned to the experimental condition and which school to the control condition, yielding two schools per condition. Within each school, one intact eleventh-grade class of exactly 30 students participated, producing  $n = 60$  per condition. Individual students and classes were therefore not randomized. The school was the unit of random assignment ( $k = 4$ ), a design feature whose analytical implications are addressed in Section 4.5. Additionally, the four selected schools were matched according to their shared history of high flood exposure, because all had been directly affected by the severe 2020 and 2024 Luwu flash floods. Consequently, all 120 participants attended schools in communities that were directly affected by these events. This matching process minimized the influence of extraneous contextual variables related to disaster familiarity.

**Table 1.** Quasi-Experimental Research Design Scheme

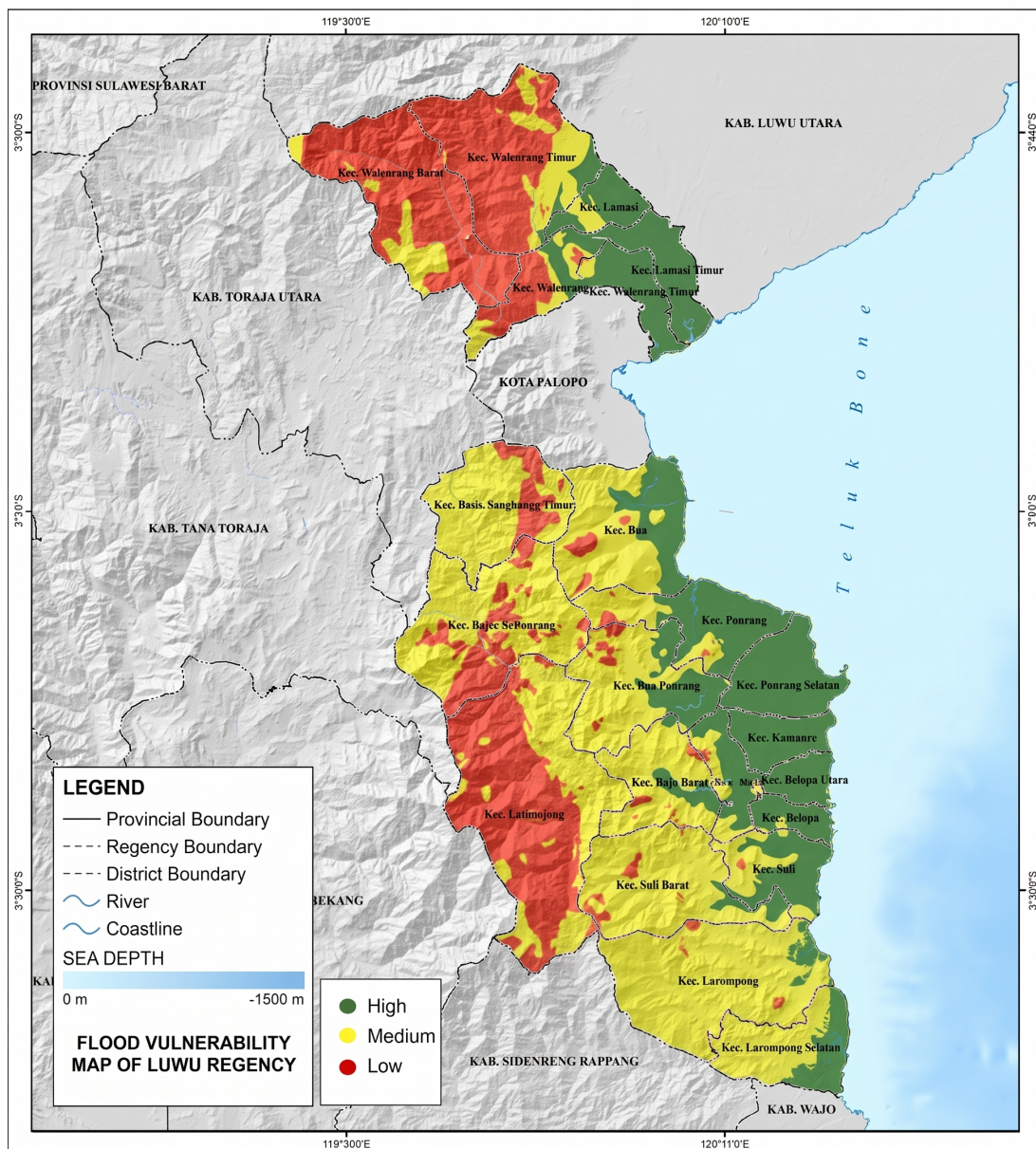
| Group        | Assignment   | Pretest | Treatment | Posttest |
|--------------|--------------|---------|-----------|----------|
| Experimental | Intact class | $O_1$   | X         | $O_2$    |
| Control      | Intact class | $O_3$   | Y         | $O_4$    |

Note. O = measurement, X = WebGIS intervention, and Y = conventional learning (printed maps and worksheets).

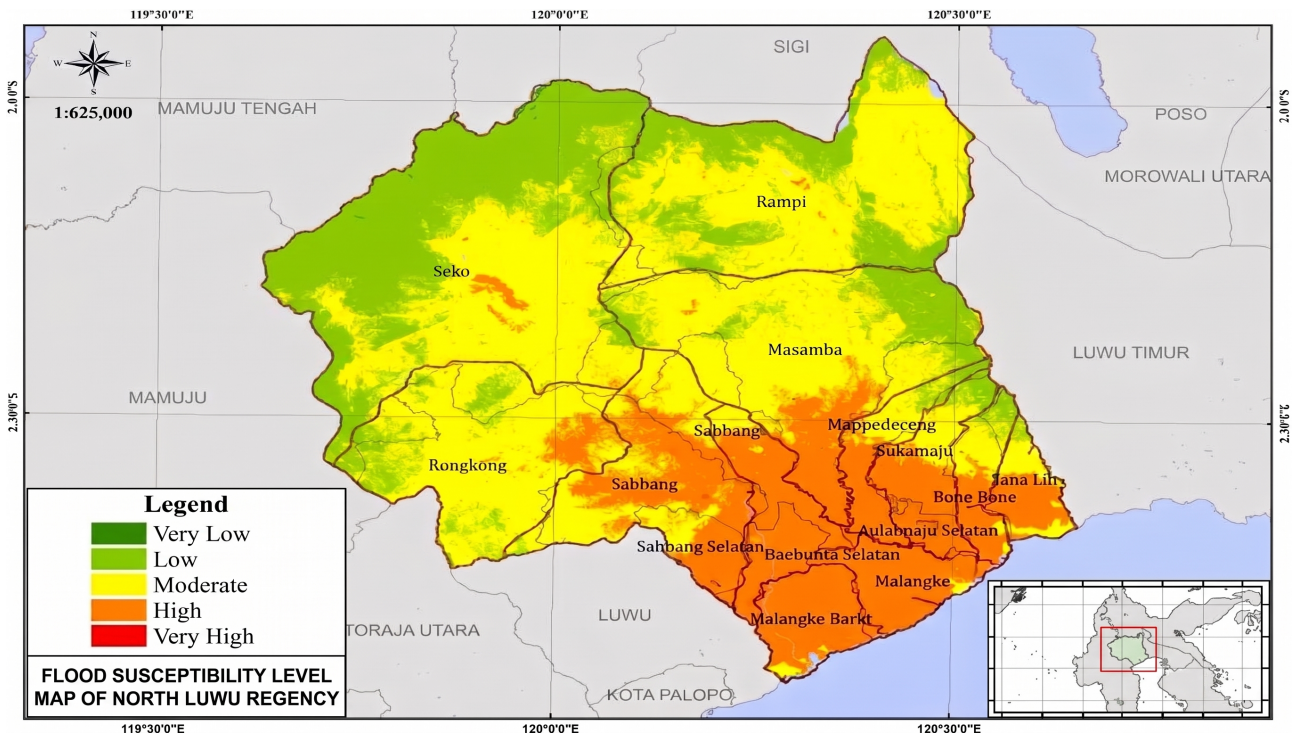
Source: Gopalan et al. (2020); Kim and Steiner (2016)

## 2.2 Participants and Location

The participants were 120 eleventh-grade students ( $n = 60$  per group) selected from four hazard-zone schools (two schools assigned to the experimental group and two to the control group) (Figure 2). Schools were purposively selected according to three criteria: (a) location in moderate- or high-hazard flood zones according to the BNPB flood-hazard layer of the inaRISK portal (BNPB, 2024b), (b) a history of flood impacts during the preceding five years based on BNPB DIBI data, and (c) the availability of minimum ICT infrastructure for WebGIS implementation. The a priori sample size was determined for a two-tailed test using G\*Power 3.1.9.7 (Faul et al., 2007) with parameters  $\alpha = 0.05$ , power = 0.80, and Cohen's  $d = 0.50$ , yielding a target sample size of 64 students per group. There was no attrition during the study, and all 120 enrolled participants completed both pretest and posttest measurements. Although the final sample of 60 students per group fell marginally below this a priori threshold, the large post-intervention effect sizes yielded post hoc statistical power exceeding 0.99. Because the affiliated institution does not require a formal Institutional Review Board (IRB) for non-medical educational research, research permits and ethical clearance were granted by the Provincial Education Agency (Dinas Pendidikan Provinsi Sulawesi Selatan) and the respective school principals. Furthermore, written informed consent was obtained from the school authorities and parents/guardians before the study commenced.



(b)



(b)

**Figure 2.** Map of flood hazard zones in Luwu (a) and North Luwu (b) Regencies based on the official BNPB inaRISK data used as the WebGIS basemap. **Source:** BNPB (2024b)

Prior flood exposure was established at the school rather than the individual level. All four participating schools were located in settlements that were directly inundated during the July 2020 and May 2024 Luwu flash floods, as documented in BNPB disaster records (BNPB, 2020, 2024a) and confirmed by school administrators during site selection. On this basis, all 120 participants were considered to have lived in flood-affected communities at the time of these events. It should be noted, however, that individual-level exposure histories, such as whether a given student's household sustained damage or was displaced, were not recorded through a dedicated instrument, and the present study therefore cannot report the distribution of exposure types within the sample. Because prior exposure is treated as a shared contextual condition rather than a measured individual variable, it could not be entered as a covariate in the ANCOVA models; residential proximity to the nearest river was retained as the operational measure of spatial risk context. Future replications should incorporate a validated disaster-exposure inventory to permit exposure to be modeled explicitly.

To address ethical considerations regarding spatial data privacy, a strict data protection protocol was implemented. In addition to parental consent, explicit student assent was obtained prior to spatial mapping. To reconcile cloud platforms with local data protection, students used inaRISK and ArcGIS Online for regional spatial orientation and entered their home GPS coordinates only into private, unshared layers in Google My Maps accessed through individual accounts on school devices. Only the primary researcher had temporary access to this raw data, and all coordinates were permanently deleted immediately after the printed Personal Flood Risk Maps were generated. To operationalize the spatial proximity variable of river distance used in the subsequent ANCOVA model, the Euclidean (straight-line) distance from each student's entered home GPS coordinate to the nearest major river network (e.g., Masamba or Balease River) was calculated in meters using the measurement tools within the WebGIS platform.

### 2.3 Learning Procedures for Experimental and Control Groups

The experimental group received six WebGIS-based learning sessions, each lasting  $2 \times 45$  minutes, using ArcGIS Online and Google My Maps. Each session used authentic spatial data from the Luwu Raya region, including the BNPB inaRISK Flood Hazard Map (BNPB, 2024b), the 8-meter-resolution DEMNAS Digital Elevation Model (BIG), the Masamba and Balease River basin networks (BIG, 2018), and historical flood event data from 2010–2024 (BNPB, 2024a). Authentic local data were intentionally used

to create personal relevance and support the principles of Place-Based Education (Hamilton & Marckini-Polk, 2023; Yemini et al., 2025). The pedagogical flow followed three phases: spatial orientation (sessions 1–2), local flood data analysis (sessions 3–4), and personal spatial artifact production (sessions 5–6). The six-session structure is detailed in Table 2. To ensure high implementation fidelity and control for device disparities, all experimental WebGIS sessions were conducted in the schools' computer laboratories.

**Table 2.** Structure of the Six WebGIS Intervention Sessions on Luwu Raya Flood Hazard Maps

| Session | Topic                        | Main Activities                                                               | Student Output                                 |
|---------|------------------------------|-------------------------------------------------------------------------------|------------------------------------------------|
| 1       | Digital Flood Hazard Map     | Exploring BNPB inaRISK; identifying district hazard zones                     | Annotated district flood hazard map            |
| 2       | Watersheds and Flow Dynamics | Analyzing DEMNAS DEM; overlaying Luwu Raya river networks                     | Sketch of watersheds and water flow directions |
| 3       | Personal Location Mapping    | Inputting home GPS coordinates into Google My Maps; overlaying inaRISK        | Personal flood hazard profile                  |
| 4       | Historical Flood Patterns    | Visualizing 2010–2024 DIBI data; event heat maps                              | Spatio-temporal analysis of flood patterns     |
| 5       | Evacuation Routes            | Multi-criteria evacuation route design (elevation + distance + accessibility) | Primary and alternative evacuation routes      |
| 6       | Personal Flood Risk Map      | Integrating all data; final map production; spatial narrative presentation    | Personal flood risk map + narrative            |

**Source:** Adapted from Fargher (2018); Kerski & Baker (2019); Yemini et al. (2025)

The control group received instruction with the same frequency and duration (6 sessions  $\times$  2  $\times$  45 minutes), testing time, and the same material coverage, namely Luwu Raya flood mitigation. The difference lay in the media and learning model. The control group received conventional instruction based on lectures and group discussions using static media in the form of printed watershed (DAS) maps and regional-scale Disaster-Prone Area (KRB) maps of Luwu Raya floods. Students in the control group manually identified hazard zones through visual interpretation of printed maps and drafted evacuation routes on paper worksheets (LKS).

To guarantee strong internal validity and high implementation fidelity across both conditions, several extraneous variables were strictly controlled. First, both the experimental and control groups were taught directly by the same researcher to eliminate instructor bias, and baseline equivalence was statistically established (as detailed in Section 3.1). Second, to control for device disparities during the WebGIS intervention, experimental students used standard school desktop computers (minimum specifications: Intel Core i3, 4GB RAM) with a 1:1 student-to-device ratio (30 units per laboratory) and a stable 20-Mbps dedicated broadband connection. Finally, the researcher directly monitored the execution of all sessions in both groups. Session fidelity was documented in a per-session log recording the completion of each planned pedagogical step; across all twelve sessions (six per group), 100% of the planned steps were delivered as designed (mean fidelity = 1.00) without significant disruptions. Consequently, differences in posttest scores are more plausibly attributable to the interactive and analytical features of WebGIS technology, rather than differences in learning material substance or teaching styles.

## 2.4 Research Instruments

This study used two instruments adapted for the Luwu Raya flood context: the Flood Spatial Literacy Test (FSLT) and the Flood Evacuation Preparedness Scale (FEPS). The FSLT is a map-based, 32-item multiple-choice test adapted from the Spatial Thinking Ability Test (Jo et al., 2016; Thayaseelan et al., 2024), using a spatial thinking taxonomy (Hickman, 2023; McLaughlin & Bailey, 2023) to measure flood spatial concepts, spatial representation, overlay analysis, and evacuation reasoning. For both the FSLT and FEPS, items and dimensions were differentially weighted based on their taxonomic complexity prior to final conversion to a 0–100 scale. The FEPS is a non-test instrument using a 4-point Likert scale with 24 items adapted from the UNESCO/ISDR LIPI framework (Widowati et al., 2021), with the addition of a digital map literacy dimension. Instrument specifications are presented in Table 3. Both instruments met the criterion for content validity, specifically S-CVI/Ave  $\geq$  0.80 (Shi et al., 2012; Zamanzadeh et al.,

2015). Prior to the main study, both instruments were pilot-tested with a separate, nonparticipating sample of 45 twelfth-grade students from a similarly flood-prone school in Luwu Raya. The pilot test demonstrated excellent internal consistency, with KR-20 for FSLT = 0.83 and Cronbach's  $\alpha$  for FEPS = 0.86 (Cho & Kim, 2015). Reliability coefficients were computed on unweighted item responses, since the differential weights are applied at the dimension level during score aggregation rather than being properties of the items themselves. The weighting scheme was specified a priori, before data collection, on the basis of the taxonomic complexity of each dimension, and was applied identically to both conditions and to both measurement occasions.

The use of Luwu Raya spatial items and scenarios in the pretest and posttest reflects a methodological decision based on Place-Based Education (PBE) (Yemini et al., 2025). In flash flood mitigation education, ecological validity is deemed more essential than abstract spatial reasoning (Kamil et al., 2020). To mitigate the testing effect (memory bias) resulting from the use of the same instruments, four measures were used to control the testing effect: (1) item randomization and answer option rotation using the schools' Computer-Based Test (CBT) platform, (2) the collection of pretest sheets immediately after completion, (3) the absence of feedback regarding the tests during the intervention, and (4) a time interval spanning the entire six-session intervention period to minimize short-term memory retention. These measures were intended to ensure that any significant score improvement reflected the assimilation of WebGIS mapping skills, rather than rote memorization from retaking the same test.

**Table 3.** Specification and Validity of Research Instruments

| Instrument | Dimensions                                                                                  | Items | Sample Item                                                                      | Scoring and Differential Weighting                                                                                                                                                                                                                                                                                                                                                                                        | Adaptation & Validity                                                            |
|------------|---------------------------------------------------------------------------------------------|-------|----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| FSLT       | Spatial concepts (8), representation (8), overlay analysis (8), evacuation reasoning (8)    | 32    | "Based on the inaRISK map overlay, which block is safest for an assembly point?" | 0–100 (Multiple Choice)<br>Weighting: Lower-order items (concepts/ representation) = 1 point; Higher-order items (overlay/ reasoning) = 2 points. Total raw score (48) is percentage-scaled to 100.                                                                                                                                                                                                                       | Adapted from Jo et al. (2016). Validated by 3 experts (S-CVI/ Ave = 0.88).       |
| FEPS       | Digital map literacy (6), disaster knowledge (6), evacuation planning (6), mobilization (6) | 24    | "I can independently determine an alternative route using a digital map."        | Percentage-scaled score (4-point Likert, coded 1–4)<br>Weighting: basic dimensions (digital map literacy, disaster knowledge) = 1.0 per item; cognitive/action dimensions (evacuation planning, mobilization) = 1.5 per item.<br>Maximum weighted raw score = $(12 \times 4 \times 1.0) + (12 \times 4 \times 1.5) = 120$ ; minimum = 30. Raw scores are percentage-scaled to 100, yielding an effective range of 25–100. | Adapted from Widowati et al. (2021). Validated by 3 experts (S-CVI/ Ave = 0.92). |

**Source:** Adapted from Jo et al. (2016) and Widowati et al. (2021); Primary data validation

Finally, to evaluate the students' map products in the experimental group, the Personal Flood Risk Map Rubric (PFRMR) was employed. This rubric was validated by two GIS education experts (S-CVI = 1.00) and consists of two main dimensions evaluated on a 4-point scale (1 = missing/inaccurate to 4 = comprehensive/highly accurate): (1) cartographic element completeness, and (2) spatial interpretation narrative depth. To ensure consistent scoring, two independent raters (geography educators)

underwent a one-hour calibration session using three anchor samples prior to evaluation. Inter-rater reliability was subsequently calculated using the two-way mixed intraclass correlation coefficient (ICC) for absolute agreement.

## 2.5 Data Analysis

Data analysis was conducted sequentially. First, prerequisite assumption tests were performed, including tests for normality (Shapiro-Wilk), homogeneity of variances (Levene's test), and homogeneity of regression slopes as a requirement for ANCOVA (Field, 2018). Second, while an independent-samples t test was initially conducted to evaluate absolute post-intervention score differences, Analysis of Covariance (ANCOVA) was employed as the primary and most robust inferential analysis to effectively isolate the treatment effect by statistically controlling for both pretest scores and residential spatial proximity (river distance) as covariates. Third, intervention effectiveness was measured using normalized N-Gain (Cengiz & Calik, 2018; Hake, 1998):  $g = (\text{posttest} - \text{pretest}) / (100 - \text{pretest})$ , categorized as low ( $g < 0.30$ ), moderate ( $0.30 \leq g \leq 0.70$ ), and high ( $g > 0.70$ ). Fourth, the between-group effect size and its confidence interval were estimated using Cohen's d, calculated via the noncentral-t distribution approach. Fifth, mediation testing (path analysis) was conducted using the Structural Equation Modeling (SEM) module in JASP with a Maximum Likelihood estimator; the significance of the indirect effect was evaluated using normal-theory (Wald) confidence intervals derived from the delta method. Sixth, to disentangle the between-group from the individual-level association between spatial literacy and preparedness, Pearson correlations between posttest FSLT and posttest FEPS were computed separately within each group.

## 3. Results and Discussion

### 3.1 Results

#### 3.1.1 Descriptive Statistics, Initial Equivalence, and Absolute Differences

Table 4 presents the descriptive statistics of the pretest and posttest scores for both groups, along with the normalized N-Gain values for the Flood Spatial Literacy Test (FSLT) and Flood Evacuation Preparedness Scale (FEPS) measures. The pretest scores suggest descriptive baseline equivalence between the experimental and control groups (FSLT: 38.67 vs 37.93; FEPS: 42.35 vs 41.82).

**Table 4.** Descriptive Statistics of Pretest-Posttest and Normalized N-Gain (0–100 Scale)

| Variable      | Group | Mean  | SD   | Min   | Max   | N-Gain |
|---------------|-------|-------|------|-------|-------|--------|
| Pretest FEPS  | Exp   | 42.35 | 6.95 | 25.00 | 58.00 | -      |
|               | Ctrl  | 41.82 | 7.01 | 25.00 | 59.00 | -      |
| Pretest FSLT  | Exp   | 38.67 | 7.50 | 20.00 | 54.00 | -      |
|               | Ctrl  | 37.93 | 7.13 | 22.00 | 55.00 | -      |
| Posttest FEPS | Exp   | 78.63 | 7.16 | 64.00 | 96.00 | 0.63   |
|               | Ctrl  | 56.10 | 7.52 | 40.00 | 72.00 | 0.25   |
| Posttest FSLT | Exp   | 74.22 | 8.15 | 54.00 | 92.00 | 0.58   |
|               | Ctrl  | 52.35 | 7.91 | 36.00 | 69.00 | 0.23   |

**Source:** Primary data analysis

Baseline equivalence was assessed with an independent-samples t test, which indicated no statistically significant difference in baseline spatial literacy ( $t = 0.555$ ;  $p = 0.580$ ) or evacuation preparedness ( $t = 0.416$ ;  $p = 0.680$ ) between the two groups. The absence of statistically significant baseline differences supports baseline equivalence and reduces the likelihood that posttest differences were attributable to differences in students' initial abilities (Kim & Steiner, 2016).

Following the implementation of the six-session intervention, the experimental group recorded a normalized N-Gain value categorized as moderate, for both spatial literacy ( $g = 0.58$ ) and evacuation preparedness ( $g = 0.63$ ). Conversely, the control group recorded an N-Gain value in the low category (FSLT:  $g = 0.23$ ; FEPS:  $g = 0.25$ ).

Prior to primary hypothesis testing, an independent-samples t test was conducted to evaluate absolute post-intervention score differences. Assumption testing indicated that the data were approximately normally distributed (Shapiro-Wilk:  $W > 0.95$ ;  $p > 0.05$ ) and variance homogeneity

(Levene:  $F < 2.0$ ;  $p > 0.05$ ), thus the independent-samples  $t$  test could be applied, as shown in Table 5 (Field, 2018).

**Table 5.** Independent-Samples  $t$  Test Results for Posttest Scores

| Instrument | $t$   | df  | $p$    | Cohen's $d$ | SE Cohen's $d$ | 95% CI for $d$ |
|------------|-------|-----|--------|-------------|----------------|----------------|
| FEPS       | 16.82 | 118 | < .001 | 3.07        | 0.27           | [2.54, 3.60]   |
| FSLT       | 14.92 | 118 | < .001 | 2.72        | 0.25           | [2.22, 3.22]   |

Note. df = degrees of freedom.  $\alpha = 0.05$ . The SE for Cohen's  $d$  is an approximate standard error based on the noncentral  $t$  distribution. Source: Primary data analysis.

The difference in posttest scores was highly significant for both instruments ( $p < 0.001$ ), indicating absolute improvements. However, to robustly isolate the treatment effect from initial variations and test the formal hypotheses, analysis of covariance (ANCOVA) was used as the primary analytical model.

### 3.1.2 Primary Hypothesis Testing: Treatment Effects and Spatial Factors (ANCOVA)

Prior to interpreting the ANCOVA results to test Hypotheses 1, 2, and 4, key assumptions were evaluated. The assumption of equality of variances was met for both the FEPS model ( $F = 0.144$ ;  $p = 0.705$ ) and the FSLT model ( $F = 0.020$ ;  $p = 0.886$ ), as assessed by Levene's test. Furthermore, the assumption of homogeneity of regression slopes was met for the FEPS model (Group  $\times$  Pretest FEPS:  $F = 1.412$ ,  $p = 0.237$ ; Group  $\times$  River distance:  $F = 1.160$ ,  $p = 0.284$ ) and the FSLT model (Group  $\times$  Pretest FSLT:  $F = 2.344$ ,  $p = 0.129$ ; Group  $\times$  River distance:  $F = 0.593$ ,  $p = 0.443$ ), indicating no significant interaction between the covariates and the independent variable on the posttest scores.

**Table 6.** ANCOVA Results, Dependent Variable: FEPS Posttest Scores

| Source         | Sum of Squares | df  | Mean Square | $F$    | $p$    | $\eta^2_p$ | $\omega^2_p$ |
|----------------|----------------|-----|-------------|--------|--------|------------|--------------|
| Group          | 15,228.00      | 1   | 15,228.00   | 281.30 | < .001 | 0.71       | 0.70         |
| Pretest FEPS   | 29.14          | 1   | 29.14       | 0.54   | 0.465  | 0.00       | 0.00         |
| River distance | 37.49          | 1   | 37.49       | 0.69   | 0.407  | 0.00       | 0.00         |
| Residuals      | 6,279.42       | 116 | 54.13       |        |        |            |              |

Source: Primary data analysis.  $\alpha = 0.05$ .

Consequently, the ANCOVA results (Table 6) indicate that the WebGIS intervention (Group) is the strongest predictor of evacuation preparedness posttest scores ( $F = 281.30$ ;  $p < 0.001$ ). The effect size for this group variable is classified as very large, based on the partial eta-squared estimate ( $\eta^2_p = 0.71$ ) and the partial omega-squared ( $\omega^2_p = 0.70$ ) which corrects for overestimation bias. Crucially, after being entered into the statistical model to be controlled, neither variations in students' initial literacy abilities (Pretest FEPS) nor spatial proximity factors (River distance) made a statistically significant contribution ( $p > 0.05$ ;  $\eta^2_p = 0.00$ ). These results support the conclusion that WebGIS improved independent evacuation preparedness compared to conventional learning and support Hypothesis 2. Furthermore, because this significant main effect remains robust even after statistically controlling for variations in students' initial abilities and spatial proximity to the river, the results also support Hypothesis 4.

**Table 7.** ANCOVA Results, Dependent Variable: FSLT Posttest Scores

| Source         | Sum of Squares | df  | Mean Square | $F$    | $p$    | $\eta^2_p$ | $\omega^2_p$ |
|----------------|----------------|-----|-------------|--------|--------|------------|--------------|
| Group          | 14,348.90      | 1   | 14,348.90   | 227.15 | < .001 | 0.66       | 0.65         |
| Pretest FSLT   | 173.51         | 1   | 173.51      | 2.75   | 0.100  | 0.02       | 0.01         |
| River distance | 81.02          | 1   | 81.02       | 1.28   | 0.260  | 0.01       | 0.00         |
| Residuals      | 7,328.05       | 116 | 63.17       |        |        |            |              |

Source: Primary data analysis.  $\alpha = 0.05$ .

The parallel ANCOVA for FSLT (Table 7) indicates that, controlling for Pretest FSLT and river distance, the WebGIS intervention maintained a highly significant main effect on Posttest FSLT scores ( $F = 227.15$ ;  $p < 0.001$ ;  $\eta^2_p = 0.66$ ), confirming that the pedagogical treatment improved spatial literacy after adjustment for baseline differences, supporting Hypothesis 1.

### 3.1.3 Mediation Analysis: The Role of Spatial Literacy

Path analysis was conducted to test Hypothesis 3, namely whether spatial literacy (FSLT) acts as a mediator bridging the effect of the WebGIS intervention on evacuation preparedness (FEPS).

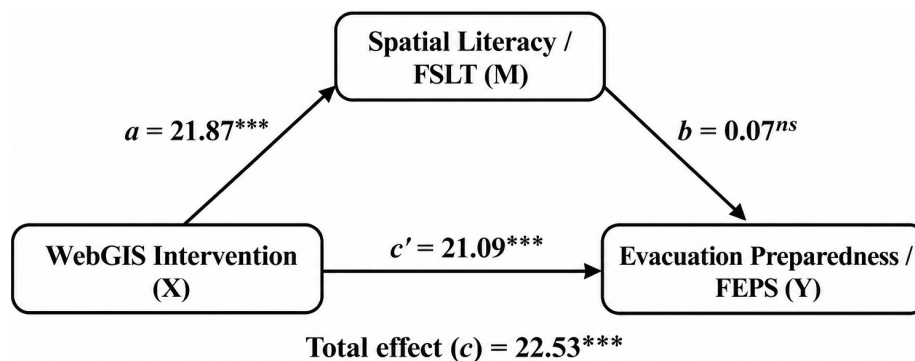
**Table 8.** Mediation Analysis Results

| Path | Description                             | B     | SE   | Z     | p      | 95% CI (Wald)  |
|------|-----------------------------------------|-------|------|-------|--------|----------------|
| a    | WebGIS to Spatial Literacy (FSLT)       | 21.87 | 1.45 | 15.04 | < .001 | [19.02, 24.72] |
| b    | Spatial Literacy to Preparedness (FEPS) | 0.07  | 0.08 | 0.79  | 0.429  | [-0.10, 0.23]  |
| c    | WebGIS to Preparedness (total effect)   | 22.53 | 1.33 | 16.96 | < .001 | [19.93, 25.14] |
| c'   | WebGIS to Preparedness (direct effect)  | 21.09 | 2.25 | 9.37  | < .001 | [16.68, 25.51] |
| a×b  | Indirect effect (a×b)                   | 1.44  | 1.82 | 0.79  | 0.430  | [-2.13, 5.01]  |

**Source:** Primary data analysis

B = unstandardized coefficient; SE = standard error. The 95% Wald (normal theory) confidence interval for the indirect effect includes zero, indicating a non-significant mediation. Bootstrap intervals, which are generally preferred for asymmetric indirect-effect distributions (Hayes, 2018), were not computed; see Section 4.5. Based on the estimation results in Table 8, the WebGIS intervention significantly predicted an increase in spatial literacy (Path a:  $B = 21.87$ ;  $p < 0.001$ ). However, when spatial literacy was tested for its effect on evacuation preparedness by controlling for the intervention variable, the result was not statistically significant (Path b:  $B = 0.07$ ;  $p = 0.429$ ). Consequently, the indirect effect of WebGIS on preparedness through spatial literacy was also not statistically significant ( $B = 1.44$ ; 95% CI [-2.13, 5.01];  $p = 0.430$ ). This confidence interval, which crosses zero, does not support Hypothesis 3. Although the mediation hypothesis was not supported, this model reveals an important empirical finding: WebGIS has a large direct effect on evacuation preparedness (Path c':  $B = 21.09$ ;  $p < 0.001$ ), as illustrated in Figure 3, \*\*\* $p < .001$ . ns = not significant.

To further clarify this mechanism, Pearson correlations between Posttest FSLT and Posttest FEPS were computed separately within each group. The within-group associations were weak and non-significant (experimental:  $r = -0.022$ ,  $p = 0.870$ ; control:  $r = 0.164$ ,  $p = 0.211$ ), consistent with the near-zero path b estimate. By contrast, the correlation computed across the pooled sample was strong ( $r = 0.70$ ), but this pooled value largely reflects the between-group mean separation produced by the intervention rather than an individual-level cognitive link. This distinction indicates that the absence of mediation is not merely a suppression artifact of the pooled association.



**Figure 3.** Path diagram illustrating the direct and indirect effects of the WebGIS intervention on evacuation preparedness.

### 3.1.4 Evaluation of Student Map Products

Evaluation of the final product in the form of a Personal Flood Risk Map produced by experimental group students was assessed using the PFRMR rubric by two independent raters, demonstrating excellent inter-rater reliability ( $ICC = 0.87$ ). The average composite score reached 73.40 out of a 100 scale ( $SD = 9.20$ ). Dimension means were averaged and rescaled to 0–100 ( $((3.20 + 2.67)/2 \div 4 \times 100 = 73.40)$ ). The aspect of cartographic element completeness recorded the highest score ( $M = 3.20/4.00$ ), whereas the depth aspect of spatial interpretation narratives remained limited ( $M = 2.67/4.00$ ).

### 3.1.5 Sensitivity to Clustering

Because treatment was assigned at the school level, the degree of within-school dependence was quantified before interpreting the student-level inferential results. Two quantities must be distinguished. Unconditional intraclass correlations, estimated without adjusting for condition, were  $ICC = 0.71$  for posttest FSLT and  $ICC = 0.76$  for posttest FEPS. These values are not interpretable as clustering, however, because treatment was confounded with school: the between-school variance they capture is largely the treatment effect itself. The relevant quantity for design-effect calculation is the residual intraclass correlation, estimated with condition included as a fixed effect. These were  $ICC < 0.001$  for FSLT and  $ICC < 0.001$  for FEPS, corresponding to design effects of approximately 1.00 at an average cluster size of  $m = 30$ . It must be emphasised that with two clusters per condition the residual between-school variance is estimated with virtually no precision and may be reported at the boundary of the parameter space; a small residual ICC in this design constitutes an absence of detectable clustering rather than evidence that clustering is absent.

As a sensitivity check, the models were re-estimated with cluster-robust standard errors, with a CR2 correction and Satterthwaite degrees of freedom (Pustejovsky & Tipton, 2018), treating the school as the clustering unit. Under this specification the estimated treatment effect on FEPS was  $B = 22.53$ ,  $SE = 1.35$ ,  $t(1.04) = 16.71$ ,  $p = 0.034$ , and on FSLT  $B = 21.87$ ,  $SE = 0.98$ ,  $t(1.85) = 22.39$ ,  $p = 0.003$ . The point estimates are unchanged from the student-level models, as expected. Consistent with the small residual intraclass correlation, the cluster-robust standard errors are close to those of the student-level models; the substantive correction implied by the design appears in the degrees of freedom, which fall to approximately one to two, rather than in the standard errors themselves. These results are reported as an exploratory robustness check rather than as definitive inference: with only four clusters, cluster-robust methods themselves rest on asymptotic arguments that are not satisfied here. Their value lies in demonstrating the magnitude of the correction implied by the design, not in furnishing an alternative p-value.

## 3.2 Discussion

### 3.2.1 Main Effects and the Role of Active Spatial Engagement

The statistical results demonstrate that WebGIS significantly improved both spatial literacy and evacuation preparedness. While the normalized N-Gains for the experimental group were categorized as moderate ( $g = 0.58$  and  $0.63$ ), the extreme between-group effect sizes (Cohen's  $d > 2.70$ ) arise arithmetically because the 22.5-point mean separation on FEPS corresponds to approximately three within-group standard deviations ( $SD \approx 7.34$ ), while the control group's improvement remained within the low N-Gain category ( $g = 0.25$ ). Variances were comparable across groups (Levene's  $F = 0.144$ ,  $p = 0.705$ ), so the magnitude reflects the size of the mean shift rather than any restriction of range in the control condition. Substantively, this large divergence may partly reflect the steep learning curve associated with WebGIS technology, where students transitioned from a lack of digital map literacy to mastery of interactive spatial tools. Consistent with previous studies (Gürhan & Yağbasan, 2024; Kara & Özdemir, 2021), the superiority of WebGIS over conventional learning lies in its capacity to facilitate active spatial engagement (McLaughlin & Bailey, 2023).

Unlike conventional static maps that restrict students to passive observation, WebGIS provides a dynamic, multi-layered analytical environment. In this study, students actively manipulated authentic spatial datasets, such as DEMNAS topography and inaRISK hazard zones, transforming abstract geographic concepts into tangible mitigation strategies. By identifying hazard zones around their own homes and designing evacuation routes based on real elevation data, students operationalized the GeoCapabilities principle (Fargher, 2018). This process fundamentally empowers students, shifting

their pedagogical role from mere recipients of declarative disaster knowledge to capable spatial decision-makers. The ability to perform multi-criteria spatial reasoning, such as determining safe distances from river networks while analyzing elevation contours for optimal evacuation paths, demonstrates a higher-order cognitive achievement that static printed worksheets simply cannot stimulate.

### 3.2.2 The Absence of Mediation: Methodological and Theoretical Explanations

In interpreting the non-significant mediation finding, a methodological rival explanation must first be acknowledged. The WebGIS intervention (X) predicted both spatial literacy (M) and evacuation preparedness (Y) with exceptionally large effect sizes (Cohen's  $d > 2.70$ ). Consequently, X and M share a massive amount of variance, creating conditions of multicollinearity within the path model. This is evidenced by the 69% inflation of the standard error for the direct effect (from  $SE = 1.33$  in the total effect to  $SE = 2.25$  in the direct effect). Under such high collinearity, the statistical power to detect the specific M to Y path (path b) is severely compromised. Therefore, the observed absence of mediation might partially be a statistical artifact rather than a pure absence of a cognitive linking mechanism. Nevertheless, multicollinearity inflates the standard error rather than shrinking the point estimate; the near-zero within-group association between spatial literacy and preparedness (Section 3.3) indicates that the collinearity artifact alone cannot fully account for the null mediation.

Nevertheless, assuming the direct effect holds, a major theoretical implication emerges. Contrary to the traditional assumption that disaster preparedness requires a tiered cognitive progression through theoretical spatial literacy, we propose that WebGIS operates primarily through visual risk immersion and personal relevance. Because students discovered that their homes were in an inARISK high-hazard zone, we propose that this visual immersion acts as a plausible explanation for an immediate elevation in perceived risk and self-efficacy (Hamilton & Marckini-Polk, 2023; Yemini et al., 2025). This localized relevance may bypass traditional theoretical spatial cognitive loads, allowing students to directly convert geospatial information into practical evacuation decisions.

### 3.2.3 Robustness of Intervention Effects Across Initial Ability and Residential Proximity

Furthermore, the ANCOVA results indicate that the intervention effect was robust across both initial ability and residential proximity to the river. Unlike general trends in the literature that assume proximity to a hazard source independently dictates preparedness levels (Sultan et al., 2024), the WebGIS intervention consistently elevated preparedness capacities, producing learning gains that were not contingent on students' initial cognitive baseline or residential proximity to the river. This finding is particularly significant for disaster risk reduction (DRR) pedagogy. In traditional instructional settings, students with lower initial spatial literacy often struggle to internalize complex cartographic data, which typically widens the preparedness gap. However, the interactive and highly visual nature of WebGIS appears to scaffold these cognitive deficits, providing an inclusive learning environment where all students can acquire essential mitigation skills. Spatially, by virtually immersing students in their specific hazard zones, the technology may bring the flood risk into their immediate cognitive proximity. This virtual immersion may reduce the psychological complacency typically experienced by students living further from the riverbanks. Consequently, WebGIS offers an equitable educational framework that supports a more uniform baseline of preparedness across diverse student demographics in highly vulnerable regions. It should be noted, however, that these interpretations rest on two distinct statistical results. First, residential proximity showed no significant main effect on preparedness once the treatment was accounted for ( $F = 0.69$ ,  $p = 0.407$ ,  $\eta^2 p = 0.00$ ; Table 6). Second, the Group  $\times$  River distance interaction in the FEPS model was likewise non-significant ( $F = 1.160$ ,  $p = 0.284$ ), indicating that the association between residential proximity and preparedness did not differ significantly between conditions. The present design therefore supports the weaker claim that intervention gains were not contingent on proximity, rather than the stronger claim that WebGIS actively equalized a pre-existing proximity gradient.

### 3.2.4 Quality of Personal Flood Risk Maps and Contextual Implications

The evaluation of the Personal Flood Risk Maps produced by the students revealed a distinct disparity between cartographic completeness and narrative depth. This disparity is consistent with Song et al. (2023) postulate that the acquisition of digital mapping technical skills generally precedes

the ability for verbal spatial articulation. This finding suggests the urgency of more explicit pedagogical scaffolding to bridge WebGIS technical skills with analytical spatial narrative abilities (Kerski & Baker, 2019).

Contextually, the findings on this intervention's effectiveness have critical implications for disaster mitigation in Luwu Raya. Given the historical track record of flash floods in the Masamba Watershed that trigger runoff into settlements within hours after extreme upstream rainfall (Maulana et al., 2023), the speed of independent evacuation based on spatial understanding becomes an absolute survival skill. The personal risk maps extracted by students are not merely academic artifacts but risk communication instruments ready to be disseminated to family units. The extension of pedagogical impacts from the classroom to the household level aligns with the mandate of community-based disaster education advocated in the 2015–2030 Sendai Framework (Aitsi-Selmi et al., 2015). Furthermore, this research provides the first controlled evidence from the Luwu Raya area, directly responding to the empirical gap identified in the bibliometric analysis of school disaster education in Indonesia (Amri et al., 2025).

### 3.2.5 Limitations and Future Directions

Interpretations of this study's results must consider several inherent limitations. First, the use of a quasi-experimental design limits the strength of absolute causal claims due to the absence of pure sample randomization. Second, the exceptionally large effect sizes warrant cautious interpretation due to potential confounding factors. There is a strong likelihood of a "teaching to the test" alignment, as the experimental group spent six sessions actively practicing digital map overlays and routing tasks that closely mirrored the measurement instruments, whereas the control group utilized static media. Third, an experimenter expectancy bias cannot be entirely ruled out, given that the same researcher designed the instruments, delivered both treatments, and administered the assessments. Fourth, the analytical approach risks pseudoreplication. Because the treatment was effectively assigned to intact classes across only four schools, the true independent unit of the intervention is the school context, not the individual student. Analyzing the data via a student-level ANCOVA artificially inflates the degrees of freedom, treating  $N = 120$  rather than  $k = 4$  as the basis for inference.

In principle this also understates standard errors, although the diagnostics reported in Section 3.5 indicate that in this sample the distortion is confined almost entirely to the degrees of freedom rather than to the standard errors. To quantify rather than merely acknowledge this issue, we report intraclass correlations, design effects, and cluster-robust sensitivity estimates in Section 3.5. A formal multilevel model remains inestimable with four clusters, and the cluster-robust estimates themselves should be read as illustrative rather than inferential. Taken together, these diagnostics indicate that the student-level  $p$ -values reported in Section 3.2 rest on degrees of freedom that the design does not support, and that the treatment contrast retains its sign and magnitude under cluster-robust estimation but is tested with almost no power at  $k = 4$ . The effect sizes should therefore be read as estimates requiring replication across a larger number of schools rather than as precisely bounded inferential results. Fifth, the mediation path analysis used normal-theory (Wald) confidence intervals rather than bootstrapping. Given that the sampling distribution of indirect effects is often asymmetrical, the absence of bootstrapped intervals represents a minor statistical limitation in interpreting the mediation paths. Future studies should employ Multilevel Modeling (MLM) and expand the population scope across all regencies in Luwu Raya to accelerate the generalizability of these pedagogical findings (Kim & Steiner, 2016).

## 4. Conclusion

WebGIS-based geography learning significantly improved flood spatial literacy ( $t = 14.92$ ;  $p < 0.001$ ;  $d = 2.72$ ;  $g = 0.58$ ) and independent evacuation preparedness ( $t = 16.82$ ;  $p < 0.001$ ;  $d = 3.07$ ;  $g = 0.63$ ) among high school students in the Luwu Raya region compared to conventional learning. Path analysis revealed an unexpected finding: spatial literacy did not mediate the effect of WebGIS on evacuation preparedness ( $p = 0.430$ ). Instead, WebGIS exerted a large direct effect. These findings suggest that visual immersion and spatial data interactivity may reduce students' theoretical spatial cognitive load, thus directly fostering practical mitigation decisions. Furthermore, analysis of covariance indicated that the intervention effect was independent of residential spatial proximity. This pedagogical treatment improved preparedness consistently, producing gains that were not contingent on students' initial cognitive baseline or residential distance to the hazard sources. This study presents the first empirical

evidence from the Luwu Raya area that the integration of WebGIS with authentic local disaster data is a robust, equitable, and replicable pedagogical innovation to strengthen the architecture of disaster risk reduction (DRR) education in Indonesian high schools.

## 5. Acknowledgments

The authors express their gratitude to the Institute for Research and Community Service (LPPM) of Universitas Cokroaminoto Palopo, as well as the undergraduate students of the Geographic Information System Concentration who assisted with logistical preparation of the computer laboratories and data entry.

**Funding.** This research received no external funding.

**Conflict of interest.** The authors declare no conflicts of interest.

**Data availability.** All data reported in this publication are available within the article.

**AI Use Declaration.** The AI application used to assist with writing, and content organization was ChatGPT. All AI-assisted output has been reviewed, verified, and edited by the authors, who are fully responsible for the content and accuracy of this publication.

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