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Subsurface Instability Characterization Using the Microtremor HVSR Method for Landslide Risk Assessment in Sriharjo Village, Bantul, Yogyakarta, Indonesia

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Abstract: Sriharjo Village, Bantul, Yogyakarta, is affected by recurrent mass movements and slope deformations due to complex geological conditions and groundwater infiltration. This study aims to assess subsurface instability using the Horizontal-to-Vertical Spectral Ratio (HVSR) method. Fifty-three microtremor measurements were conducted along four survey lines, with each recording lasting approximately 20 minutes. The data were processed using Geopsy and Dinver software, employing spectral curve analysis to extract key subsurface parameters. The analysis yielded shear wave velocity (Vs), compressional wave velocity (Vp), Vp/Vs ratio, and Poisson's ratio. Vs values below 750 m/s indicate soft, less consolidated materials, typically associated with unconsolidated sediments. High Vp/Vs ratios (>2.5) and Poisson's ratios approaching 0.5 suggest elevated pore water content and low shear strength, indicating saturated and nearly incompressible conditions. Spatial patterns reveal subsurface fluid migration from the north toward the deformation zone, highlighting the role of groundwater infiltration and increased pore pressure in triggering slope instability. This study demonstrates that the interaction between pore pressure and lithological heterogeneity contributes significantly to the development of slip surfaces and ongoing deformation. The findings provide a geophysical framework applicable to slope stability assessment and landslide risk mitigation in vulnerable terrains such as Sriharjo Village.

Keywords: Groundwater Infiltration; Landslides; Poisson's Ratio; Slope Stability; Wave Velocity.

Introduction

Landslides are among Indonesia's most frequent and destructive geohazards. Particularly, steep slopes, intense rainfall, and complex subsurface geology converge to produce recurrent ground failure. The nation's vulnerability is compounded by active tectonic frameworks, a tropical climate that fosters high water infiltration, and widespread unconsolidated deposits overlaying volcanic or sedimentary bedrock. Indonesia's intricate geological framework, marked by steep inclines, eroded volcanic formations, and considerable alterations in land use, heightens its vulnerability to landslides, especially in localities such as the Kulon Progo Mountains and upper watershed regions (Putra et al., 2025). Furthermore, variables such as rainfall intensity, land use, and geological faults substantially influence this susceptibility, with high-risk areas often associated with steep slopes and areas of significant human activity, including road construction (Wijayanti et al., 2025; Erzagian et al., 2023).

At Sriharjo Village, Bantul, Yogyakarta, land subsidence has repeatedly occurred along a key access road leading to a popular hillside tourist destination. In response, the local government constructed sheet piles to mitigate soil strain and prevent landslides; however,

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subsidence reoccurred shortly after construction, indicating unresolved subsurface instability. This highlights the need for a detailed geophysical investigation to understand the underlying causes.

This study employs the microtremor Horizontal-to-Vertical Spectral Ratio (HVSR) method. This non-invasive, cost-effective geophysical technique uses ambient seismic noise to estimate site resonance frequencies, amplification factors, and subsurface mechanical properties, including shear wave velocity (Vs), compressional wave velocity (Vp), and Poisson's ratio. The method is particularly advantageous in landslide-prone areas, as it provides critical insights into subsurface layering and bedrock depth without requiring expensive active-source equipment or drilling (Setyo et al., 2023; Baharuddin et al., 2023; Medwedeff et al., 2022).

Previous studies in Indonesia have demonstrated the effectiveness of HVSR in mapping soft sediment thickness, identifying weak layers, and correlating Vs with landslide potential. However, no comprehensive HVSR-based investigation has been conducted in Sriharjo, despite its history of persistent slope deformation. This study addresses that gap by delineating Vs, Vp/Vs ratios, and Poisson's ratios across the subsurface, mapping slip-surface geometry, and correlating these parameters with geological and hydrogeological conditions. The novelty of this research lies in its first application of HVSR in Sriharjo and in its integration of geophysical parameters to interpret mechanisms of slope instability. The findings are expected to advance understanding of slope mechanics in fault-affected regions and support the development of effective mitigation strategies. This method facilitates the identification of geological features and sediment deposits that increase the likelihood of ground shaking and movement (Setyo et al., 2023). Studies in Indonesia have successfully applied HVSR to map soft sediment thickness, identify weak layers, and correlate Vs with landslide potential. Poisson's ratio derived from Vp/Vs inversion further enhances interpretation by indicating material compressibility and fluid saturation. The data, usually gathered with tools such as a Digital Portable Seismograph, are cleaned to remove noise. After that, HVSR analysis is performed to identify the most significant frequencies and amplification factors, which are crucial for determining soil properties and sediment layer thicknesses (Siddig et al., 2021). Understanding the complex interplay between geological formations, hydrogeological conditions, and subsurface deformation is crucial for practical landslide hazard assessment and mitigation, particularly in seismically active regions. Although its effectiveness in pinpointing areas prone to seismic amplification and ground instability is acknowledged, no extensive HVSR-based research has been published for Sriharjo, an area characterized by persistent subsurface deformation. Given the limitations of conventional approaches and the need for detailed subsurface characterisation, this study adopts the microtremor HVSR method to investigate slope instability in Sriharjo.

Although HVSR has proven effective in identifying zones of seismic amplification and ground instability, no comprehensive application of this method has been conducted in Sriharjo, an area marked by persistent subsurface deformation. This study addresses that gap by delineating Vs, Vp/Vs ratios, and Poisson's ratios across the subsurface, mapping slip-surface geometry, and correlating these parameters with geological and hydrogeological conditions. The findings are expected to advance understanding of slope mechanics in fault-affected regions and support the development of effective mitigation strategies.

Microtremor

Microtremors are ambient seismic vibrations generated by natural and human activities that can be recorded to evaluate subsurface conditions without the need for intrusive drilling. The Horizontal to Vertical Spectral Ratio HVSR method analyzes the ratio of these horizontal and vertical spectral components to determine the site's fundamental resonance frequency (Nakamura, 1989). The microtremor HVSR method is a reliable method for identifying areas with high impedance contrast. These areas are crucial for understanding how seismic waves can become trapped, causing the ground to shake for an extended period and increasing the likelihood of recurrent slope failure (Mokhtari, 2023). The HVSR method, which utilizes ambient microtremor measurements, is widely employed for seismic microdonation and landslide hazard assessment because it can reveal subsurface velocity structures and estimate Vs30, a parameter crucial for determining site effects and potential ground instability (Das & Sivakugan, 2017). This method uses the spectral ratio of the ambient noise's horizontal and vertical parts to find the fundamental resonance frequencies and amplification factors of layers below the surface (Susilo et al., 2024). By inverting these HVSR curves, we can create a detailed subsurface velocity model that includes P-wave, S-wave, and Poisson's ratios. This model is essential for understanding the geological structure of places prone to landslides (Baharuddin et al., 2023). A clear resonance peak corresponds to the dominant frequency f_0, which indicates sediment stiffness and thickness. Initially introduced by Nogoshi and Igarashi and refined by Nakamura, the method efficiently estimates site transfer functions for S-waves based on ambient noise characteristics (Araque-Perez, 2024; Abdelrahman et al., 2023).

Inversion of HVSR curves yields subsurface velocity structures, including shear-wave velocity (Vs) and compressional-wave velocity (Vp) (Das & Sivakugan, 2017). A high-precision agriculture strategy and new geophysical technology (Sanny et al., 2023) can be used to map soil characteristics. The fundamental frequency and peak HVSR values, derived from the horizontal-to-vertical spectral ratio of ambient microtremors, reflect local geological conditions and seismic resilience (Araque-Perez, 2024). The Vp/Vs ratio provides additional insight into material composition and water content: high ratios typically indicate saturated or clay-rich deposits with low rigidity. In contrast, lower ratios suggest compact or dry materials (Keçeli, 2024; Eyinla et al., 2021). As summarised in Table 1, this classification aids in identifying mechanically weak zones and delineating potential slip surfaces. The resonance frequency, marked by a distinct HVSR peak, signifies an impedance contrast between the unconsolidated surface layers and the underlying bedrock (Kumar et al., 2025). Integrating Vs and Vp/Vs ratios thus enables precise mapping of subsurface instability and supports landslide hazard assessment.

Poisson's Ratio

Poisson's ratio, v, expresses the relationship between lateral and axial strain when a material is subjected to stress and reflects its elastic behaviour and compressibility. This essential material quality indirectly reflects lithological features and groundwater saturation, with higher values associated with increased pore water pressure and reduced shear strength (Wang et al., 2022). Values generally range from 0.1 to 0.5 in most geological formations; values below 0.3 are typical of dry, dense, or stiff materials such as compact sand or competent rock, while values above 0.4 signify saturated clays or loose sands, indicating high deformability and diminished rigidity (Qaher et al., 2023). The shear wave velocity, primarily influenced by lithology rather than water saturation, is crucial in determining Poisson's ratio, offering a more intuitive reflection of a stratum's porosity and water content (Wang et al., 2022). Shear waves flow through the solid matrix, and their velocity is minimally influenced by the fluid phase, establishing a direct correlation with the material's skeletal properties (Li et al., 2023). Consequently, precise shear wave velocity (Vs) measurements are essential for comprehensive geomechanical and petrophysical evaluations, especially in reservoir characterisation and hydrogeological modelling (Onyelowe et al., 2025).

High v values are often associated with saturated fine-grained deposits in areas affected by groundwater flow. Continuous infiltration increases pore water pressure, lowers effective stress, and enhances the potential for slope instability (Susilo et al., 2023). Poisson's ratio is a sensitive indicator for detecting zones of weakness influenced by groundwater circulation. Analysing shear wave velocity and the Vp/Vs ratio enhances understanding of subsurface mechanical behaviour and the influence of hydrogeological factors on slope instability.

Method

Fifty-three microtremor stations were deployed along four survey lines (A, B, C, and D) to cover the deformation zone (as shown in Figure 1) comprehensively. Ambient ground vibrations were recorded for 20 minutes at each station using VHL PS2B triaxial geophones, which have natural frequencies ranging from 2 to 4.5 Hz, connected to DI710 and GL240 dataloggers operating at a sampling rate of 400 Hz. The VHL PS2B geophone has a natural frequency of 2–4.5 Hz, which means it can't pick up signals below 1 Hz very well. However, it is still good enough for finding the dominant resonance frequencies (>0.5 Hz) that are expected in the study area. We made this choice based on the tools we had and the geology of Sriharjo.

Figure 1. The road that suffered land subsidence was oriented eastward

Data processing followed the SESAME standard procedure using Geopsy software. Recorded time-series data were detrended, bandpass filtered between 0.5 and 20 Hz, and divided into stationary time windows to remove transient noise. The Horizontal-to-Vertical Spectral Ratio (HVSR) technique was applied to estimate the fundamental resonance frequency and amplification factor, representing the impedance contrast between surface sediments and the underlying competent layers. Assessing slope stability and anticipating potential geohazards requires an understanding of subsurface conditions (Zakaria, 2023; Akbar et al., 2024), especially in complex geological systems such as the Sriharjo region (Figure 2). This study presents a comprehensive geophysical methodology that integrates seismic inversion with spatial analysis to accurately delineate subsurface mechanical parameters relevant to slope stability (Wagner & Uhlemann, 2021).

Figure 2. The research site is a subsiding road segment (shown in orange) aligned west-east, adjacent to the river. The allocation of measuring sites is also displayed.

The HVSR curves were inverted using the Dinver module in Geopsy through a stochastic optimization approach to obtain subsurface velocity models. The inversion used an L2-norm misfit function to assess how well the synthetic and observed HVSR curves matched. Based on geological constraints in the area, the parameter search space was set to Vs ranging from 100 to 3000 m/s, Vp from 500 to 5000 m/s, and layer thickness from 1 to 50 m. The stochastic evaluation produced 5000 models, and the one that fit most accurately was chosen based on the lowest misfit value. The inversion yielded compressional wave velocity (Vp), shear wave velocity (Vs), and layer thickness parameters, all of which were constrained by regional geological information. Poisson's ratio was then calculated from Vp and Vs values to evaluate the elastic response and degree of water saturation in the subsurface materials. The Poisson ratio parameter model analysis in this study utilizes the classification established by Das and Sivakugan (2017) as a reference, presented in Table 1. This method leverages the strengths of geophysical techniques to identify subsurface differences, which often signal potential failure zones. It combines them with spatial modelling for an in-depth landslide susceptibility analysis (Zakaria, 2023).

Table 1. Soil type classification

Soil type	Poisson's ratio
Saturated clay	0.4 – 0.5
Unsaturated clay	0.1 – 0.3
Sandy clay	0.2 – 0.3
Silt	0.3 – 0.35
Sand	0.1 – 1.0
Rock	0.1 – 0.4
Commonly used for soil	0.3 – 0.4

Surfer software was used for visualization and spatial interpretation. The derived parameters (Vs, Vp/Vs ratio, and Poisson's ratio) were interpolated to generate contour and cross-sectional models of subsurface conditions. This integrated workflow provides a reproducible and noninvasive framework for assessing subsurface mechanical contrasts and understanding the geophysical controls on slope instability in the Sriharjo area. Settlement along the access road was evaluated by constructing a shear wave velocity (Vs) distribution model derived from intersecting cross sections, progressively covering sections 9 through 4 in a north–south orientation (Figure 3). In uncemented coarse-grained soils, Vs is significantly influenced by effective confinement and varies with depth. Numerous empirical correlations between Vs and depth are documented in the literature, allowing for refined classification ranges (Foti et al., 2018). As shown in Table 2, geological materials can be categorized based on Vs values: materials with Vs < 750 m/s are typically soft, saturated, and highly compressible, conditions strongly associated with soil subsidence.

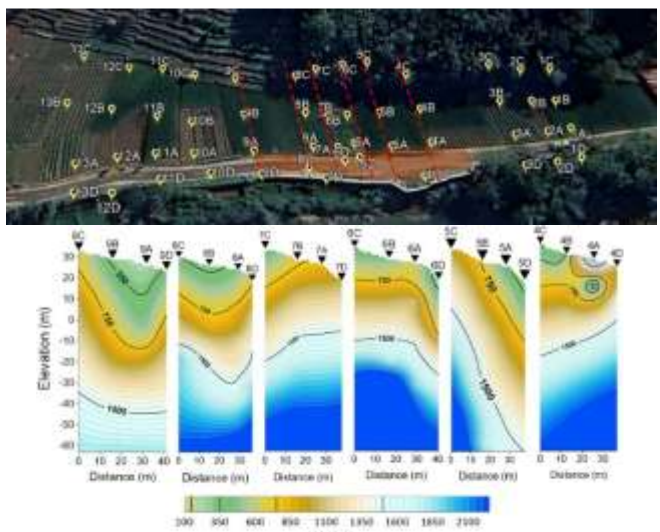

Figure 3. Cross sections of the secondary wave velocity model are displayed successively from left to right, illustrating the vertical distribution of Vs.

Table 2. Prospective rates of shear wave velocity for soils and rocks (Foti et al., 2018).

Material	Vs (m/s)
Soft clay	80-200
Stiff clay	200-600
Loos sand	80-250
Dense sand	200-500
Gravel	300-900
Weathered rock	600-1000
Competent rock	1200-2500

Results and Discussion

Schematic Illustration of Shear-Wave Velocity Model

Figure 3 presents a cross-sectional view of the vertical shear wave velocity distribution (Vs). Across the profile, sites A and D exhibit notably low Vs values (<350 m/s), classifying the subsurface material as clay according to Table 2. The low-velocity zone indicates the existence of extremely compressible soils, potentially affecting ground stability (Susilo et al., 2024).

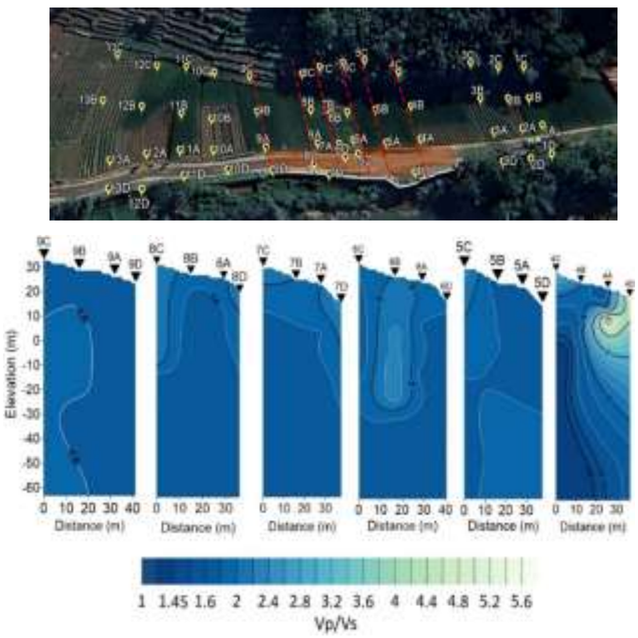

Figure 4. Vertical cross-section of the measurement data, presented sequentially from left to right.

The spatial configuration of subsurface layers further reveals the structural controls on slope deformation. A notable observation is a widespread low-velocity zone (Vs) extending from the surface to depths of approximately 10 to 30 meters. This zone comprises unconsolidated sediments with low mechanical strength, indicative of excessive saturation and reduced shear resistance, consistent with the observed recurrent ground deformation. The base of this layer, which inclines gradually southward across all profiles, defines the primary slip surface. In contrast, higher Vs values suggest competent bedrock, likely corresponding to the consolidated Imogiri Formation. The sloping, uneven interface between the weak overburden and the rigid bedrock reflects tectonic influences, possibly associated with the Oyo Fault. This two-layer configuration, characterised by saturated, low-stiffness sediments overlying inclined bedrock, governs mass movement dynamics and facilitates shear displacement toward the river under hydrogeological stress.

Cross-sectional model of the P-wave to S-wave velocity ratio

This section examines the theoretical basis of how pore fluids affect seismic wave propagation, specifically their differential impact on compressional (Vp) and shear (Vs) wave velocities (Wang et al., 2022). Fluids significantly affect the bulk modulus of a medium, thereby increasing Vp, while Vs remains unaffected, mainly, especially in clay-rich soils (Ortiz et al., 2023). This contrast makes the Vp/Vs ratio a sensitive indicator of fluid saturation in porous media, with higher ratios reflecting greater fluid content due to water's incompressibility relative to the solid matrix (Eyinla et al., 2021). In unconsolidated sediments, increased pore fluid content raises Vp with minimal impact on Vs, resulting in high Vp/Vs ratios that signal reduced shear strength and potential instability (Tsuji et al., 2021). These elevated ratios are crucial for geotechnical assessments, as they indicate zones of high pore pressure and reduced effective stress, which are prone to failure (Yan et al., 2023). Additionally, fluid-filled pore spaces influence elastic properties, such as Young's modulus, particularly in surface layers, further increasing the Vp/Vs ratio. This phenomenon arises because pore fluids resist compression but offer little resistance to shear, enhancing Vp while Vs remains stable or slightly reduced (Eyinla et al., 2021; Wang et al., 2022).

The Vp/Vs ratio, derived from compressional and shear wave velocities, is a critical parameter for assessing subsurface conditions associated with landslide susceptibility. Elevated ratios indicate high pore pressure and reduced shear strength, contributing to slope instability (Wang et al., 2022). Values exceeding 2.2-2.3 often correspond to persistent weak layers that act as potential slip surfaces, providing a quantitative basis for evaluating hydrogeological influences on failure mechanisms. These findings are visualized in the vertical cross-section shown in Figure 4, which highlights zones of elevated Vp/Vs ratios aligned with areas of observed deformation.

The Vp/Vs ratio provides critical information on lithological and hydrogeological conditions, enhancing subsurface characterization. The Vp/Vs ratio, derived from seismic compressional and shear wave velocities, is a key parameter in geotechnical applications, including assessing rock mechanical properties, characterizing pore structure, and analyzing fluid saturation (Kim et al., 2023). Elevated Vp/Vs ratios typically indicate saturated or unconsolidated materials with low shear wave velocities, as Vp increases due to the incompressibility of fluids, while Vs decreases or remains stable (Medwedeff et al., 2022). Conversely, low Vp/Vs ratios are associated with dry, competent soils or rocks, where shear strength is preserved by low pore pressure and high interparticle friction. Additionally, reduced Vp/Vs ratios may signal gas-bearing formations, where gas lowers compressional wave velocity by increasing transit time, thereby affecting subsurface mechanical behavior (Eyinla et al., 2021; Fazriati et al., 2023).

The regional distribution of Vp/Vs ratios further confirms the hydrogeological influences on slope failure. The reported surface subsidence and collapse area coincides with the highest Vp/Vs ratio observed in section 4, between points 4A and 4D. A Vp/Vs ratio of 2.5 or higher indicates near-total saturation in unconsolidated sediments, suggesting a zone of critically reduced shear strength. This concentration confirms that slope instability in this segment is primarily driven by elevated pore water pressure. Persistent, depth-dependent elevated Vp/Vs ratios corroborate the continuity of mechanically weak layers and align with prior Vs interpretations. These results underscore the significance of pore pressure in diminishing effective stress.

Cross-Sectional Model of Poisson's Ratio for Road Subsidence Assessment

In addition to the Vp/Vs analysis, Poisson's ratio modelling provides further insight into subsurface mechanical variations and fluid saturation. Poisson's ratio is a critical elastic parameter for evaluating the mechanical behavior of near-surface materials, where variations in depositional history, lithology, and water content significantly influence seismic wave propagation (Wang et al., 2022). Defined as the ratio of lateral to longitudinal strain, Poisson's ratio is susceptible to fluid saturation and can indicate subsurface porosity and fluid distribution (Siddig Ali et al., 2021). Values typically range from near zero in hard, consolidated rocks to approximately 0.4 in saturated or unconsolidated sediments (Qaher et al., 2023). Elevated Poisson's ratios are associated with increased compressibility and reduced shear strength, while lower values reflect dry, stiff, and mechanically stable formations (Liu et al., 2023; Liu et al., 2024). Dynamic Poisson's ratio values derived from P- and S-wave velocities enable continuous subsurface characterization through geophysical surveys (Siddig Ali et al., 2021). Figure 5 presents vertical cross-sections of Poisson's ratio modelling, highlighting elevated Poisson's ratio values corresponding to areas of observed road subsidence.

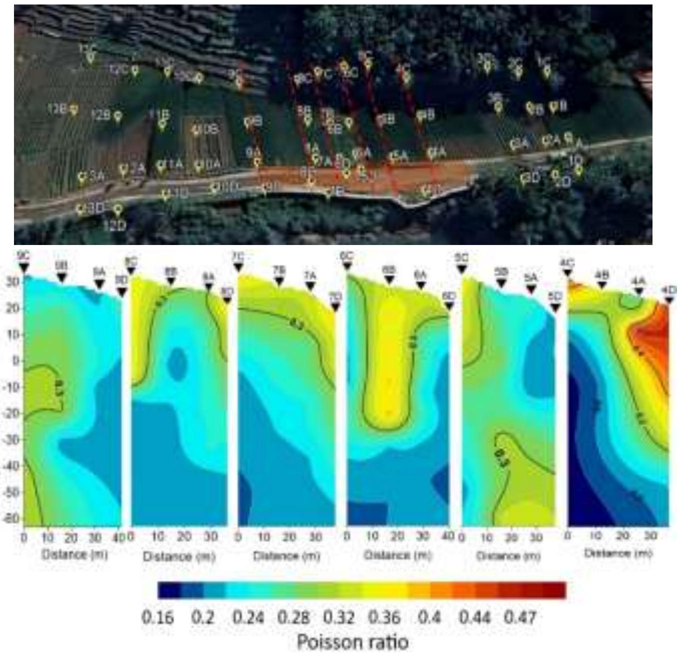

Figure 5. The vertical cross-sections of the Poisson ratio modelling

The regional distribution of Poisson's ratio values further corroborates the hydrogeological factors contributing to slope instability. The five profile sections (9, 8, 7, 5, and 4) consistently support interpretations derived from Vs and Vp/Vs analyses, particularly in delineating subsurface fluid-migration pathways. The most prominent observation is the concentration of elevated Poisson's ratio values, approaching 0.5, in section 4, as indicated by red and orange zones. This area aligns precisely with the site of most significant road subsidence, signifying a highly saturated zone where the material behaves nearly as an incompressible medium, confirming a substantial reduction in effective stress. The spatial pattern reveals predominant subsurface fluid movement from the northern region toward the failure zone, emphasizing the role of groundwater infiltration in the deformation process. In contrast, sections 9, 8, 7, and 5 exhibit lower Poisson's ratio values at depth, indicating drier, more consolidated, and mechanically stable strata beneath the critical slip surface. These findings confirm that recurrent slope failure is primarily driven by pore pressure buildup within a saturated, mechanically compromised layer.

This part synthesizes the geophysical and hydrogeological findings and discusses their broader implications for slope stability and hazard reduction. It is essential to incorporate a variety of techniques into the process of understanding how regional variables, including precipitation and groundwater changes, affect fundamental properties, such as slope geometry and the likelihood of liquefaction (Pourverdi et al., 2025). Integrating several geophysical and remote sensing approaches enhances overall understanding. This allows us to describe the underlying structure of unstable slopes better and detect small displacement trends (Ciampi et al., 2025). This work systematically examines the influence of groundwater dynamics and pore pressure accumulation as primary factors contributing to recurrent slope instability, utilizing advanced Poisson's ratio analysis based on seismic data. The method provides a reliable framework for detecting fluid-saturated subsurface zones, which often indicate impending slope failure. The research elucidates the hydro-mechanical interactions that diminish effective stress and induce deformation by amalgamating geophysical approaches with geotechnical principles (Onyelowe et al., 2025). Spatial research reveals distinct pathways for fluid movement through the Earth, and groundwater penetration is a significant contributor to slope instability (Zakaria, 2023). After heavy rain, surface water infiltrates fracture networks and accumulates in permeable soils. This raises pore pressure and considerably lowers shear strength (Himi et al., 2022; Osawa et al., 2023; Kumar et al., 2025). This tendency is pronounced in coastal slopes characterized by porous and loose structures (Jia et al., 2024). Similar mechanisms are observable in the Sriharjo region, underscoring the need for targeted mitigation strategies.

The integrated geophysical data provide a clearer understanding of the structural configuration contributing to slope instability. Subsurface models incorporating Vs, Vp/Vs, and Poisson's ratio data indicate a continuous, weak horizon throughout the study area, sloping toward the river, confirming its role as the primary slip surface responsible for the ongoing deformation. In Vp/Vs models, this horizon is characterized by ratios exceeding 2.2-2.3, further corroborated by Poisson's ratio values exceeding 0.4 in Section 4, which is suggestive of saturated, low-strength materials with diminished effective stress. This enduring weak layer, extending from near the surface to depths of 15-25 meters, exhibits consistent lateral continuity across various profiles. A sloped interface between unconsolidated sediments and solid bedrock may indicate the presence of structural forces. The proximity of the Oyo Fault suggests a potential tectonic influence; however, additional geological and structural investigations are necessary to validate this connection. As a result, the interaction between increased pore pressure and changes in lithology designates this horizon as the central detachment plane accountable for the subsidence observed in Sriharjo.

This study demonstrates how lithological vulnerabilities and groundwater dynamics lead to slope failures in Sriharjo. The potential influence of regional tectonic formations, including the Oyo Fault, remains speculative and warrants further research. The integration of HVSR-derived parameters—Vs, Vp/Vs ratio, and Poisson's ratio—indicates a saturated, mechanically weak layer functioning as the primary slip surface. This study has introduced a classification for the Poisson's ratio values obtained, indicating that most values fall within the range characteristic of saturated, unconsolidated sediments. Table 3 presents the classification of Poisson's ratio and the observed values in this study, highlighting that most critical zones are categorized as highly saturated (>0.4), indicating mechanically weak layers susceptible to failure. The microtremor HVSR method has shown its effectiveness as a non-invasive tool for subsurface characterization in areas susceptible to landslides, successfully identifying critical instability zones with precision. The findings highlight the importance of geophysical data in assessing slope stability, particularly in regions affected by active faulting and groundwater infiltration. Suggested mitigation strategies include installing subsurface drainage, replacing soft soils with compacted granular materials, and stabilizing slopes through structural anchoring. Interventions informed by thorough geophysical analysis can significantly improve the resilience and safety of infrastructure in geologically vulnerable areas.

Table 3. The classification of Poisson's ratio and observed values in this study (Kulhawy et al., 1990)

Poisson's Ratio (υ)	Material Type	Condition	Observed in This Study
<0.25	Hard, Consolidated rock	Dry and mechanically stable	Not observed
0.25-0.35	Semi-consolidated Sediments	Moderately stable	Section 9,8,7 (deep layer)
0.35-0.40	Unconsolidated sediments	Partialy saturated, weak	Section 5 and 7 (mid depth)
>0.40(up to 0.50)	Highly saturated sediements	Very weak, prone to failure	Section 4 (critical slip zone)

Conclusion

This study effectively illustrates the applicability of the microtremor HVSR method in detecting areas of vulnerability linked to persistent slope instability in Sriharjo, Bantul. The main aim of this study was to delineate subsurface conditions affecting slope stability by estimating essential mechanical parameters, namely shear-wave velocity (Vs), the Vp/Vs ratio, and Poisson's ratio—through the microtremor HVSR method. The combination of Vs, the Vp/Vs ratio, and Poisson's ratio modelling indicates a mechanically impaired, continuous, and saturated layer that serves as the primary sliding surface. The integration of Vs (<350 m/s), the Vp/Vs ratio (>2.2–2.5), and Poisson's ratio (>0.4, nearing 0.5) modelling suggests a mechanically compromised, continuous, and saturated layer that functions as the principal sliding surface. Elevated pore water pressure, arising from groundwater infiltration and potentially influenced by regional structural discontinuities such as the Oyo Fault, may lead to diminished effective stress and shear strength, causing persistent deformation and subsidence within the 15–25 m depth range. An additional inquiry is necessary to validate this structural impact. The spatial relationship between geophysical anomalies, such as Vp/Vs ratios exceeding 2.3 and Poisson's ratios near 0.5, and recorded ground failures underscores the significant role of hydrogeological forces in slope instability. These findings contribute to the development of a comprehensive, non-invasive approach for assessing landslide hazards and planning mitigation in geologically susceptible regions, particularly by identifying zones with Vs < 350 m/s and Vp/Vs > 2.3. Considering the observed weak zones, suggested mitigation strategies include installing subsurface drainage systems to alleviate pore water pressure, substituting highly compressible soils with compacted granular materials, and reinforcing slopes with structural anchoring or retaining walls.

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Author Contributions

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Conflicts of Interest

The authors confirmed that there is no conflict of interest in this article.

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