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Seismic Site Characterization and Ground Shear Strain Assessment for the Development of Indonesia's New Capital City, East Kalimantan

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A B S T R A C T

The development of Indonesia's new capital, Ibu Kota Nusantara (IKN), requires reliable seismic and geotechnical assessments to support safe urban planning. This study evaluates seismic site characteristics and potential earthquake-induced ground deformation in the Sepaku area using the Horizontal-to-Vertical Spectral Ratio (HVSR) and Ground Shear Strain (GSS) methods. Microtremor data were analyzed over 0–20 Hz using 20–40 s windows and a 1–10 Hz Butterworth band-pass filter. The results show dominant periods of 0.1–1.1 s and seismic vulnerability indices of 0.001–0.016 s^2/cm. Higher GSS values (0.5–0.8) identify four priority zones for further assessment of landslides, soil compaction, and liquefaction. These results provide an efficient first-stage basis for seismic microzonation and earthquake-resilient planning in IKN

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INTRODUCTION

The development of Indonesia's new capital city, Ibu Kota Nusantara (IKN), represents one of the country's largest long-term urban-development projects. The planned capital is intended to establish a modern and internationally competitive urban environment while maintaining the ecological character of East Kalimantan. The concept of a "city in the forest" requires urban development to be integrated with the natural landscape and therefore demands a detailed understanding of geological, geomorphological, hydrological, and geohazard conditions.

Geological and geophysical conditions are particularly important because the safety and long-term performance of infrastructure depend strongly on subsurface characteristics. Variations in lithology, sediment thickness, groundwater conditions, and shear-wave velocity can produce substantial differences in local seismic response even within areas subjected to similar regional earthquake hazard. Consequently, regional seismic hazard assessments should be complemented by local-scale seismic site characterization and microzonation.

The IKN region is situated within the broader geological framework of the Kutai Basin, one of the major Cenozoic sedimentary basins of Indonesia. The basin contains a thick succession of sedimentary deposits ranging from Eocene to Recent age and developed over a basement with mixed continental and oceanic affinities, including ophiolitic components. Its geological architecture (Figure 1) reflects a complex history of extension, subsidence, sedimentation, tectonic inversion, and deltaic progradation (Moss & Chambers, 1999).

The tectonic framework of the Kutai Basin is also structurally complex. Wain and Berod (1989) described the Upper Kutai Basin as being influenced by major regional tectonic trends, including the NW–SE Adang–Cross Barito trend and the NNE–SSW Meratus trend. They interpreted the Adang–Cross Barito system as part of a broader Trans-Kalimantan tectonic zone linking the Paternoster Platform and Lupar fault zone.

The presence of major geological structures does not, however, automatically demonstrate that every associated fault segment is presently active. Therefore, the seismic significance of the Adang–Lupar structural system should be considered within the broader regional seismic-hazard framework rather than assuming present-day activity without independent evidence from paleoseismology, geodesy, relocated seismicity, or other active-fault investigations. This distinction is particularly important for infrastructure planning because the Indonesian seismic hazard framework incorporates geological, geodetic, seismological, instrumental, and ground-motion information to identify and characterize earthquake sources (Pusat Studi Gempa Nasional [PuSGeN], 2017).

The Indonesian earthquake hazard framework provides the regional basis for evaluating expected ground motion. The 2017 Indonesian Earthquake Source and Hazard Map incorporated updated earthquake catalogs, newly identified earthquake sources, active-fault investigations, geodetic information, ground-motion prediction equations, and probabilistic seismic-hazard analysis (PuSGeN, 2017). Nevertheless, regional hazard maps do not fully capture local amplification associated with sediment thickness and near-surface soil properties. This limitation provides a strong justification for local seismic microzonation.

The Horizontal-to-Vertical Spectral Ratio (HVSR) method is widely used as a reconnaissance technique for evaluating the dynamic characteristics of near-surface geological materials. The method is particularly useful for estimating the dominant or fundamental frequency of a site and for identifying spatial variations in sedimentary thickness and impedance contrast (Molnar et al., 2018). The method is also useful in areas of relatively low to moderate seismicity where earthquake recordings may be limited (SESAME, 2004).

However, HVSR interpretation requires caution. Although HVSR provides valuable information about site response, it should not be interpreted independently of geological and geotechnical information. The theoretical basis and limitations of the method have been extensively discussed in the literature, and integration with geological, geophysical, and geotechnical data is recommended for reliable seismic microzonation (Molnar et al., 2018; SESAME, 2004).

The present study therefore aims to characterize the local seismic response of the Sepaku area using HVSR-derived parameters and Ground Shear Strain (GSS). The specific objectives are to:

1. Determine the spatial distribution of dominant frequency and dominant period;
2. Evaluate the seismic vulnerability index based on HVSR parameters;
3. Characterize near-surface soil conditions using Vs30 information;
4. Identify areas with relatively high GSS values;
5. Evaluate potential zones susceptible to earthquake-induced ground deformation, including landsliding, soil compaction, and liquefaction; and
6. Provide a preliminary seismic microzonation framework to support earthquake-resilient planning and future geotechnical investigation in IKN.

LITERATURE REVIEW

Geological and Seismotectonic Setting

The Kutai Basin is a major Cenozoic sedimentary basin occupying a substantial part of eastern Kalimantan. Its geological evolution involved development over a basement containing continental and oceanic components, followed by extensive Cenozoic sedimentation. Moss and Chambers (1999) described a near-complete Tertiary sedimentary succession extending from the Eocene to the Recent and emphasized the importance of tectonic subsidence, sediment supply, and basin-margin structures in controlling sedimentary architecture.

The sedimentary succession includes fluvial, deltaic, shallow-marine, and deeper-marine facies. Younger depositional systems, including fluvial and deltaic deposits, are particularly relevant to engineering-geological assessment because they can contain relatively soft, loose, and water-saturated materials.

The regional structural framework includes the Adang–Cross Barito trend and Meratus trend. Wain and Berod (1989) interpreted the Adang–Cross Barito trend as a major Trans-Kalimantan tectonic element, while subsequent geological studies have demonstrated the importance of structural deformation in controlling the architecture and evolution of the Kutai Basin.

For the purpose of seismic-hazard assessment, the presence of geological structures should therefore be considered as part of the regional tectonic framework. However, structural presence and present-day fault activity should be distinguished. The 2017 Indonesian earthquake hazard assessment specifically improved the identification and characterization of earthquake sources using geological, geodetic, seismological, and instrumental evidence (PuSGeN, 2017).

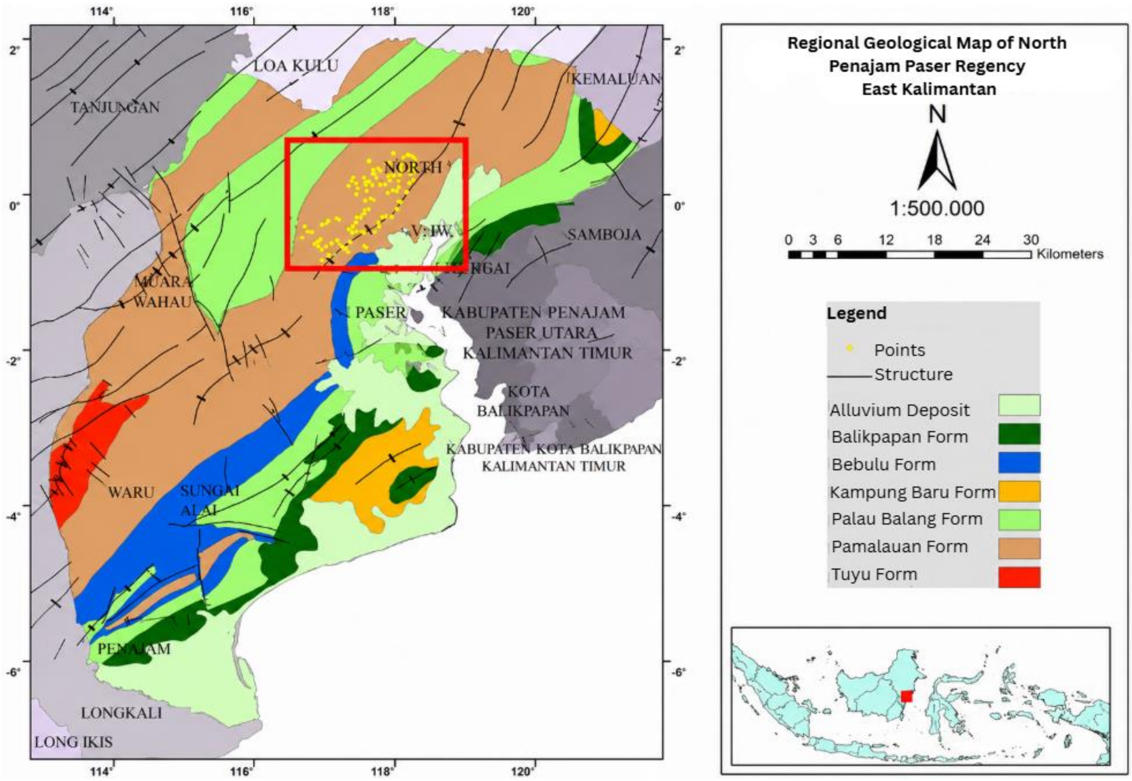

Figure 1. Geological Map Area Around New Capital of Republic Indonesia
(Modified from Hidayat et.al, 1994 & Supriatna et. al, 1995).

METHODOLOGY

Microtremor Measurement and HVSR Analysis

Microtremor measurements were analyzed using the Horizontal-to-Vertical Spectral Ratio method. HVSR is calculated from the ratio between the horizontal and vertical components of ambient seismic noise and can be used to identify the predominant frequency of the near-surface geological structure.

The method was originally popularized by Nakamura (2000) for estimating the dynamic characteristics of surface layers.

Subsequent research has demonstrated its broad application in seismic site characterization and microzonation, although its interpretation should account for the complexity of the ambient-wavefield composition and subsurface structure (Molnar et al., 2018).

In this study, the recorded signals were segmented into approximately **20–** 40 s windows. The analyzed frequency (Figure 2) range was approximately 0–20 Hz, and a Butterworth band-pass filter with corner frequencies of 1–10 Hz was applied. The processing procedure was designed to reduce unwanted low- and high-frequency components while retaining the frequency range relevant to the local site response.

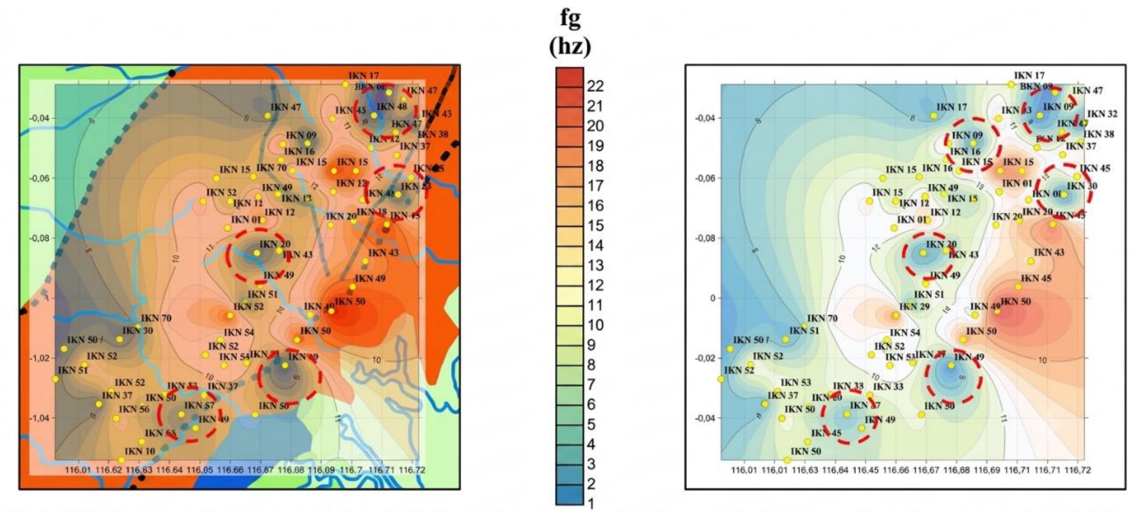

Figure 2. Dominant Frequency Maps

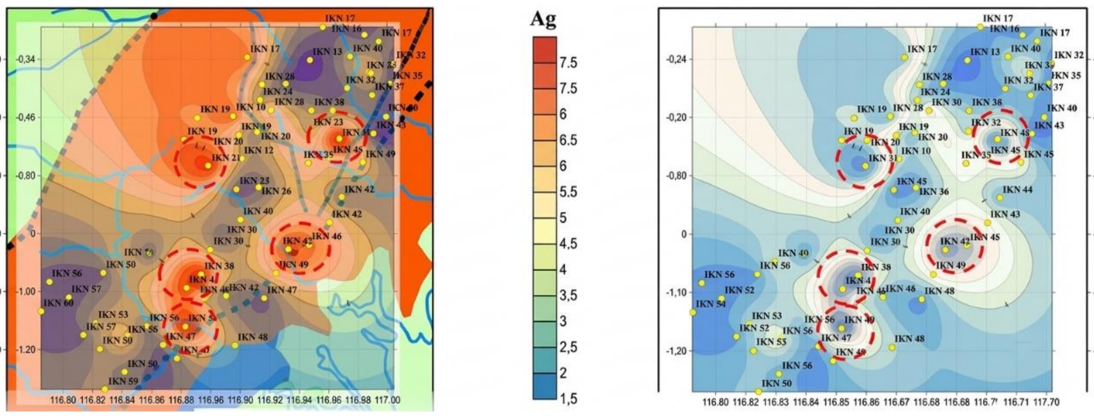

Figure 3. Amplification Factor Maps

Quality control of HVSR measurements should consider the stability and reliability of spectral peaks. The SESAME guidelines recommend that H/V results be evaluated together with geological and geotechnical information, particularly when identifying resonance frequencies of soft sedimentary deposits (SESAME, 2004).

Herak (2008) also demonstrated that HVSR modeling can be used to evaluate theoretical site amplification and investigate the relationship between observed H/V spectra and subsurface models.

Dominant Frequency and Dominant Period

The dominant frequency, f_0, represents the frequency at which the H/V spectrum reaches its principal peak. The corresponding dominant period can be calculated as:

$$T_0 = \frac{1}{f_0} \ldots\ldots (1)$$

where:
T_0 = dominant period (s)
f_0 = dominant frequency (Hz)

A relatively low dominant frequency generally indicates a relatively thick and/or soft sedimentary layer overlying a stiffer material, whereas a higher dominant frequency may indicate shallower or stiffer subsurface conditions. However, the relationship is not unique and should be constrained using geological and geotechnical information (Molnar et al., 2018; SESAME, 2004).

Vs30 and Soil Classification

The average shear-wave velocity in the upper 30 m, commonly expressed as Vs30, is an important parameter for seismic site classification. Castellaro and Mulargia (2009) demonstrated that constrained H/V measurements can provide Vs30 estimates that are consistent with independent geophysical methods under appropriate geological conditions.

The soil classification (Table 1) adopted in this study follows SNI 1726:2019, which uses shear-wave velocity and other geotechnical parameters for seismic site classification.

Table 1. Soil/Rock Classification Based on Vs30

Soil/Rock Classification	**Vs30 (m/s)**
Hard rock (SA)	>1,500
Rock (SB)	750–1,500
Hard soil, very dense soil, and soft rock (SC)	350–750
Medium/stiff soil (SD)	175–350
Soft soil (SE)	<175
Special soil (SF)	Requires site-specific evaluation

Soft or loose sedimentary deposits may experience stronger nonlinear response during earthquake shaking. Nevertheless, Vs30 alone is not sufficient to establish liquefaction susceptibility, because liquefaction depends on soil composition, density, saturation, groundwater level, cyclic loading, and resistance to cyclic shear stress.

Peak Ground Acceleration

Regional Peak Ground Acceleration (PGA) was evaluated using the Indonesian earthquake hazard framework developed by PuSGeN (2017). The 2017 national hazard map incorporated updated earthquake sources, seismic catalogs, active-fault information, ground-motion prediction equations, and probabilistic seismic-hazard analysis.

The hazard level corresponding to a 10% probability of exceedance in 50 years corresponds to a return period of approximately 475 years, rather than exactly 500 years. This distinction is retained here to maintain consistency with probabilistic seismic-hazard terminology.

Ground Shear Strain

Ground Shear Strain (GSS) provides an estimate of the magnitude of strain that may develop in the near surface as a consequence of seismic excitation. In HVSR-based microzonation, GSS can be used as an indicator for identifying areas where soft or thick sediments may experience relatively large deformation.

The Sepaku study by Kusuma and Sanny (2022) demonstrated the use of GSS derived from microtremor/HVSR observations for preliminary mapping of areas potentially susceptible to liquefaction and other earthquake-induced ground deformation.

However, GSS should be regarded as a screening parameter rather than a definitive liquefaction criterion. Established liquefaction assessment procedures require information about soil resistance, groundwater, earthquake magnitude and intensity, and soil characteristics. The NCEER recommendations provide established approaches based on SPT, CPT, and shear-wave velocity measurements (Youd et al., 2001).

RESEARCH RESULT

Peak Ground Acceleration

The PGA distribution indicates relatively low regional ground acceleration within the study area, with a maximum value of approximately 0.05 g, equivalent to approximately 49 cm/s^2.

Although the regional PGA is relatively low, this value should not be interpreted as indicating negligible seismic risk. Local amplification may significantly modify surface ground motion depending on sediment thickness, shear-wave velocity, impedance contrast, and site resonance. Consequently, local seismic response must be considered alongside regional PGA.

This distinction is important for IKN because infrastructure may be constructed across areas with substantially different geological and geotechnical conditions even where the regional seismic hazard is relatively uniform.

DISCUSSION

Dominant Period and Sediment Thickness

Figure 4 presents the dominant-period distribution, ranging from approximately 0.1 to 1.1 s.

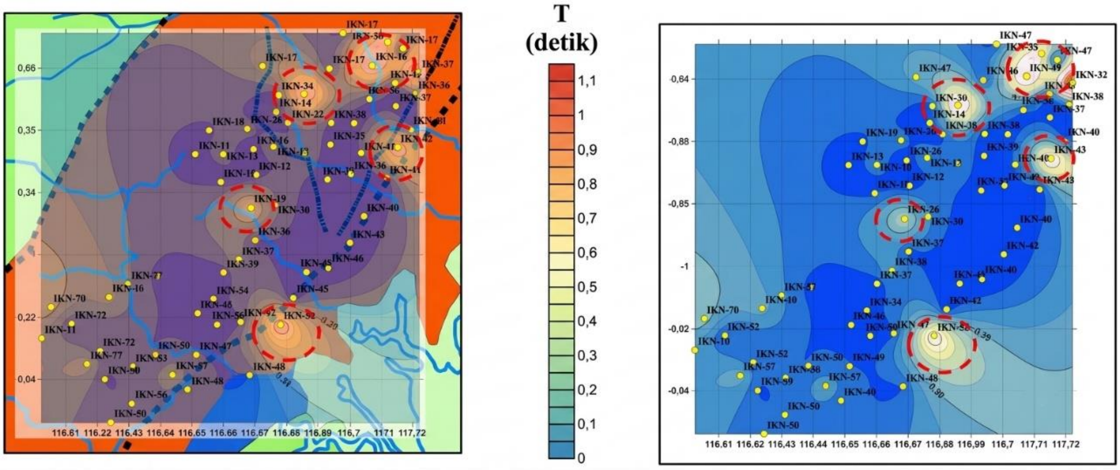

Figure 4. Dominant Period Maps

The spatial variation in dominant period indicates significant differences in the dynamic characteristics of the near-surface geological structure. Areas characterized by longer dominant periods may correspond to thicker and/or softer sedimentary sequences. This interpretation is consistent with the established relationship between site resonance, shear-wave velocity, and sediment thickness (Molnar et al., 2018; SESAME, 2004).

The relatively long dominant periods observed in portions of the study area may be associated with unconsolidated alluvial, fluvial, or deltaic deposits. The geological evolution of the Kutai Basin involved extensive fluvial and deltaic sedimentation, providing a geological basis for the presence of relatively thick unconsolidated materials in parts of East Kalimantan (Moss & Chambers, 1999).

The association of longer dominant periods with thicker sediments is particularly important for urban development. Thick soft sediments can modify the amplitude and frequency content of earthquake waves and may increase the seismic demand on structures whose natural periods overlap with the dominant period of the site.

Therefore, areas exhibiting relatively long dominant periods should receive additional attention during infrastructure planning, particularly for tall buildings, bridges, critical facilities, and other structures sensitive to long-period ground motion.

Seismic Vulnerability Index

The seismic vulnerability index derived from the HVSR results ranges from approximately 0.001 to 0.016 s^2/cm in figure 5.

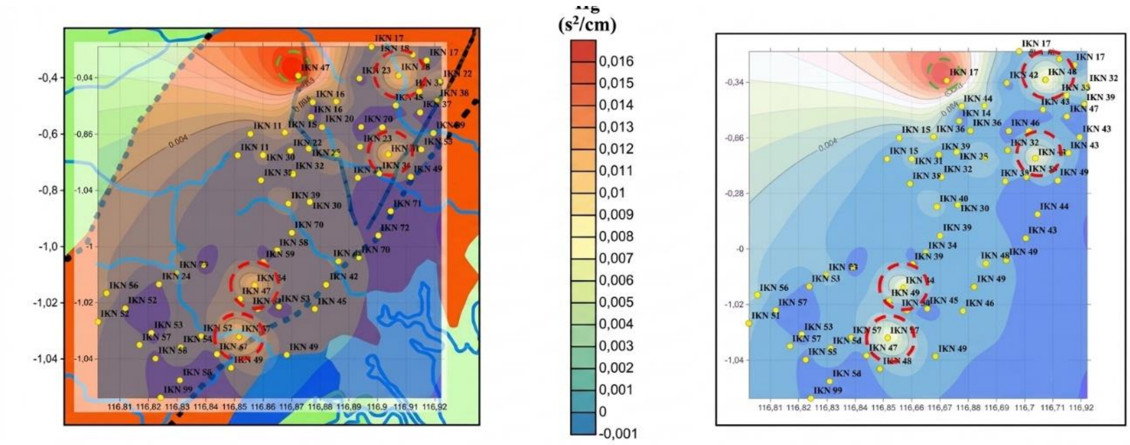

Figure 5. Seismic Vulnerability Index

Higher values occur in areas characterized by relatively low dominant frequencies. This combination suggests that these locations may contain thicker and/or softer sedimentary layers with stronger impedance contrasts relative to underlying materials.

Such areas may have greater potential for local amplification than areas underlain by relatively stiff or shallow materials. Nevertheless, the seismic vulnerability index should not be interpreted as a direct measure of expected building damage. Actual structural damage depends on earthquake characteristics, site response, structural period, foundation conditions, construction quality, and nonlinear soil behavior.

The GSS analysis identifies several areas with relatively high strain values. Four zones exhibit values approximately within the range of 0.5–0.8 in figure 6.

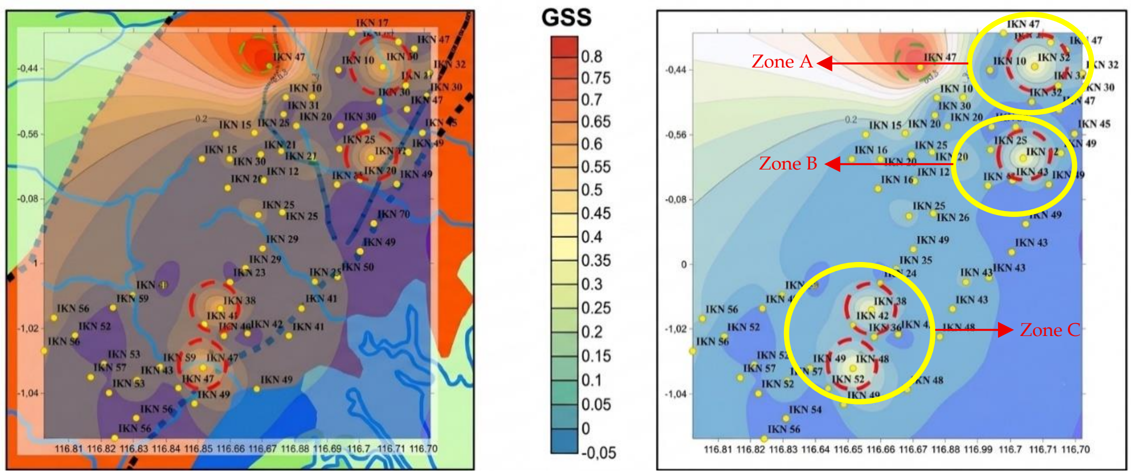

Figure 6. Ground Shear Strain with Zone Classification Maps

These areas are interpreted as potentially susceptible to earthquake-induced ground deformation, including soil compaction, slope instability, and liquefaction-related processes. The spatial association between high GSS, low dominant frequency, and soft sediment provides a reasonable basis for identifying these areas as priority zones for further investigation.

The results are broadly consistent with the previous Sepaku study by Kusuma and Sanny (2022), which used GSS derived from HVSR observations to identify areas with potential liquefaction vulnerability.

However, a critical distinction must be made between liquefaction susceptibility and confirmed liquefaction potential.
Liquefaction generally requires a combination of:
1. susceptible soil material;
2. sufficiently loose or contractive soil structure;
3. high degree of saturation;
4. appropriate groundwater conditions;
5. sufficient cyclic earthquake loading; and
6. inadequate resistance to cyclic shear stress.

Therefore, a high GSS value does not independently demonstrate that liquefaction will occur. The NCEER recommendations emphasize the importance of SPT, CPT, and Vs-based assessments for evaluating liquefaction resistance (Youd et al., 2001). Accordingly, the four zones identified in this study should be classified as potentially susceptible zones, rather than confirmed liquefaction zones.

Groundwater and Liquefaction Susceptibility

Groundwater is a critical factor in liquefaction assessment because liquefaction requires saturated or near-saturated soil conditions. A shallow groundwater table can increase susceptibility where loose, contractive soils are present.

However, groundwater depth alone cannot determine whether liquefaction will occur. Two sites with similar groundwater levels may have substantially different liquefaction resistance because of differences in soil density, grain size, fines content, stress history, and soil fabric.

Consequently, areas with shallow groundwater and high GSS should be prioritized for detailed geotechnical investigation.
For IKN, this is particularly important in alluvial and fluvial environments associated with river systems. The combination of unconsolidated sediment, shallow groundwater, and potentially low Vs should be considered when evaluating the suitability of sites for critical infrastructure.

Landslide Susceptibility and Seasonal Hydrological Effects

The study also identifies potential relationships between microseismic characteristics and slope instability. Areas with thick, weak, or highly weathered materials may become increasingly unstable when subjected to rainfall infiltration and increased pore-water pressure.

During prolonged dry periods, vegetation loss and peatland fires may alter near-surface conditions. During subsequent periods of intense rainfall, infiltration may increase pore-water pressure and reduce effective stress, potentially contributing to slope failure in susceptible terrain.

Nevertheless, the relationship between seasonal burning, rainfall, and landsliding cannot be established from HVSR or GSS measurements alone. A robust landslide assessment should incorporate:

1. slope angle;
2. lithology;
3. geological structures;
4. soil thickness;
5. rainfall intensity and duration;
6. groundwater level;
7. pore-water pressure;
8. drainage conditions;
9. shear strength; and
10. historical landslide distribution.

Therefore, the present microtremor results should be regarded as a screening layer for identifying areas requiring integrated slope-stability assessment.

Implications for IKN Urban Planning

The findings have direct implications for seismic-resilient development of IKN. The results suggest that the study area cannot be considered homogeneous from a seismic site-response perspective. Variations in dominant period, seismic vulnerability index, Vs30, GSS, sediment thickness, and groundwater conditions indicate that different parts of the development area may respond differently during earthquake excitation. A practical planning framework can therefore be established using three levels:

a) Zone I – Relatively favorable ground conditions

Areas characterized by relatively high dominant frequency, shorter dominant period, higher Vs30, and low GSS may be considered relatively favorable for development, subject to conventional geotechnical investigation.

b) Zone II – Intermediate conditions

Areas characterized by intermediate dominant periods, moderate seismic vulnerability indices, and moderate GSS should undergo additional geotechnical investigation before construction of major infrastructure.

c) Zone III – Priority investigation zones

Areas characterized by long dominant periods, low dominant frequencies, relatively high seismic vulnerability indices, shallow groundwater, and high GSS should be classified as priority zones for detailed geotechnical investigation.

For Zone III, recommended investigations include:

1. borehole drilling;
2. SPT;
3. CPT/CPTu;
4. MASW or other Vs profiling;
5. groundwater monitoring;
6. laboratory grain-size analysis;
7. Atterberg limits;
8. density and saturation assessment;

9. cyclic resistance evaluation; and
10. site-specific seismic-response analysis.

This integrated approach is more defensible than relying solely on HVSR or GSS for land-use decisions.

Limitations of the Study

Several limitations should be recognized. First, HVSR provides information about the dynamic response of the near-surface system but does not uniquely determine the complete subsurface model. Interpretation can be affected by lateral heterogeneity, 2D/3D geological structures, and the composition of the ambient wavefield (Molnar et al., 2018).

Second, Vs30 estimates derived indirectly from HVSR should preferably be constrained using independent geophysical or geotechnical measurements. Castellaro and Mulargia (2009) demonstrated that constrained H/V can provide useful Vs30 estimates, but they also emphasized that the method is not intended to reproduce highly detailed Vs profiles.

Third, GSS provides an effective screening parameter for identifying potentially vulnerable zones but should not be considered a substitute for established liquefaction analyses.

Fourth, the PGA value represents regional hazard conditions and does not fully represent local surface ground motion. Site-specific response analysis is therefore recommended for critical infrastructure.

Finally, the relationship between microtremor characteristics and landslide occurrence requires additional geological, hydrological, and geotechnical evidence.

CONCLUSIONS AND RECOMMENDATIONS

The seismic site characterization of the Sepaku area provides important information for earthquake-resilient planning of Indonesia's new capital city. The study demonstrates that:

1. The IKN area is situated within a complex geological environment associated with the Cenozoic Kutai Basin, where sedimentary architecture, alluvial deposits, and regional tectonic structures contribute to spatial variations in subsurface conditions.
2. The HVSR method provides an effective reconnaissance tool for identifying spatial variations in dominant frequency and dominant period. Its application is particularly valuable for seismic microzonation when integrated with geological and geotechnical information.
3. The observed dominant periods range from approximately **0.1 to 1.1 s**, indicating significant variation in near-surface dynamic characteristics.
4. Areas with longer dominant periods and lower dominant frequencies are interpreted as potentially containing thicker and/or softer sedimentary deposits and therefore require greater attention in seismic site-response assessment.

5. The seismic vulnerability index ranges from approximately **0.001 to 0.016 s^2/cm**, with relatively higher values concentrated in areas characterized by low dominant frequencies.
6. The regional PGA is relatively low, with a maximum value of approximately **0.05 g**. Nevertheless, low regional PGA does not eliminate the possibility of significant local site amplification.
7. Four areas exhibit relatively high GSS values of approximately **0.5–0.8**. These areas should be regarded as **potentially susceptible zones for earthquake-induced ground deformation**, including soil compaction, slope instability, and liquefaction.
8. High GSS should not be interpreted as confirmation of liquefaction. Liquefaction susceptibility requires additional information concerning soil density, grain-size distribution, groundwater conditions, and cyclic resistance.
9. Shallow groundwater can increase liquefaction susceptibility when loose, saturated, contractive soils are present. Therefore, groundwater monitoring should be incorporated into future investigations.
10. The combination of HVSR, GSS, Vs30, geological mapping, groundwater information, and geotechnical testing provides a more robust basis for seismic microzonation than any individual parameter.
11. For critical infrastructure in IKN, the four identified high-GSS zones should receive priority for CPT/CPTu, SPT, borehole, Vs profiling, groundwater monitoring, and site-specific seismic-response analysis.

ADVANCED RESEARCH

This study has some limitations because the HVSR and Ground Shear Strain (GSS) methods provide preliminary information about seismic site conditions. The GSS values indicate areas that may be susceptible to liquefaction, soil compaction, and landslides, but they cannot confirm that these hazards will occur. Therefore, further research should combine HVSR and GSS with CPT, SPT, MASW, Vs30, groundwater measurements, and laboratory soil testing to obtain more reliable results. Future studies should also consider site-specific seismic response and seasonal groundwater changes to improve the seismic microzonation and support safer infrastructure development in IKN.

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REFERENCES

Castellaro, S., & Mulargia, F. (2009). Vs30 estimates using constrained H/V measurements. Bulletin of the Seismological Society of America, 99(2A), 761–773. https://doi.org/10.1785/0120080179

Herak, M. (2008). ModelHVSR—A Matlab® tool to model horizontal-to-vertical spectral ratio of ambient noise. Computers & Geosciences, 34(11), 1514–1526. https://doi.org/10.1016/j.cageo.2007.07.009

Hidayat, S., & Umar, I. (1994). Peta geologi lembar Balikpapan, Kalimantan [Geological map of the Balikpapan quadrangle, Kalimantan]. Pusat Penelitian dan Pengembangan Geologi.

Kusuma, W. H., & Sanny, T. A. (2022). Analysis of Ground Shear Strain (GSS) in mapping liquefaction vulnerability potential using HVSR (Horizontal to Vertical Spectral Ratio) method: Case study Sepaku Subdistrict, North Penajam Paser Regency, East Kalimantan. *IOP Conference Series: Earth and Environmental Science, 1031*, 012027. https://doi.org/10.1088/1755-1315/1031/1/012027

Molnar, S., Cassidy, J. F., Castellaro, S., Cornou, C., Crow, H., Hunter, J. A., Matsushima, S., Sánchez-Sesma, F. J., & Yong, A. (2018). Application of microtremor horizontal-to-vertical spectral ratio (MHVSR) analysis for site characterization: State of the art. Surveys in Geophysics, 39(4), 613–631. https://doi.org/10.1007/s10712-018-9464-4

Moss, S. J., & Chambers, J. L. C. (1999). Tertiary facies architecture in the Kutai Basin, Kalimantan, Indonesia. Journal of Asian Earth Sciences, 17(1–2), 157–181. https://doi.org/10.1016/S0743-9547(98)00035-X

Nakamura, Y. (2000). Clear identification of fundamental idea of Nakamura's technique and its applications. Proceedings of the 12th World Conference on Earthquake Engineering, Paper 2656.

Pusat Studi Gempa Nasional. (2017). Peta sumber dan bahaya gempa Indonesia tahun 2017. Pusat Penelitian dan Pengembangan Perumahan dan Permukiman, Kementerian Pekerjaan Umum dan Perumahan Rakyat.

SESAME. (2004). Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: Measurements, processing and interpretation. European Commission, SESAME European Research Project.

Wain, T., & Berod, B. (1989). The tectonic framework and paleogeographic evolution of the Upper Kutei Basin. Proceedings of the Indonesian Petroleum Association, 18th Annual Convention.

Youd, T. L., Idriss, I. M., Andrus, R. D., Arango, I., Castro, G., Christian, J. T., Dobry, R., Finn, W. D. L., Harder, L. F., Jr., Hynes, M. E., Ishihara, K., Koester, J. P., Liao, S. S. C., Marcuson, W. F., III, Martin, G. R., Mitchell, J. K., Moriwaki, Y., Power, M. S., Robertson, P. K., Seed, R. B., & Stokoe, K. H., II. (2001). Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils. Journal of Geotechnical and Geoenvironmental Engineering, 127(10), 817–833. https://doi.org/10.1061/(ASCE)1090-0241(2001)127:10(817)