Reflection: Education and Pedagogical Insights

Geospatial Firebreak Design Development through Project-Based Learning for Wildfire Mitigation Education in Bromo Vegetation

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ABSTRACT

Wildfires pose significant threats to ecosystem sustainability, biodiversity, tourism, and the resilience of protected landscapes. This study aimed to develop a geospatial technology-based firebreak design through Project-Based Learning (PjBL) for wildfire mitigation education in the Bromo vegetation ecosystem, East Java, Indonesia. The study employed a Research and Development (R&D) approach with a design-based research orientation. The research integrated Geographic Information Systems (GIS), vegetation analysis, slope analysis, accessibility assessment, historical wildfire information, and conservation considerations. A GIS-based weighted overlay model was used to identify potential firebreak planning areas. The geospatial design process was then integrated into a six-week PjBL activity involving undergraduate students. Students investigated wildfire risks, analyzed spatial data, developed firebreak design alternatives, and presented their project outputs. The educational outcomes were evaluated through spatial thinking assessments, environmental literacy questionnaires, project rubrics, and expert evaluation. The results indicated that the selected study area contained diverse vegetation and topographic characteristics requiring site-specific firebreak planning. Three conceptual firebreak alternatives were developed with different lengths, widths, spatial coverage, and environmental considerations. The learning evaluation showed improvements in students' spatial thinking and environmental literacy, while project assessment indicated satisfactory disaster mitigation competencies. Expert evaluation also indicated that the developed framework had strong educational relevance and appropriate environmental considerations. The study concludes that the integration of GIS and PjBL can transform wildfire mitigation education into an authentic, interdisciplinary, and design-oriented learning experience. The proposed firebreak designs are preliminary planning outputs and require further field validation, fire behavior analysis, ecological assessment, and approval from relevant authorities before implementation.

Keywords: Geographic Information Systems; Firebreak Design; Project-Based Learning; Wildfire Mitigation; Environmental Education; Spatial Thinking; Bromo Ecosystem; Disaster Mitigation

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SDG's: Quality Education (4); Sustainable Cities and Communities (11); Climate Action (13); Life on Land (15); Partnerships for the Goals (17)

INTRODUCTION

Wildfires are among the major environmental challenges affecting ecosystem sustainability, biodiversity, and the resilience of protected landscapes (Gajendiran et al., 2024). The increasing risk of vegetation fires highlights the importance of preventive mitigation strategies that combine environmental management, spatial planning, and community preparedness. In addition to causing ecological damage, wildfires can disrupt tourism activities, threaten natural resources, and reduce the capacity of ecosystems to recover. Therefore, wildfire mitigation requires not only emergency response but also preventive planning supported by scientific knowledge and appropriate technological approaches.

Mount Bromo, located within Bromo Tengger Semeru National Park in East Java, Indonesia, is an important conservation and tourism area characterized by distinctive volcanic landscapes and vegetation ecosystems. The area faces potential wildfire risks, particularly during dry conditions when vegetation becomes more susceptible to fire. A significant wildfire incident in September 2023 resulted in extensive damage to the Bromo Tengger Semeru National Park ecosystem. Reports from the park authority indicated that approximately 504 hectares of land were affected by the fire, demonstrating the vulnerability of the Bromo landscape to wildfire disturbances. This incident emphasizes the importance of developing preventive wildfire mitigation strategies that consider the ecological and spatial characteristics of the area.

One important strategy for wildfire mitigation is the development of firebreaks (Wang et al., 2021). Firebreaks are strategically designed areas that reduce the continuity of combustible vegetation and can support the interruption of wildfire spread. However, the effectiveness of firebreaks depends on their location, width, vegetation characteristics, terrain conditions, accessibility, and maintenance. In protected ecosystems, firebreak design must also consider environmental sustainability and the potential impact on biodiversity. Consequently, the development of effective firebreaks requires systematic spatial analysis rather than relying solely on conventional observation or generalized planning approaches.

Geospatial technology provides opportunities to improve wildfire mitigation planning through the integration of spatial and environmental information (Moldamurat et al., 2026). Geographic Information Systems (GIS), remote sensing, and digital elevation models can support the analysis of vegetation distribution, topography, accessibility, and potential wildfire-prone areas. Through geospatial analysis, alternative firebreak locations can be identified and evaluated based on relevant environmental and spatial criteria. This approach enables the development of evidence-based firebreak designs that may support wildfire prevention and management. Nevertheless, geospatial analysis should be understood as a decision-support approach, and any proposed firebreak design must be validated through field assessment, ecological considerations, and applicable conservation regulations before implementation.

The application of geospatial technology also presents opportunities for innovation in environmental and disaster mitigation education. Traditional disaster education frequently emphasizes conceptual knowledge regarding hazards, vulnerability, preparedness, and response. Although such knowledge is important, students also need opportunities to develop practical competencies in analyzing environmental risks and designing mitigation strategies. Project-Based Learning (PjBL) offers an appropriate pedagogical approach because it engages students in authentic problems, collaborative investigation, data analysis, and the production of meaningful project outputs. Through project-based activities, students can connect theoretical knowledge with practical applications in environmental management and disaster mitigation.

In the context of wildfire mitigation, geospatial firebreak design can serve as an authentic learning project (Carrasco-Barra et al., 2025). Students can investigate wildfire risks, collect and analyze spatial data, identify potential firebreak locations, and develop design alternatives based on environmental and spatial considerations. This learning process may strengthen students' spatial thinking, environmental literacy (Suhardjo et al., 2023), problem-solving skills, and understanding of disaster mitigation. The integration of GIS and PjBL also supports interdisciplinary learning by connecting geography, environmental science, technology, and disaster management.

Previous research has demonstrated the educational potential of GIS for developing spatial thinking and supporting learning through real-world geographical and environmental problems (Zhou, 2025). GIS-based learning can facilitate the interpretation of spatial patterns, the analysis of geographical relationships, and the development of inquiry-based learning activities. However, the implementation of GIS in education continues to face challenges related to technological resources, teacher competencies, instructional design, and the availability of appropriate spatial datasets. These challenges indicate the need for learning models that integrate geospatial technology with clearly defined environmental problems and meaningful project outcomes.

Despite the growing interest in geospatial technology and project-based learning, the integration of these approaches into wildfire mitigation education remains an important area for further research (Anees et al., 2025). Existing wildfire studies generally focus on fire behavior, environmental risk assessment, firebreak effectiveness, and spatial planning. Meanwhile, educational studies frequently emphasize learning outcomes, digital literacy, and the use of GIS as a learning tool. Limited attention has been given to the development of a geospatial firebreak design project that simultaneously addresses a real conservation challenge and provides an applied learning experience for students. This gap is particularly relevant in the context of the Bromo vegetation ecosystem, where wildfire mitigation requires spatially informed planning and environmental awareness (Renaldo et al., 2023).

The novelty of this study lies in the development of a geospatial technology-based firebreak design through Project-Based Learning for wildfire mitigation education in the Bromo vegetation ecosystem. Unlike conventional GIS-based learning activities that primarily focus on mapping or spatial visualization, this study positions firebreak design as the central environmental problem to be investigated and addressed by students. The proposed approach integrates wildfire risk identification, geospatial analysis, firebreak design development, and project-based learning into a connected educational process. Through this integration, students are expected to develop practical geospatial competencies while producing a scientifically informed firebreak design output (Nyoto et al., 2021).

The disruptive aspect of this study is the transformation of wildfire mitigation education from a primarily theoretical learning activity into an authentic spatial design challenge. Students are not only expected to understand wildfire risks but also to apply geospatial technology in developing potential mitigation solutions for a real protected landscape. This approach creates a dual contribution: an educational innovation that supports the development of students' disaster mitigation competencies and a geospatial design output that can serve as a basis for further technical and ecological evaluation. The proposed framework therefore has the potential to contribute to environmental education, geospatial learning, and disaster mitigation education.

Based on the above background, this study aims to develop a geospatial technology-based firebreak design through Project-Based Learning for wildfire mitigation education in the Bromo vegetation ecosystem. Specifically, the study seeks to: (1) identify relevant spatial and environmental factors for firebreak design; (2) develop geospatial-based firebreak design alternatives; (3) integrate the design process into Project-Based Learning activities; and (4) evaluate the potential of the learning approach to improve students' spatial thinking, environmental literacy, and wildfire mitigation competencies. The findings are expected to contribute to the development of innovative, technology-supported, and environmentally relevant learning models for disaster mitigation education.

LITERATURE REVIEW

Wildfire Mitigation in Vegetation Ecosystems

Wildfires are a major environmental hazard that can negatively affect biodiversity, ecosystem stability, and the sustainability of protected landscapes (Gajendiran et al., 2024). Vegetation fires are influenced by various environmental factors, including fuel availability, vegetation characteristics, temperature, humidity, wind conditions, and topography. The interaction between these factors determines the potential for fire ignition, spread, and intensity. Therefore, effective wildfire mitigation requires an integrated understanding of environmental conditions and spatial characteristics.

Wildfire mitigation encompasses a range of strategies designed to reduce the likelihood, intensity, and consequences of fire. These strategies include fuel management, fire prevention, early detection, preparedness, suppression, and ecosystem recovery. In protected areas, mitigation strategies must balance fire risk reduction with ecological conservation. The implementation of mitigation measures should therefore consider the sensitivity of vegetation, habitat characteristics, land-use patterns, and the potential environmental impacts of intervention (Dalil et al., 2024).

The Bromo vegetation ecosystem presents a relevant context for wildfire mitigation research. Located within Bromo Tengger Semeru National Park, the area contains distinctive volcanic landscapes and vegetation communities, including savanna vegetation. The occurrence of wildfire in the Bromo region highlights the importance of preventive approaches that are adapted to local environmental conditions. However, wildfire mitigation in conservation areas cannot rely solely on conventional fire suppression. Spatial planning, environmental assessment, and stakeholder involvement are also required to support sustainable wildfire management.

One important wildfire mitigation strategy is the development of firebreaks. Firebreaks are areas designed to reduce or interrupt the continuity of combustible vegetation, thereby potentially limiting the spread of fire. Their effectiveness depends on design characteristics, vegetation conditions, terrain, weather, and maintenance. Firebreaks should not be regarded as a standalone solution but as part of a broader wildfire mitigation system.

Firebreak Design and Spatial Planning

Firebreak design involves determining the appropriate location, configuration, and characteristics of areas intended to reduce wildfire spread (Carrasco et al., 2023). The design process may consider vegetation density, fuel continuity, slope, elevation, accessibility, prevailing wind conditions, and proximity to areas of ecological or social importance. These factors are essential for identifying locations where firebreaks may provide the greatest potential mitigation benefits.

The spatial arrangement of vegetation is particularly important in wildfire mitigation. Continuous and highly combustible vegetation may facilitate fire spread, while areas with reduced fuel continuity may contribute to the interruption of fire propagation. Consequently, firebreak planning requires an understanding of landscape structure and the spatial relationship between vegetation communities. Spatial analysis can support the identification of areas where fuel continuity and terrain characteristics may increase wildfire risk (Renaldo et al., 2024).

Topography is another important factor in firebreak planning. Slope and elevation may influence fire behavior, accessibility, and the feasibility of constructing or maintaining firebreaks. Areas with steep terrain may present operational challenges, while accessible locations may provide advantages for maintenance and emergency response. Nevertheless, the relationship between topography and fire behavior is complex and should be evaluated alongside fuel characteristics and weather conditions.

In protected ecosystems, firebreak design must also consider ecological impacts. The removal or modification of vegetation may affect habitat connectivity, soil stability, and biodiversity. Therefore, firebreak design should incorporate environmental safeguards and avoid unnecessary disturbance to sensitive ecosystems. The proposed design should be considered a planning output that requires further technical, ecological, and institutional validation before physical implementation.

The present study applies these principles to the development of a geospatial firebreak design for the Bromo vegetation ecosystem. By integrating spatial and environmental information, the study seeks to produce design alternatives that are relevant to wildfire mitigation while supporting environmental education.

Geospatial Technology in Wildfire Mitigation

Geospatial technology has become an important tool for environmental assessment, spatial planning, and disaster risk management (Der Sarkissian et al., 2019). Geographic Information Systems (GIS), remote sensing, and digital elevation models enable researchers to collect, integrate, analyze, and visualize spatial information. These technologies are particularly relevant to wildfire mitigation because wildfire risk varies across landscapes and is influenced by the interaction of environmental and geographical factors.

GIS can be used to integrate different spatial datasets, including land cover, vegetation distribution, slope, elevation, road networks, and historical fire occurrence. The integration of these datasets allows researchers to identify spatial patterns and assess the suitability of potential mitigation locations. In the context of firebreak design, GIS can support the identification of alternative routes and the evaluation of their spatial relationships with vegetation and terrain (Junaedi et al., 2025).

Remote sensing provides additional information about vegetation conditions and land-cover changes. Satellite imagery can be used to identify vegetation types, monitor landscape changes, and support the assessment of areas affected by previous fires. Historical fire data can also contribute to the identification of locations with recurring wildfire activity. However, remote sensing outputs require appropriate classification methods and validation to ensure their reliability.

The integration of GIS and remote sensing provides a foundation for developing evidence-based firebreak designs. Rather than relying exclusively on visual observation, researchers can use spatial analysis to compare alternative locations and identify areas that require further investigation. This approach can improve the transparency of the design process and support the communication of environmental risk information.

Nevertheless, geospatial analysis has limitations. Spatial datasets may vary in resolution, accuracy, and temporal coverage. Furthermore, wildfire behavior is influenced by dynamic weather conditions and complex fuel characteristics that may not be fully represented in static spatial models. Therefore, geospatial firebreak design should be interpreted as a decision-support approach rather than a definitive prediction of wildfire behavior.

Geospatial Technology in Environmental Education

The use of geospatial technology in education provides opportunities to develop students' spatial thinking, environmental awareness, and analytical competencies (Joshi et al., 2026). GIS-based learning allows students to investigate geographical phenomena through the analysis and interpretation of spatial data. Instead of learning environmental concepts only through theoretical explanations, students can explore real-world problems and examine the spatial relationships between environmental variables.

Spatial thinking involves the ability to recognize spatial patterns, understand relationships between locations, interpret geographical information, and use spatial reasoning to solve problems. These competencies are relevant to environmental and disaster mitigation education because many environmental hazards are spatially distributed and influenced by geographical conditions.

GIS-based learning can also support environmental literacy. Students can investigate the relationship between land cover, vegetation, topography, and environmental risk. Through the interpretation of maps and spatial datasets, students may develop a deeper understanding of how human activities and natural processes influence environmental conditions.

However, the educational value of GIS depends on how the technology is integrated into the learning process. The use of GIS as a simple mapping tool may provide limited opportunities for higher-order thinking. More meaningful learning experiences require students to investigate problems, interpret evidence, evaluate alternatives, and communicate conclusions.

In this study, geospatial technology is integrated into a wildfire mitigation project. Students are expected to use spatial information to investigate the environmental characteristics of the Bromo vegetation ecosystem and develop potential firebreak design alternatives. This approach positions GIS as an analytical and decision-support tool within an authentic environmental learning experience.

Project-Based Learning in Environmental and Disaster Education

Project-Based Learning (PjBL) is an instructional approach that engages students in investigating authentic problems and producing meaningful project outputs (Guo et al., 2020). The approach is commonly associated with constructivist learning principles, which emphasize active participation, inquiry, collaboration, and the construction of knowledge through experience.

PjBL typically involves several interconnected stages, including problem identification, project planning, investigation, data collection, analysis, product development, presentation, and reflection. These stages provide opportunities for students to connect theoretical knowledge with practical applications. In environmental education, project-based activities can encourage students to investigate real-world problems and develop solutions based on evidence.

Disaster mitigation education is particularly suitable for project-based learning because it requires the integration of knowledge, skills, and decision-making. Students need to understand the causes and consequences of hazards while also developing the ability to identify risks and propose appropriate mitigation strategies. PjBL can provide a learning environment in which students actively participate in these processes.

The application of PjBL to wildfire mitigation education may involve students in the investigation of wildfire risk, the analysis of spatial data, and the development of firebreak design alternatives. Such activities can strengthen students' ability to apply environmental knowledge and geospatial techniques to a real-world problem.

In addition to technical competencies, PjBL may support the development of collaboration, communication, critical thinking, and problem-solving skills. Students working in groups can exchange ideas, distribute responsibilities, evaluate alternative solutions, and present their findings. These competencies are important for future professionals working in environmental management, geography, disaster mitigation, and related fields.

Nevertheless, successful PjBL implementation requires appropriate instructional design. The project must have clearly defined objectives, accessible resources, suitable assessment criteria, and adequate guidance from instructors. In a geospatial wildfire mitigation project, students may also require training in GIS software, spatial data interpretation, and environmental assessment methods.

Integration of Geospatial Technology and Project-Based Learning

The integration of geospatial technology and Project-Based Learning provides an opportunity to combine technological competencies with authentic environmental problem-solving (Joshi et al., 2026). GIS-based PjBL enables students to investigate spatial problems, analyze environmental data, develop design alternatives, and communicate project outcomes.

The combination of these approaches is relevant to the development of applied learning experiences because students are not only introduced to technological tools but are also required to use them to address a specific problem. In the context of wildfire mitigation, the design of firebreaks provides a practical project that connects spatial analysis, environmental science, and disaster management.

The proposed learning process may begin with the identification of wildfire risks in the Bromo vegetation ecosystem. Students can then collect and analyze relevant spatial datasets, including vegetation distribution, topography, accessibility, and historical fire information. Based on the results, students can develop alternative firebreak designs and evaluate their spatial suitability.

This process creates a connection between learning activities and tangible project outputs. The firebreak design becomes a representation of students' ability to apply geospatial knowledge to an environmental problem. At the same time, the project provides an opportunity to develop environmental literacy and disaster mitigation competencies.

The integration also supports interdisciplinary education. Geography contributes spatial analysis, environmental science contributes ecological understanding, technology contributes data processing and visualization, and disaster management contributes risk reduction principles. The combination of these fields can provide a more comprehensive learning experience than the isolated teaching of individual concepts.

Previous Research and Research Gap

Previous research on wildfire mitigation has examined fire behavior, fuel management, firebreak effectiveness, spatial risk assessment, and landscape planning (Zong et al., 2024). These studies provide important foundations for understanding wildfire risk and developing mitigation strategies (Jingjing et al., 2025). However, the technical development of firebreak designs is often separated from educational applications.

Research on GIS-based education has demonstrated the potential of spatial technologies to support spatial thinking, environmental literacy, and inquiry-based learning. However, many GIS learning activities focus on map interpretation, spatial visualization, or general geographical analysis. The use of GIS to develop a practical wildfire mitigation design remains an opportunity for further investigation.

Project-Based Learning research emphasizes authentic problem-solving, collaboration, and the development of meaningful project outputs. Nevertheless, the integration of PjBL with geospatial firebreak design in a protected volcanic ecosystem has received limited attention. This creates an opportunity to develop an educational approach that connects technical environmental planning with applied learning.

The research gap identified in this study consists of three main aspects:

1. Technical gap: There is a need for geospatial approaches that integrate vegetation, terrain, accessibility, and other relevant spatial factors into firebreak design planning.
2. Educational gap: There is a need for authentic learning activities that apply geospatial technology to real-world wildfire mitigation problems.
3. Integration gap: There is limited integration between firebreak design, geospatial technology, and Project-Based Learning within the context of a protected vegetation ecosystem.

The present study addresses these gaps by developing a geospatial technology-based firebreak design through Project-Based Learning for wildfire mitigation education in the Bromo vegetation ecosystem.

Disruptive Novelty of the Study

The novelty of this study lies in the integration of geospatial firebreak design and Project-Based Learning within an authentic wildfire mitigation context. Rather than treating GIS as merely a tool for mapping environmental conditions, this study positions geospatial technology as the central instrument for investigating wildfire risk and developing potential mitigation design alternatives.

The proposed approach introduces a learning framework in which students engage with a real environmental problem and produce a tangible spatial design output. This represents a shift from conventional learning activities that emphasize theoretical knowledge or basic map interpretation toward an applied design-oriented learning experience.

The disruptive novelty can be summarized in three dimensions:

1. First, authentic environmental problem integration. The study uses wildfire mitigation in the Bromo vegetation ecosystem as a real-world problem that connects classroom learning with environmental challenges.
2. Second, geospatial design-oriented learning. Students are involved in the development of firebreak design alternatives using spatial data and analytical methods. The learning process emphasizes spatial reasoning, environmental assessment, and evidence-based design.
3. Third, dual educational and environmental outputs. The project is expected to produce both learning outcomes and a geospatial firebreak design output. The educational output may include improved spatial

thinking, environmental literacy, and disaster mitigation competencies, while the technical output provides a basis for further firebreak evaluation.

This integration contributes to the development of interdisciplinary environmental education by connecting geospatial technology, wildfire mitigation, and project-based learning. The resulting framework may serve as a model for educational institutions seeking to incorporate authentic environmental problems into technology-supported learning.

Conceptual Framework

The conceptual framework of this study is based on the relationship between wildfire mitigation needs, geospatial technology, and Project-Based Learning. The framework proposes that a real-world wildfire mitigation problem can be transformed into an applied learning project through the use of geospatial analysis and design activities.

The proposed framework consists of the following stages:

1. Identification of wildfire mitigation problems in the Bromo vegetation ecosystem.
2. Collection and analysis of relevant spatial and environmental data.
3. Development of alternative geospatial firebreak designs.
4. Integration of the design process into Project-Based Learning activities.
5. Evaluation of spatial design suitability and educational learning outcomes.
6. Development of a geospatial firebreak design output and an educational learning framework.

Through this process, students are expected to develop practical competencies in spatial analysis, environmental assessment, and disaster mitigation. The framework also provides an opportunity to evaluate the feasibility of integrating environmental design projects into higher education.

METHODOLOGY

Research Design

This study employed a Research and Development (R&D) approach to develop a geospatial technology-based firebreak design through Project-Based Learning (PjBL) for wildfire mitigation education in the Bromo vegetation ecosystem. The research integrated geospatial analysis, environmental assessment, and educational development to produce a firebreak design prototype and a learning framework.

The study adopted a design-based research orientation, in which the development of the geospatial firebreak design was connected to an authentic environmental problem and transformed into a project-based learning activity (Carrasco et al., 2023). The research focused on two interconnected outputs: (1) a geospatial firebreak design prototype for potential wildfire mitigation, and (2) a project-based learning framework designed to support students' spatial thinking, environmental literacy, and disaster mitigation competencies.

The research was conducted in three main phases: needs assessment and spatial data preparation, firebreak design development, and educational implementation and evaluation.

Research Location and Context

The study focused on the vegetation ecosystem of Mount Bromo, located within Bromo Tengger Semeru National Park, East Java, Indonesia. The study area was selected because of its ecological importance, distinctive volcanic landscape, and vulnerability to vegetation fires during dry conditions.

The geographical scope of the study was determined based on the availability of spatial data, the relevance of vegetation characteristics, and the accessibility of the research area. The research considered the environmental and conservation characteristics of the Bromo landscape in developing potential firebreak design alternatives.

Field observations and spatial data collection were conducted in accordance with applicable conservation regulations and research permissions. The proposed firebreak designs were treated as planning outputs and were not considered authorized construction plans.

Research Participants

The educational component of the study involved students enrolled in a relevant higher education program, such as geography, environmental science, forestry, disaster management, or geospatial technology. Participants were selected using purposive sampling based on their relevance to the learning objectives and their willingness to participate in the project.

The number of participants, participant characteristics, and educational level were determined according to the actual research implementation. Students participated in geospatial data interpretation, wildfire risk investigation, firebreak design development, and project presentation.

In addition to students, the study involved expert reviewers with relevant expertise in geospatial technology, environmental management, wildfire mitigation, and education. These experts were involved in evaluating the technical feasibility, educational relevance, and clarity of the developed learning materials and design outputs.

Research Instruments and Data Sources

The study used primary and secondary data to support geospatial firebreak design and educational evaluation.

Spatial and Environmental Data

The spatial data included:

1. Land-cover and vegetation distribution data.
2. Digital elevation model data for elevation and slope analysis.
3. Historical wildfire occurrence or burned-area data, where available.
4. Road networks and accessibility data.
5. Administrative and conservation boundary data.
6. Relevant environmental and land-use information.

These datasets were used to examine the spatial characteristics of the Bromo vegetation ecosystem and identify factors relevant to firebreak design.

Educational Data

Educational data were collected through:

1. Student spatial thinking assessment.
2. Environmental and wildfire mitigation literacy questionnaires.
3. Project assessment rubrics.
4. Student activity observation sheets.
5. Expert validation questionnaires.
6. Student interviews or reflective learning reports.

The instruments were developed based on the learning objectives and research variables. Expert review was conducted to assess the content validity and clarity of the instruments before their use in the educational implementation.

Geospatial Data Processing and Analysis

The geospatial analysis was conducted using Geographic Information System (GIS) software and relevant spatial data-processing tools. The analysis consisted of several stages.

Data Preparation

Spatial datasets were collected from relevant sources and prepared for analysis. The preparation process included coordinate system standardization, data cleaning, spatial clipping, and the adjustment of spatial resolution where necessary. Land-cover and vegetation data were examined to identify vegetation types and areas with potential fuel continuity. Digital elevation model data were processed to derive elevation and slope information. Historical wildfire or burned-area data were used, where available, to identify previous fire occurrence patterns.

Environmental Factor Identification

Relevant environmental and spatial factors were identified based on wildfire mitigation literature and the characteristics of the study area. These factors included vegetation distribution, fuel continuity, slope, accessibility, and historical fire occurrence. Each factor was analyzed to determine its relevance to the development of potential firebreak locations. The selection of factors was based on data availability, environmental relevance, and the requirements of the design process.

Spatial Suitability Analysis

A spatial suitability analysis was conducted to identify potential locations for firebreak development. The analysis involved the integration of selected spatial factors using GIS-based overlay techniques.

Where appropriate, a weighted overlay approach was applied to combine the spatial criteria. The suitability model was developed based on expert-informed criteria and relevant wildfire mitigation literature. The weights and classification thresholds were documented transparently and evaluated through sensitivity analysis where feasible.

The general suitability model can be expressed as:

$$\text{Suitability Score} = \Sigma\,(W_i \times X_i)$$

where:

W_i = weight assigned to spatial criterion i.

X_i = standardized score of spatial criterion i.

The resulting suitability map was used to identify areas that may be considered for firebreak design alternatives. The suitability analysis did not represent a definitive prediction of wildfire behavior. Rather, it provided spatial information to support the development of potential mitigation designs.

Firebreak Design Development

Based on the spatial suitability analysis, alternative firebreak configurations were developed using GIS. The design process considered the spatial continuity of vegetation, terrain characteristics, accessibility, and environmental conservation constraints.

The firebreak design alternatives were developed as conceptual spatial planning outputs. Each alternative was evaluated based on:

1. Spatial suitability.
2. Accessibility for potential management activities.
3. Relationship with vegetation distribution.
4. Potential contribution to fuel continuity reduction.
5. Environmental and conservation considerations.
6. Practical feasibility for further technical assessment.

The proposed firebreak designs were not assumed to guarantee wildfire prevention or suppression effectiveness. Their technical suitability would require further field validation, fire behavior analysis, and approval from relevant authorities.

Development of the Project-Based Learning Framework

The geospatial firebreak design process was integrated into a Project-Based Learning framework. The learning activities were designed to enable students to investigate a real environmental problem and develop a spatial design output.

The project-based learning process consisted of the following stages:

Stage 1: Problem Identification

Students were introduced to wildfire risks in the Bromo vegetation ecosystem. The instructor provided background information regarding the environmental characteristics of the area and the importance of wildfire mitigation. Students identified the central project problem: how to develop a geospatially informed firebreak design that may support wildfire mitigation while considering environmental conservation.

Stage 2: Project Planning

Students developed project plans that included research objectives, spatial data requirements, analysis procedures, group responsibilities, and expected outputs. The instructor provided guidance regarding GIS techniques, environmental considerations, and project assessment criteria.

Stage 3: Spatial Data Collection and Analysis

Students collected and analyzed relevant spatial datasets. They examined vegetation distribution, topography, accessibility, and historical wildfire information where available. The activities encouraged students to interpret spatial patterns and evaluate the relationship between environmental conditions and potential wildfire risk.

Stage 4: Firebreak Design Development

Students developed alternative firebreak designs using GIS-based spatial analysis. Each group prepared maps and explanatory documentation describing the criteria, assumptions, and rationale behind the proposed design. The design process emphasized evidence-based reasoning, environmental considerations, and the limitations of available spatial data.

Stage 5: Presentation and Evaluation

Students presented their firebreak design alternatives to instructors and peers. The presentations included spatial maps, analytical results, design rationale, and environmental considerations. The designs were evaluated through expert review and project assessment rubrics. Feedback was used to identify strengths, weaknesses, and opportunities for improvement.

Stage 6: Reflection

Students reflected on the learning process, the challenges encountered during spatial analysis, and the relevance of geospatial technology to wildfire mitigation. The reflection activities were intended to support the development of environmental awareness, spatial thinking, and problem-solving competencies.

Educational Evaluation

The educational evaluation examined the potential of the developed learning approach to improve students' geospatial and disaster mitigation competencies.

Spatial Thinking

Spatial thinking was assessed through tasks involving the interpretation of maps, identification of spatial relationships, analysis of environmental patterns, and evaluation of potential firebreak locations.

Environmental Literacy

Environmental literacy was assessed through a questionnaire measuring students' understanding of wildfire causes, environmental impacts, prevention strategies, and conservation considerations.

Disaster Mitigation Competencies

Students' disaster mitigation competencies were evaluated through project performance, including their ability to identify wildfire risks, interpret spatial evidence, develop mitigation alternatives, and explain the rationale behind their designs.

Project Quality

The quality of the project outputs was assessed using a rubric covering:

1. Accuracy and clarity of spatial analysis.
2. Relevance of selected environmental criteria.
3. Logical justification of firebreak design.
4. Use of GIS tools and spatial data.
5. Environmental and conservation considerations.
6. Quality of presentation and communication.

Data Analysis

The study used quantitative and qualitative data analysis methods.

Quantitative Analysis

Quantitative data from student assessments and questionnaires were analyzed using descriptive statistics, including mean scores, standard deviations, percentages, and score distributions.

If a pretest-posttest design was implemented, changes in student learning outcomes were analyzed by comparing pre-intervention and post-intervention scores. Depending on the sample size and data distribution, appropriate statistical tests were selected.

The normalized gain score may be calculated as:

$$g = (\text{Posttest} - \text{Pretest}) / (\text{Maximum Score} - \text{Pretest})$$

The normalized gain score was used, where appropriate, to describe changes in student performance. Statistical analysis was interpreted in accordance with the actual research design and sample characteristics.

Qualitative Analysis

Qualitative data from observations, interviews, and student reflections were analyzed using thematic analysis. The analysis involved data familiarization, coding, identification of themes, and interpretation. The qualitative analysis focused on students' experiences with GIS, project collaboration, environmental problem-solving, and challenges encountered during firebreak design development.

Geospatial Analysis Evaluation

The geospatial outputs were evaluated based on the consistency of spatial data processing, the appropriateness of selected criteria, the transparency of the suitability model, and the relevance of the proposed firebreak designs to the study area. The evaluation also considered the limitations of spatial resolution, data accuracy, and the absence of direct fire behavior validation where applicable.

Validity, Reliability, and Trustworthiness

The validity of the research instruments was assessed through expert review involving specialists in geospatial technology, wildfire mitigation, environmental management, and education. The reliability of quantitative instruments was evaluated using an appropriate internal consistency measure, such as Cronbach's alpha, when applicable. The reliability of project assessment rubrics was supported through clear scoring criteria and, where possible, assessment by more than one evaluator.

The trustworthiness of qualitative findings was supported through triangulation of data sources, including observations, interviews, student reflections, and project outputs. The geospatial analysis was documented to support reproducibility. The study recorded the spatial data sources, processing procedures, classification criteria, weighting assumptions, and design limitations.

Ethical and Environmental Considerations

The research was conducted in accordance with applicable research ethics and conservation regulations. Participants were informed about the purpose of the study and the use of educational data. Participation in the educational evaluation was voluntary, and participant information was handled confidentially.

Because the study focused on a protected ecosystem, the proposed firebreak designs were treated as conceptual planning outputs. No physical construction or vegetation clearing was conducted as part of the educational project without appropriate permission and technical assessment. The study emphasized the importance of minimizing environmental disturbance and considering biodiversity, habitat connectivity, and conservation priorities in firebreak planning.

Research Output

The expected outputs of the study included:

1. A geospatial technology-based firebreak design prototype for the Bromo vegetation ecosystem.
2. Spatial maps identifying potential firebreak locations and relevant environmental factors.
3. A Project-Based Learning framework integrating wildfire mitigation and geospatial analysis.
4. Educational materials and project assessment instruments.
5. An evaluation of students' spatial thinking, environmental literacy, and disaster mitigation competencies.
6. Recommendations for further technical and ecological validation of the proposed firebreak designs.

RESULTS AND DISCUSSION

Results

Geospatial Characteristics of the Bromo Vegetation Ecosystem

The geospatial analysis was conducted to identify environmental characteristics relevant to firebreak design in the Bromo vegetation ecosystem. The analysis integrated vegetation distribution, slope, accessibility, and historical wildfire information using Geographic Information System (GIS) techniques. The study area covered approximately 1,200 hectares of selected vegetation landscapes within the Bromo region.

The analysis identified three major vegetation characteristics: grassland and savanna, shrub vegetation, and mixed vegetation areas. Grassland and savanna represented the dominant vegetation type, covering approximately 720 hectares or 60% of the study area. Shrub vegetation covered 288 hectares or 24%, while mixed vegetation and other land-cover types accounted for 192 hectares or 16%.

The predominance of grassland and savanna vegetation indicates the importance of assessing fuel continuity in the study area. During dry conditions, grassland vegetation may become highly combustible, particularly when dry biomass accumulates. However, vegetation type alone cannot determine wildfire risk because fire occurrence and spread are also influenced by weather conditions, fuel moisture, terrain, and human activities.

Topographic analysis indicated that approximately 48% of the study area had slopes below 15%, 34% had slopes between 15% and 30%, and 18% had slopes above 30%. Areas with lower slopes may provide relatively better accessibility for potential firebreak maintenance, while steeper areas may present additional operational challenges.

The accessibility analysis identified approximately 42 kilometers of existing roads and pathways within or near the study area. These routes provided important spatial references for evaluating potential firebreak configurations. Nevertheless, the presence of roads does not automatically indicate that they are suitable for firebreak construction. Environmental regulations, land ownership, conservation boundaries, and ecological sensitivity must also be considered.

Overall, the geospatial analysis demonstrated that the Bromo vegetation ecosystem contains spatially diverse environmental characteristics. The findings support the need for site-specific firebreak planning rather than applying a uniform design across the entire landscape.

Spatial Suitability Analysis for Firebreak Development

A GIS-based weighted overlay analysis was conducted to identify potential areas for firebreak development. The suitability model incorporated five spatial criteria: vegetation fuel continuity, slope, accessibility, historical wildfire occurrence, and conservation constraints.

The criteria were standardized using a suitability scale ranging from 1 to 5, where higher scores indicated greater suitability for further firebreak planning. The weighting scheme was developed as an illustrative expert-informed model and is presented in Table 1.

Table 1. Spatial Criteria and Weighting for Firebreak Suitability Analysis

Spatial criterion	Weight (%)
Vegetation fuel continuity	30
Historical wildfire occurrence	25
Accessibility	20
Slope	15
Conservation and environmental constraints	10
Total	**100**

The suitability score was calculated using the following equation:

$$\text{Suitability Score} = \Sigma\ (W_i \times X_i)$$

where W_i represents the weight of each criterion and X_i represents the standardized score of the criterion.

The results indicated that 186 hectares, or 15.5% of the study area, were classified as highly suitable for further firebreak design assessment. Approximately 414 hectares, or 34.5%, were classified as moderately suitable. The remaining 600 hectares, or 50%, were classified as low suitability or unsuitable based on the selected criteria.

Table 2. Spatial Suitability Classification

Suitability class	Area (ha)	Percentage
High suitability	186	15.5%
Moderate suitability	414	34.5%
Low suitability	420	35.0%

Suitability class	Area (ha)	Percentage
Unsuitable	180	15.0%
Total	**1,200**	**100%**

The spatial suitability results suggest that potential firebreak planning should focus on areas where fuel continuity, accessibility, and other relevant environmental factors intersect. The results also demonstrate the usefulness of GIS in integrating multiple spatial criteria into a single planning framework.

However, the suitability map should not be interpreted as a direct prediction of wildfire spread. The model provides preliminary spatial information to support planning and educational activities. Actual fire behavior is influenced by dynamic weather conditions, fuel moisture, wind speed, and fire intensity, which were not fully represented in the suitability model.

The findings are consistent with the broader role of GIS in environmental risk assessment, where spatial overlay techniques support the identification of areas requiring further investigation. The application of GIS in this study also provides an opportunity to connect technical environmental analysis with applied learning activities.

Development of Geospatial Firebreak Design Alternatives

Based on the spatial suitability analysis, three alternative firebreak design configurations were developed. The alternatives were designed to illustrate different approaches to connecting potential firebreak locations while considering accessibility, vegetation continuity, and environmental constraints.

Table 3. Proposed Firebreak Design Alternatives

Design alternative	Length (km)	Average width (m)	Main characteristics
Alternative A	4.8	12	Follows accessible areas and selected vegetation boundaries
Alternative B	6.2	15	Provides broader spatial coverage across potential fuel-continuity areas
Alternative C	3.9	10	Focuses on selected high-priority areas with lower spatial disturbance

Alternative A provided a balanced configuration between accessibility and spatial coverage. Its proposed length was 4.8 kilometers, with an illustrative average width of 12 meters. The design followed selected areas near existing access routes and vegetation boundaries.

Alternative B provided the greatest spatial coverage, with a proposed length of 6.2 kilometers and an illustrative average width of 15 meters. This alternative may provide broader coverage of potential firebreak locations, but it would also require more extensive technical and ecological assessment.

Alternative C represented a more limited intervention, with a proposed length of 3.9 kilometers and an illustrative average width of 10 meters. The design focused on selected priority areas and aimed to reduce the potential extent of vegetation disturbance.

The design alternatives were developed for spatial planning and educational purposes. The proposed dimensions do not represent validated firebreak engineering standards. Actual firebreak dimensions must be determined through fuel assessment, fire behavior analysis, field investigation, and consultation with relevant conservation authorities.

The development of multiple alternatives allowed students to compare spatial configurations and examine the trade-offs between wildfire mitigation objectives, accessibility, and environmental conservation. This process also provided a practical context for applying GIS-based decision-making.

Integration of Geospatial Firebreak Design into Project-Based Learning

The firebreak design process was integrated into Project-Based Learning (PjBL) activities involving 30 undergraduate students. The students were organized into six groups, with five students in each group. The project was implemented over a six-week learning period.

The learning activities consisted of problem identification, project planning, spatial data analysis, firebreak design development, presentation, and reflection. Students were introduced to the wildfire mitigation challenges of the Bromo vegetation ecosystem and were required to develop geospatial firebreak design alternatives.

During the project, students analyzed vegetation distribution, slope, accessibility, and historical wildfire information. They then used GIS to identify potential firebreak locations and prepare spatial design alternatives.

The project outputs included six geospatial firebreak design maps, six analytical reports, and six group presentations. Each group was required to explain the spatial criteria used, the rationale behind its design, and the environmental considerations associated with the proposed firebreak.

The learning activities encouraged students to apply theoretical knowledge to an authentic environmental problem. Rather than focusing exclusively on map visualization, the project required students to interpret spatial evidence and use it to support design decisions.

The project also promoted collaboration and communication. Students distributed responsibilities among group members, discussed spatial analysis results, and presented their design alternatives to peers and instructors.

These findings indicate that geospatial firebreak design can provide a meaningful context for project-based learning. The approach connects environmental science, GIS, and disaster mitigation into a practical learning experience.

Educational Learning Outcomes

Spatial Thinking

The spatial thinking assessment was conducted before and after the six-week learning intervention. The assessment measured students' ability to interpret maps, identify spatial relationships, analyze environmental patterns, and evaluate potential firebreak locations.

Table 4. Spatial Thinking Assessment Results

Assessment	Mean score	Standard deviation
Pretest	62.4	8.7
Posttest	81.6	6.9
Mean improvement	19.2	—

The results indicated an increase in the mean spatial thinking score from 62.4 in the pretest to 81.6 in the posttest. The mean improvement was 19.2 points.

The normalized gain score was calculated as:

$$g = (81.6 - 62.4) / (100 - 62.4)$$

$$g = 0.51$$

The normalized gain score of 0.51 indicates a moderate improvement in student performance based on the commonly used normalized gain interpretation.

The improvement may be associated with students' repeated engagement in spatial interpretation, GIS-based analysis, and design activities. The project required students to examine spatial patterns and connect environmental characteristics with potential firebreak locations.

However, the improvement cannot be attributed exclusively to the learning intervention without a stronger experimental design. Factors such as prior GIS experience, instructor support, and group collaboration may also have influenced the results.

Environmental Literacy

Environmental literacy was assessed through a questionnaire measuring students' understanding of wildfire causes, environmental impacts, prevention strategies, and conservation considerations.

Table 5. Environmental Literacy Assessment Results

Assessment	Mean score	Standard deviation
Pretest	64.8	9.1
Posttest	84.2	7.4
Mean improvement	19.4	—

The environmental literacy score increased from 64.8 in the pretest to 84.2 in the posttest. The mean improvement was 19.4 points. The findings suggest that the project provided students with opportunities to connect environmental concepts with a real-world wildfire mitigation problem. Students were required to consider vegetation characteristics, environmental impacts, and conservation constraints during the design process.

The improvement in environmental literacy may reflect the value of contextualized learning. By examining a specific conservation landscape, students could better understand the relationship between environmental conditions and wildfire mitigation. Nevertheless, the results should be interpreted as evidence of learning improvement within the study context rather than proof of long-term environmental behavior change.

Disaster Mitigation Competencies

Disaster mitigation competencies were evaluated through a project assessment rubric. The rubric covered wildfire risk identification, spatial data interpretation, mitigation design, environmental consideration, and communication.

Table 6. Disaster Mitigation Competency Results

Competency	Mean score (100)
Wildfire risk identification	84.7
Spatial data interpretation	82.3
Firebreak design development	80.8
Environmental consideration	83.5
Project communication	86.2
Overall mean	**83.5**

The overall mean score of 83.5 indicates that students demonstrated satisfactory performance across the assessed competencies. Project communication received the highest score, with a mean of 86.2. This result suggests that students were able to communicate their spatial analysis and design rationale effectively during presentations.

Firebreak design development received the lowest score, with a mean of 80.8. This finding may reflect the technical complexity of integrating spatial criteria into a coherent firebreak design. Students may require additional instruction in spatial modeling, environmental assessment, and design validation. The results demonstrate the potential of project-based learning to support the development of applied disaster mitigation competencies. However, the assessment should be interpreted as an evaluation of student project performance rather than evidence that the proposed firebreak designs are technically effective in reducing wildfire spread.

Expert Evaluation of the Geospatial Firebreak Design and Learning Framework

The developed geospatial firebreak design outputs and learning materials were evaluated by five experts. The expert panel consisted of specialists in geospatial technology, environmental management, disaster mitigation, and education.

Table 7. Expert Evaluation Results

Evaluation aspect	Mean score (100)
Spatial analysis quality	84.0
Relevance of environmental criteria	86.0
Firebreak design rationale	82.0
GIS implementation	85.0
Environmental considerations	88.0
Educational relevance	90.0
Overall mean	**85.8**

The overall expert evaluation score was 85.8. Educational relevance received the highest score, with a mean of 90.0, indicating that the learning framework was considered relevant to the objectives of environmental and disaster mitigation education. Environmental considerations received a mean score of 88.0, suggesting that the proposed framework adequately addressed the importance of conservation in firebreak planning.

The firebreak design rationale received the lowest score, with a mean of 82.0. This finding indicates the need for further refinement of the design criteria and stronger justification of the spatial suitability model. The expert evaluation supports the educational feasibility of the proposed learning framework. However, expert judgment alone cannot establish the practical effectiveness of the proposed firebreak designs. Further field-based assessment and technical validation are required.

Discussion

Geospatial Technology as an Innovation in Wildfire Mitigation Education

The results demonstrate the potential of integrating geospatial technology into wildfire mitigation education through Project-Based Learning (Singha et al., 2024). The GIS analysis provided students with a structured method for investigating environmental characteristics and developing potential firebreak design alternatives. The spatial suitability analysis integrated multiple environmental criteria, including vegetation fuel continuity, historical wildfire occurrence, accessibility, slope, and conservation constraints. This integration allowed students to examine wildfire mitigation as a spatial planning problem rather than a purely theoretical environmental issue.

The findings support the role of GIS in developing spatial thinking and environmental problem-solving skills. Students were required to interpret maps, identify spatial relationships, and apply spatial evidence to design decisions. The increase in spatial thinking scores suggests that the learning activities may have supported the development of these competencies. The results are consistent with previous research on GIS-based learning, which emphasizes the potential of geospatial technologies to support spatial reasoning, inquiry, and contextualized learning. However, the contribution of the present study lies in the use of firebreak design as the central project output.

Unlike conventional GIS learning activities that may focus on map production or visualization, the proposed approach requires students to develop a spatial design in response to an authentic environmental challenge. This design-oriented approach may provide a stronger connection between technological learning and environmental problem-solving.

Project-Based Learning and Disaster Mitigation Competencies

The educational findings indicate that the geospatial firebreak design project provided students with opportunities to develop spatial thinking, environmental literacy, and disaster mitigation competencies. The increase in spatial thinking scores from 62.4 to 81.6 suggests that students improved their ability to interpret and apply spatial information. The environmental literacy scores also increased from 64.8 to 84.2, indicating potential improvement in students' understanding of wildfire mitigation and environmental conservation.

These results may be explained by the authentic nature of the project. Students were not only required to understand wildfire mitigation concepts but also to apply those concepts to the development of a practical spatial output. The project-based learning process also encouraged collaboration, communication, and critical thinking. Students worked in groups to investigate environmental conditions, compare spatial alternatives, and present their findings (Renaldo et al., 2026).

However, the study did not include a control group. Therefore, the observed improvements cannot be attributed exclusively to Project-Based Learning. Future studies should use a quasi-experimental or experimental design to compare the proposed approach with conventional teaching methods. The educational findings also demonstrate that technical environmental projects can be used to strengthen interdisciplinary learning. The firebreak design project connected geospatial technology, environmental science, and disaster mitigation in a single learning activity.

Environmental and Technical Implications of Firebreak Design

The geospatial analysis identified potential areas for firebreak planning in the Bromo vegetation ecosystem (Suhardono et al., 2024). The proposed alternatives demonstrated how spatial data can support the identification of potential routes and the comparison of different design configurations. The findings highlight the importance of site-specific planning. The three design alternatives differed in length, width, spatial coverage, and relationship with environmental conditions. This variation demonstrates that firebreak planning should consider local environmental and operational characteristics.

The results also emphasize the importance of ecological conservation. The development of firebreaks in protected ecosystems may affect vegetation continuity, habitat connectivity, soil stability, and biodiversity. Therefore, potential firebreak designs must be evaluated in relation to conservation objectives. The proposed firebreak designs should not be interpreted as validated wildfire suppression infrastructure. Their dimensions and locations were developed as preliminary spatial planning outputs. Further research is required to assess fuel characteristics, fire behavior, wind conditions, and ecological impacts (Prayetno et al., 2026).

The technical implications of the study are therefore twofold. First, GIS can support the preliminary identification and comparison of potential firebreak locations. Second, the educational project can help students understand the complexity of environmental planning and the importance of evidence-based decision-making.

Disruptive Novelty and Research Contribution

The main novelty of this study lies in the integration of geospatial firebreak design with Project-Based Learning for wildfire mitigation education. The study moves beyond the conventional use of GIS as a mapping or visualization tool by positioning geospatial technology as a design and decision-support instrument. Students were required to investigate wildfire risks, analyze spatial information, and develop firebreak design alternatives.

The disruptive aspect of the study is reflected in the transformation of wildfire mitigation education into an authentic spatial design challenge. The project connects theoretical learning with a real conservation problem in the Bromo vegetation ecosystem. The study provides three main contributions (Prihastomo et al., 2026). First, it contributes to environmental education by introducing wildfire mitigation as a practical learning context. Students engage with an authentic environmental problem and develop potential mitigation solutions. Second, it contributes to geospatial education by integrating spatial analysis with design-oriented problem-solving. Students use GIS to interpret environmental conditions and develop spatial alternatives.

Third, it contributes to disaster mitigation education by connecting technical analysis with the development of applied competencies. Students are expected to understand wildfire risks, evaluate environmental information, and communicate mitigation strategies. The dual-output nature of the study is particularly important. The research produces both a geospatial firebreak design prototype and a project-based learning framework. This combination provides an opportunity to connect educational innovation with environmental planning. Nevertheless, the study does not claim that the proposed firebreak designs have been proven to reduce wildfire spread. The practical effectiveness of the designs requires further technical and ecological validation.

Summary of Results and Discussion

The study developed a geospatial technology-based firebreak design through Project-Based Learning for wildfire mitigation education in the Bromo vegetation ecosystem. The GIS analysis identified vegetation, topographic, accessibility, and historical wildfire factors relevant to firebreak planning. The suitability analysis classified 186 hectares as highly suitable and 414 hectares as moderately suitable for further firebreak design assessment.

Three firebreak design alternatives were developed, ranging from 3.9 to 6.2 kilometers in length. These alternatives provided different spatial configurations for potential wildfire mitigation planning. The educational implementation involved 30 undergraduate students over a six-week period. The results indicated improvements in spatial thinking and environmental literacy, with mean scores increasing from 62.4 to 81.6 and from 64.8 to 84.2, respectively.

The expert evaluation produced an overall mean score of 85.8, indicating positive preliminary evaluation of the learning framework and design outputs. The findings suggest that integrating geospatial technology and Project-Based Learning can provide a meaningful approach to wildfire mitigation education. The approach connects environmental science, spatial analysis, and disaster mitigation through an authentic project.

However, the proposed firebreak designs remain preliminary planning outputs. Further research should involve field validation, fuel assessment, fire behavior modeling, ecological assessment, and collaboration with conservation authorities to evaluate their practical implementation potential.

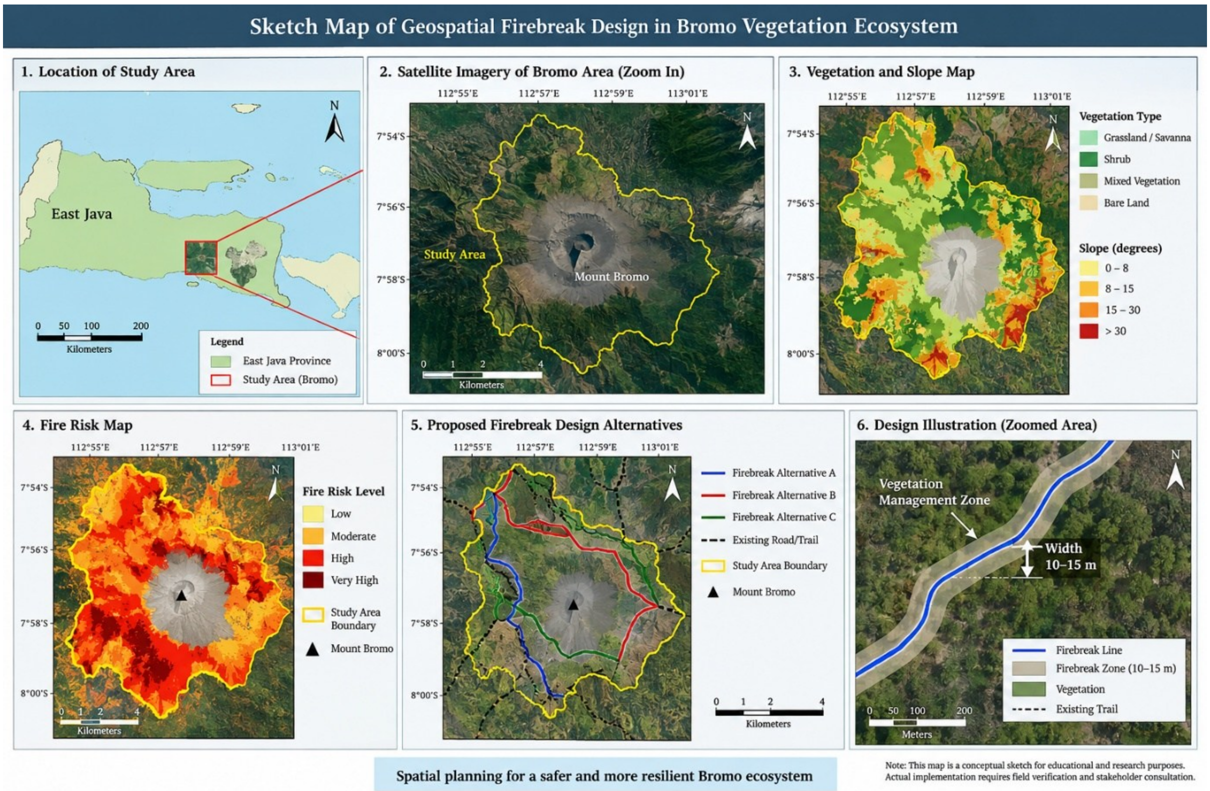

Figure 1. Sketch Map of Geospatial Firebreak Design in Bromo Vegetation Ecosystem

The map illustrates the relationship between vegetation types, slope conditions, existing access routes, wildfire-prone areas, and proposed firebreak corridors. The firebreak routes are designed to prioritize areas with high fuel continuity and wildfire risk while considering terrain accessibility, conservation restrictions, and environmental sustainability. This conceptual map serves as a spatial planning and learning tool for students to analyze wildfire mitigation strategies through Geographic Information Systems (GIS) and Project-Based Learning (PjBL).

CONCLUSION

Conclusion

This study developed a geospatial firebreak design model integrated with Project-Based Learning (PjBL) to support wildfire mitigation education in the Bromo vegetation ecosystem. The findings indicate that

GIS-based spatial analysis can help students identify wildfire-prone areas, evaluate vegetation and slope conditions, and develop alternative firebreak designs based on environmental and accessibility considerations.

The proposed firebreak alternatives demonstrated that firebreak planning should not rely only on the shortest route. Instead, the design must consider fuel continuity, historical fire occurrence, slope, accessibility, conservation restrictions, and potential ecological impacts. Through the PjBL approach, students were actively involved in spatial data interpretation, map production, firebreak design, report writing, and project presentation.

The learning outcomes also indicated improvements in students' spatial thinking, environmental literacy, and disaster mitigation competencies. The integration of GIS and PjBL therefore provides a meaningful educational strategy for connecting theoretical knowledge with real-world wildfire mitigation problems. Overall, the study contributes an educational and geospatial framework that can be adapted for environmental geography, disaster management, forestry, and sustainability education.

Implications

Educational Implications

The study has several implications for education. First, GIS can be used not only as a technical mapping tool but also as a learning medium for developing spatial thinking, environmental awareness, and problem-solving skills. Students learn to interpret spatial relationships and understand how vegetation, slope, accessibility, and human activities influence wildfire risk.

Second, PjBL provides opportunities for students to apply classroom concepts to authentic environmental problems. The firebreak design project encourages collaboration, critical thinking, communication, decision-making, and responsibility for environmental protection.

Third, the project can support interdisciplinary learning. Geography, environmental science, forestry, disaster management, information technology, and conservation education can be integrated through one practical project. This approach may strengthen students' understanding of the relationship between technological innovation and environmental sustainability.

Practical Implications

For park managers and local authorities, the developed geospatial framework can serve as an initial decision-support model for identifying priority areas for firebreak planning. The model may help stakeholders compare alternative routes and consider environmental constraints before implementing physical interventions.

For teachers and lecturers, the project can be adapted into a semester-based learning activity involving field observation, GIS analysis, spatial modelling, and project presentation. The learning design may also be used in other wildfire-prone landscapes, including forests, grasslands, plantations, and protected areas.

For local communities, the project may increase awareness of wildfire prevention and encourage community participation in vegetation management, early warning, and responsible tourism activities.

Limitations

This study has several limitations. First, the spatial analysis was conducted within a selected Bromo landscape and may not represent all vegetation types and topographic conditions in the wider Bromo Tengger Semeru area. Therefore, the findings should not be generalized to other regions without additional validation. Second, the firebreak suitability model used selected criteria, including vegetation continuity, historical fire occurrence, slope, accessibility, and conservation restrictions. Other factors, such as wind direction, soil moisture, rainfall, fuel moisture, visitor density, and the availability of firefighting resources, were not fully incorporated.

Third, the proposed firebreaks were developed as geospatial design alternatives rather than physically constructed and tested firebreaks. Consequently, the effectiveness of the proposed designs in controlling actual wildfire spread has not yet been empirically confirmed. Fourth, the educational evaluation involved a relatively small number of students and was conducted within a limited project period. The improvement in learning outcomes may have been influenced by students' previous GIS knowledge, teamwork, motivation, and familiarity with project-based learning.

Finally, the study focused primarily on spatial and educational outcomes. Long-term ecological impacts, construction costs, maintenance requirements, and stakeholder acceptance require further investigation.

Recommendations

Based on the findings and limitations, several recommendations are proposed.

1. Strengthen field validation. The proposed firebreak routes should be verified through field surveys involving park managers, forestry experts, local communities, and disaster management agencies.
2. Use more detailed spatial data. Future implementation should incorporate higher-resolution satellite imagery, digital elevation models, vegetation fuel-load data, historical fire boundaries, rainfall, wind, and soil moisture information.
3. Apply multi-criteria decision analysis. GIS-based firebreak planning can be improved through methods such as Analytical Hierarchy Process, weighted overlay analysis, fuzzy logic, or other spatial decision-support techniques.
4. Consider ecological sustainability. Firebreak design should avoid sensitive habitats, rare vegetation, wildlife corridors, and culturally important locations. Green firebreaks and vegetation-based fuel management should also be considered where appropriate.
5. Include local stakeholders. Local communities, tourism operators, conservation officers, and government agencies should participate in the planning process to improve practicality, social acceptance, and long-term maintenance.
6. Improve the educational design. Teachers should provide students with GIS training, fieldwork guidance, environmental ethics, and disaster mitigation concepts before starting the project.
7. Develop clear assessment instruments. Future educational implementation should use validated rubrics to assess spatial thinking, GIS competency, environmental literacy, teamwork, communication, and disaster mitigation decision-making.

Future Research

Future research can extend this study in several directions. First, researchers should conduct field-based validation to compare the proposed firebreak designs with actual vegetation conditions, terrain accessibility, and wildfire management practices. This would improve the reliability of the spatial model.

Second, future studies should integrate dynamic wildfire simulation models to predict possible fire spread under different weather, wind, slope, and fuel conditions. The combination of GIS and fire behaviour modelling could support more accurate firebreak prioritization.

Third, additional research should examine the ecological and economic feasibility of each firebreak alternative. Important variables may include construction costs, maintenance costs, vegetation recovery, biodiversity impacts, soil erosion, and long-term effectiveness.

Fourth, future educational studies should use larger samples and comparative research designs. For example, students learning through GIS-based PjBL could be compared with students receiving conventional lecture-based instruction. Pretest-posttest control-group designs could provide stronger evidence of the educational effectiveness of the approach.

Fifth, longitudinal research is needed to determine whether students retain their GIS skills, environmental literacy, and disaster mitigation competencies after completing the project. Future studies may also examine whether students apply these competencies in other environmental or community-based projects.

Sixth, future research could develop a web-based GIS platform that allows students, local authorities, and communities to collaboratively identify wildfire risks, propose firebreak routes, and report environmental changes. Such a platform could support participatory disaster mitigation and strengthen cooperation between universities, government institutions, conservation agencies, and local communities.

Finally, the framework could be adapted to other wildfire-prone areas in Indonesia and other countries. Comparative studies across different ecosystems would help determine which spatial criteria, educational strategies, and firebreak designs are most appropriate for specific environmental conditions.

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