Landslide Susceptibility Zonation for Mlati Village and Surroundings, Arjosari District, Pacitan, East Java, Indonesia

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***Abstract*—This paper presents a comprehensive engineering geological documentation synthesized from the provided project files. The section arrangement follows the original chapter sequence (BAB 1–BAB 8): Introduction, Geomorphology, Stratigraphy, Structural Geology, Geological History, Environmental Geology, Mass-Movement Susceptibility Zonation, and Conclusion. The mapped area covers about $81\,\mathrm{km}^2$ (RBI 1507-433, Bungur) in Mlati Village and surrounding areas, Arjosari District, Pacitan Regency, East Java Province. The integrated workflow combines preliminary review, field mapping, laboratory support, and GIS-based weighted overlay analysis, with interpretation traceability from outcrop-scale evidence to zonation-scale outputs. This document details geomorphic units, lithostratigraphic architecture, structural controls, geological evolution stages, resource–risk interactions, susceptibility parameters, and implementation-oriented engineering implications. Results indicate six geomorphic subdivisions, four principal lithological units plus mixed surficial deposits, and key fault systems that influence slope stability through discontinuity development and groundwater pathway control. Landslide susceptibility is classified into low (about 1.68), moderate (1.78–2.35), and high (2.43–2.53) classes, with moderate class dominance in both potential interpretation and areal distribution. The final synthesis provides practical mitigation, planning priorities, and staged investigation guidance for safer land use and infrastructure development.**

***Index Terms*—engineering geology, geomorphology, structural geology, stratigraphy, landslide susceptibility, GIS weighting, Pacitan, East Java**

I. Introduction

A. Background

The provided files describe a complete geological mapping and hazard-zonation project in Mlati Village and surrounding areas. The project area exhibits volcanic-volcaniclastic rock assemblages, weathering-sensitive slopes, structurally controlled discontinuities, and active land use. This combination creates recurring susceptibility to mass movement (landslide processes), particularly during high-infiltration periods and where slope modifications are uncontrolled.

From an engineering-geology perspective, the significance of the source project is not only in descriptive mapping but also in transforming geological observations into a practical zoning output for risk-informed planning. Therefore, this manuscript extends the original synthesis by structuring technical evidence, interpretation logic, and implementation-focused recommendations in conference-paper form.

B. Purpose and Objectives

The expanded documentation has four explicit objectives:

1) Preserve and reorganize the key findings from all provided source chapters.
2) Present chapter-consistent geological interpretation in an internationally recognizable format.
3) Elaborate the susceptibility-assessment logic and engineering interpretation in more technical detail.
4) Provide clear mitigation and planning guidance that can support decision-making at local scale.

C. Scope and Data Integration Approach

This documentation integrates evidence from chapter-wise source files into one coherent technical narrative. The integration approach preserves original mapping conclusions while clarifying relationships among geomorphology, stratigraphy, structures, environmental geology, and susceptibility zoning. The objective is to ensure that interpretation pathways are transparent from raw observations to engineering recommendations.

Primary data represented in the source materials include lithologic descriptions, structural measurements, geomorphic indicators, and field observations of slope condition and hydrology. Secondary support includes regional maps, prior references, and regulatory guidance for landslide-prone area assessment. The combined dataset is interpreted at planning-to-screening scale rather than project-specific design scale.

D. Location, Area, and Accessibility

The project area lies within Arjosari District, Pacitan Regency, East Java Province. The mapped frame is 9 km $\times$ 9 km (approximately $81\,\mathrm{km}^2$) at 1:25,000 scale on the Bungur map sheet (RBI 1507-433). As stated in the provided files, regional access from Yogyakarta is approximately 110 km with mixed transportation conditions; some observation points require foot access due to slope steepness and local path constraints.

E. Research Stages

The source materials define five integrated stages that are sequential but interdependent: preliminary review, field campaign, laboratory support, studio/GIS processing, and final synthesis.

Fig. 1. Regional accessibility and location context extracted from the provided files.

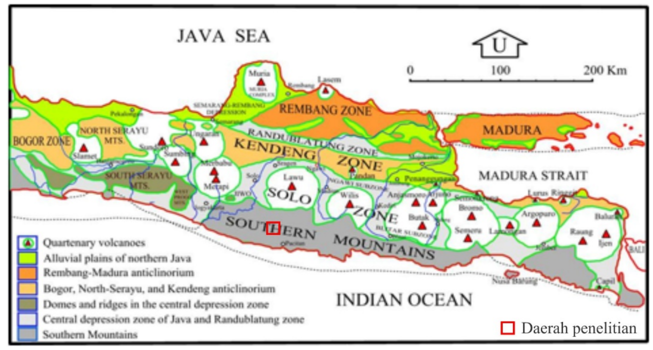

Fig. 2. Representative geomorphology figure from the provided chapter files.

TABLE I
INTEGRATED WORKFLOW FROM THE PROVIDED CHAPTER SEQUENCE

Stage	Main Activities and Outputs
Preliminary	Literature review, map checks, geomorphic and geological framework setup, route planning, and target-outcrop strategy.
Fieldwork	Outcrop logging, lithology characterization, structural measurements, slope and hydrology observations, and hazard-indicator recording.
Laboratory	Supporting sample checks and validation for lithologic consistency and stratigraphic interpretation.
Studio/GIS	Parameter scoring/weighting, thematic overlay, class assignment, zonation-map generation, and interpretation consistency checks.
Final Synthesis	Integration of chapter findings into geological model, susceptibility interpretation, and mitigation recommendations.

II. Geomorphology

Geomorphologically, the area includes denudational, volcanic-denudational, and fluvial components. The source conclusions indicate sub-rectangular to sub-dendritic drainage tendencies, suggesting combined control from bedrock structure and erosional processes.

TABLE II
GEOMORPHIC SUBDIVISIONS INTERPRETED FROM THE PROJECT RESULTS

Code/Type	Interpretive Description
S3	Denudated hills with strong structural influence (joints/faults), typically associated with irregular slope breaks.
D1	Denudational hills/slopes with comparatively lower erosional intensity and gentler local relief.
D2	Denudational hills/slopes with moderate to strong undulation and enhanced erosional signatures.
V14	Volcanic-denudational hill morphology, reflecting volcanic inheritance modified by weathering and surface runoff.
F1	River-body geomorphic unit, including active channel forms.
F2	Fluvial plain unit with depositional tendencies and lower local slope gradient.

The geomorphic interpretation has direct susceptibility relevance. Units with higher relief contrast, steeper slope segments, and denudational dissection generally correspond to higher propensity for slope instability when lithological weakness, weathering, and infiltration are co-located.

III. Stratigraphy

Four principal lithological units and younger mixed surficial deposits are consistently reported in the source files. Relative chronology is interpreted through local field relationships and regional correlation with existing geological mapping.

TABLE III
GENERALIZED LOCAL STRATIGRAPHY SYNTHESIZED FROM PROVIDED FILES

Unit	Key Characteristics (summarized)
Arjosari Tuff Unit	Volcaniclastic tuff-dominant package interpreted as early volcanic construction products with weathering-prone components.
Jaten Tuffaceous Sandstone Unit	Reworked volcaniclastic to transitional sedimentary package; textural variability suggests differing transport/deposition energy.
Wuni Andesitic Breccia Unit	Breccia-dominant volcanic unit related to later eruptive/constructive activity and heterogenous clast-matrix behavior.
Dacitic Intrusion	Intrusive body cutting older units, interpreted as later magmatic phase and useful for relative timing constraints.
Mixed Deposits	Younger surficial deposits representing alluvial transport and slope reworking products.

TABLE IV
LITHOLOGY-RELATED ENGINEERING IMPLICATIONS FOR SLOPE BEHAVIOR

Lithological Context	Slope-Stability Relevance
Tuffaceous and reworked volcaniclastic materials	Commonly sensitive to intense weathering and water infiltration; may lose shear strength under saturation.
Breccia-rich volcanic units	Heterogeneous fabric can produce variable mechanical response and localized weak zones.
Intrusion-cut host rocks	Contact zones and fractured margins may become preferential seepage/discontinuity pathways.
Surficial mixed deposits	Often weaker and more mobile under runoff concentration and toe disturbance.

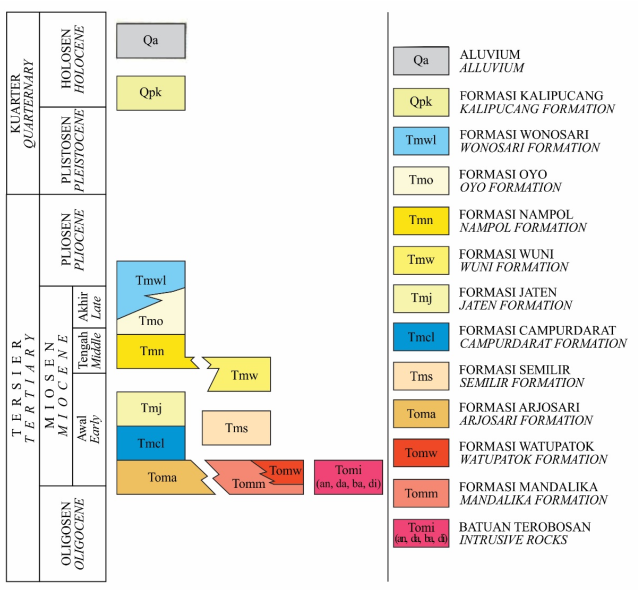

Fig. 3. Representative stratigraphic/geological panel from the provided files.

IV. Structural Geology

The area is dominated by brittle structures (joints and faults). Major interpreted structures include the Nanas dextral strike-slip fault, Bengawan Solo reverse fault, and Grindulu/Jeruk sinistral strike-slip faults. Regional interpretation in the source files associates structural development with a compressional tectonic regime.

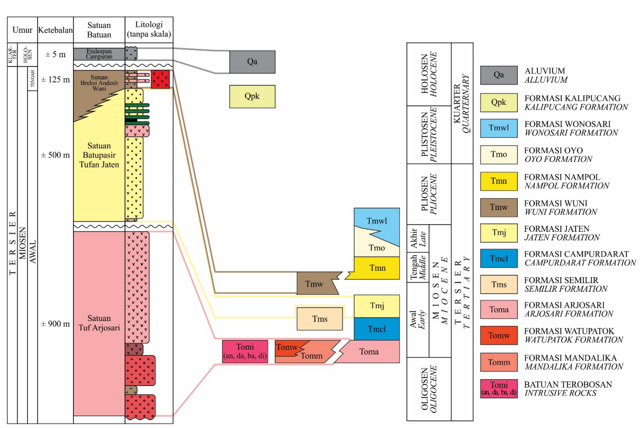

Fig. 4. Representative structural geology panel from the source documentation.

Structurally, discontinuities influence susceptibility by reducing rock-mass continuity, controlling groundwater pathways, and producing preferred failure surfaces where slope orientation is unfavorable. Consequently, structural data are not only tectonic indicators but also primary engineering constraints.

V. Geological History

The synthesized sequence from the provided history chapter includes:

1) Early Miocene volcanic constructive phase (Arjosari tuff-related products).
2) Middle Miocene reworking and transitional deposition (Jaten-related package).
3) Deformation and intrusive phase under compressional tectonics.
4) Denudational and fluvial surficial deposition stage.

This temporal model supports the observed architecture: older volcaniclastic foundations, superposed reworked units, tectonic overprint, and young surface-process products. The combination explains why present-day susceptibility reflects both inherited geology and active surficial dynamics.

VI. Environmental Geology

The project distinguishes beneficial resources and negative hazard components. Positive components include agricultural support, river-water utilization, and local material resources. Negative components are dominated by landslide susceptibility in steep, weathered, and structurally controlled terrains.

TABLE V
POSITIVE AND NEGATIVE GEO-ENVIRONMENTAL COMPONENTS

Category	**Observed/Documented Examples**
Positive (Resources)	Plantation and paddy support, domestic water from river systems, and local sand/stone/clay resources.
Negative (Hazards)	Landslide susceptibility linked to slope geometry, weathered lithology, hydrology, structural discontinuity, and land-use pressure.

TABLE VI
RESOURCE–RISK MATRIX FOR PLANNING CONSIDERATION

Domain	**Primary Benefit**	**Primary Risk if Uncontrolled**
Agricultural slopes	Local livelihood and food production	Slope loading and poor drainage can increase instability on steep terrain.
River corridors	Water source and material access	Bank erosion, toe weakening, and localized failure near settlements.
Material extraction	Local economic value	Unplanned excavation can destabilize slopes and alter runoff pathways.

VII. Mass-Movement Susceptibility Zone in Mlati Village and Surroundings, Arjosari District, Pacitan Regency, East Java Province

A. Analysis Approach

The source chapters apply multi-parameter scoring and GIS overlay adjusted from Indonesian public-works landslide-prone zoning guidance. Core indicators include slope gradient, lithology/soil properties, vegetation-land cover, and hydrological conditions.

The generic weighted-index expression is:

$$S = \sum_{i=1}^{n} w_i p_i \qquad (1)$$

where p_i is parameter score and w_i is its weighting coefficient.

TABLE VII
CORE SUSCEPTIBILITY PARAMETERS AND ENGINEERING RATIONALE

Parameter	Rationale for Inclusion
Slope gradient	Controls gravitational driving force and potential for rapid movement.
Lithology/soil condition	Determines intrinsic strength, weathering behavior, and water sensitivity.
Vegetation/land cover	Influences infiltration, root reinforcement, and surface protection against erosion.
Hydrological condition	Governs pore-water increase, seepage, and runoff concentration at slope sectors.

B. Parameter Weighting and Overlay Interpretation

The susceptibility workflow applies a weighted-overlay framework in which each thematic factor contributes proportionally to a composite susceptibility index. In practice, the process consists of: (i) classifying each parameter into relative susceptibility levels, (ii) assigning scores and weights based on engineering relevance, (iii) combining weighted layers in GIS, and (iv) interpreting resulting index intervals into susceptibility classes.

To keep interpretation technically consistent, each parameter is evaluated not in isolation but in interaction with others. For example, steep slope segments may remain conditionally stable in stronger lithology, but become highly susceptible where steepness co-occurs with weathered material, discontinuity concentration, and unfavorable drainage concentration.

C. Main Classification Results

Susceptibility classes are reported as low, moderate, and high with the following ranges.

TABLE VIII
SUSCEPTIBILITY CLASSES AND REPORTED SCORE INTERVALS

Class	Score Interval	Interpretive Meaning
Low	around 1.68	Limited instability indicators under normal conditions; routine controls generally sufficient.
Moderate	1.78–2.35	Noticeable instability potential requiring stronger planning and monitoring controls.
High	2.43–2.53	High instability potential requiring avoidance or engineered mitigation with detailed investigation.

The provided conclusions report moderate dominance: about 69.8% in potential interpretation and about 47% in areal zonation distribution. This indicates that the area is largely conditionally stable and highly sensitive to disturbance, rather than uniformly low-risk.

D. Uncertainty and Practical Interpretation

The susceptibility map is a planning-level product and should not be interpreted as deterministic prediction of exact failure time or location. For project-scale implementation, local geotechnical verification remains essential, especially in moderate-to-high classes and near critical infrastructure.

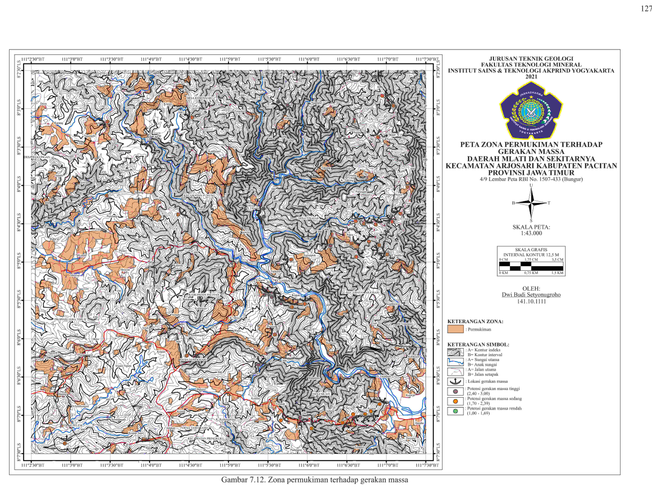

Fig. 5. Landslide susceptibility zonation map extracted from the provided files.

TABLE IX
ENGINEERING ACTIONS BY SUSCEPTIBILITY CLASS

Class	Recommended Actions
Low	Routine drainage maintenance, vegetation preservation, and periodic slope checks.
Moderate	Restrict slope cutting, improve drainage/terracing, perform site-level stability checks before construction, and control concentrated runoff.
High	Avoid dense development, prohibit unsupported toe excavation, require detailed geotechnical design and targeted stabilization where unavoidable.

VIII. IMPLEMENTATION STRATEGY AND PLANNING PRIORITIES

A. Priority Zones for Action

Based on the interpreted susceptibility distribution, planning should prioritize moderate and high classes for preventive controls. Moderate zones require stricter construction screening and drainage management, while high zones require development restriction or mandatory detailed geotechnical verification before any major intervention.

B. Recommended Investigation Sequence

For practical implementation, a staged sequence is recommended: (1) susceptibility-map screening for initial site ranking, (2) rapid field verification of slope geometry, material condition, and drainage, (3) targeted geotechnical investigation for medium-to-high-risk sites, and (4) design of mitigation measures with operation and monitoring plans.

C. Monitoring and Governance

A local monitoring framework can significantly reduce risk escalation, especially during rainy periods. Recommended governance actions include periodic slope inspections, community reporting of cracks and seepage changes, controlled excavation permits, and routine review of settlement expansion in susceptible sectors.

D. Limitations

This documentation and its zonation are intended for regional planning and preliminary engineering screening. They are not substitutes for site-specific geotechnical design analyses. Localized variability in weathering, discontinuity condition, and groundwater behavior can cause failure behavior to differ from map-scale patterns; therefore, detailed investigation remains essential for final design decisions.

IX. Conclusion

Aligned with the source final chapter and expanded synthesis, the area comprises six geomorphic subdivisions, four principal lithological units plus mixed surficial deposits, and structurally controlled slope-instability conditions. GIS-based multi-parameter assessment identifies low, moderate, and high susceptibility classes, with moderate-class dominance. The expanded chapter-by-chapter documentation demonstrates that landslide susceptibility is controlled by interacting geomorphic, lithologic, structural, hydrological, and land-use factors rather than by single-variable triggers. Accordingly, the zonation should be operationally used for risk-aware spatial planning, site screening, staged investigation, mitigation prioritization, and iterative monitoring updates in Mlati and surrounding areas.

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