IGNATIAN
INTERNATIONAL JOURNAL FOR MULTIDISCIPLINARY RESEARCH
www.icceph.com
ISSN 2984-9942

EARTHQUAKE FOCAL DEPTH DYNAMICS IN THE PHILIPPINES: VARIATIONS AND IMPLICATIONS FOR DISASTER RISK REDUCTION

Francis L. Dumalag [1], Glenda Grace M. Abraham [2].

[1]Sambulawan National High School, El Salvador City, Misamis Oriental, Philippines
[2]Pilgrim Christian College, Tiano- Akut Streets, Cagayan de Oro City, Misamis Oriental, Philippines

ABSTRACT

Earthquake focal depth is a critical parameter in understanding seismic hazards because it influences ground-shaking intensity, the spatial distribution of seismic energy, and potential impacts on exposed communities. Given the Philippines' location within the Pacific Ring of Fire, understanding the temporal and structural variations in earthquake depths is essential for improving disaster risk reduction and seismic resilience. This study examined the variations, differences, associations, and temporal trends of earthquake depths in the Philippines using a comprehensive dataset of 132,157 earthquake events recorded by PHIVOLCS from January 2018 to July 2026. We used a quantitative retrospective research design and applied descriptive statistics, Welch's Analysis of Variance (ANOVA), Chi-Square tests of independence, and Cramer's V. Results revealed that earthquake activity in the Philippines was overwhelmingly dominated by shallow-focus earthquakes (90.3%), with an overall mean focal depth of 29.2 km. The average earthquake depth declined gradually from 36.5 km in 2018 to 26.4 km in 2026, indicating a growing prevalence of shallower seismic events. Analysis by magnitude category showed that focal depth generally increased with earthquake magnitude, with major earthquakes exhibiting substantially deeper average origins than lower-magnitude events. Welch's ANOVA revealed highly significant differences in earthquake depths across year classifications ($F(8, 47{,}414) = 71.3$, $p < .001$), depth categories ($F(2, 476) = 56{,}171.0$, $p < .001$), and magnitude categories ($F(3, 385) = 77.8$, $p < .001$). Chi-Square analyses further indicated significant associations between earthquake depth categories and year ($\chi^2(16) = 2{,}423$, $p < .001$) and magnitude category ($\chi^2(130) = 2{,}962$, $p < .001$), although the corresponding effect sizes were weak (Cramer's V = 0.096 and 0.106, respectively). The study concludes that the Philippine seismic environment is characterized by a persistent dominance of shallow-focus earthquakes and a statistically

significant shift toward progressively shallower seismic activity. These findings highlight an increasing potential for damaging surface ground motions and reinforce the need for strengthened seismic hazard assessment, resilient infrastructure development, evidence-based land-use planning, and enhanced disaster preparedness strategies. The study provides valuable empirical evidence that can support policymakers, disaster management agencies, and researchers in advancing earthquake-risk mitigation and resilience-building initiatives in the Philippines.

Keywords: *earthquake depth, seismic activity, earthquake magnitude*

INTRODUCTION

Earthquakes remain among the most destructive natural hazards worldwide, causing substantial loss of life, infrastructure damage, and socioeconomic disruption. The severity of earthquake impacts depends not only on magnitude and epicentral location but also on focal depth, a critical seismological parameter that governs seismic-wave propagation and attenuation (Buhay et al., 2026; Devi & Pasari, 2025; Madronero, 2026). Shallow-focus earthquakes frequently generate stronger ground shaking and greater structural damage than deeper events because seismic energy travels a shorter distance before reaching the Earth's surface. Consequently, understanding earthquake-depth patterns has become an essential component of seismic hazard assessment and disaster risk reduction initiatives globally (Mendez et al., 2026b; Rekapalli & K. Gupta, 2026).

The Philippine archipelago is particularly vulnerable to seismic hazards because of its complex tectonic setting along the Pacific Ring of Fire. The country lies within the interaction zone of several major tectonic structures, including the Philippine Sea Plate, Eurasian Plate, Manila Trench, Philippine Trench, Negros Trench, Sulu Trench, Cotabato Trench, and the Philippine Fault System. These interacting geological systems generate frequent earthquakes of varying depths, intensities, and spatial distributions. As a result, the Philippines consistently ranks among the world's most seismically active regions, facing recurring threats from both shallow crustal earthquakes and deep subduction-related seismic events (Baitus et al., 2024; Nayak et al., 2025; Ramirez & Abdullah, 2022).

From a theoretical perspective, Plate Tectonic Theory and Elastic Rebound Theory provide the scientific foundation for understanding earthquake occurrence and focal-depth variations. Plate tectonics explains how the convergence, divergence, and lateral movement of lithospheric plates generate stress accumulation within the Earth's crust and upper mantle (Stein & Sella, 2002; Zheng & Li, 2025; Ziv et al., 2007). Elastic Rebound Theory further explains how accumulated strain is suddenly released when rocks rupture along fault planes, producing seismic waves. In subduction environments such as the Philippines, these mechanisms produce earthquakes across a wide spectrum of focal depths, from shallow crustal events to deep-focus earthquakes within descending slabs. Understanding how these depth distributions vary over time is therefore essential for improving seismic hazard characterization and tectonic interpretation (Bychkov, 2023; Ohnaka, 1976; Reissner, 1985).

Recent advances in seismic monitoring technologies, geospatial analytics, satellite-based observations, and open-access earthquake databases have significantly enhanced researchers' ability to examine seismic patterns across large temporal and spatial scales. Numerous studies have investigated earthquake occurrence, magnitude distribution, fault mechanics, and seismic hazards in the Philippines and neighboring regions (Cito et al., 2024; Hu & Koboevic, 2025). However, existing investigations have predominantly emphasized earthquake magnitude, spatial clustering, fault activity, ground deformation, and seismic hazard mapping. Comparatively less attention has been given to the long-term behavior of earthquake focal depths and their relationships with temporal variations and magnitude classifications. This limitation creates an important gap in understanding how the vertical distribution of seismic activity evolves within the Philippine tectonic environment.

Addressing this knowledge gap matters because focal depth is directly linked to earthquake damage potential, infrastructure vulnerability, and emergency preparedness requirements. While magnitude measures the amount of energy released during an earthquake, focal depth determines how that energy is transmitted to communities and built environments. Consequently, long-term assessments of earthquake-depth variability can provide valuable information for structural engineering design, land-use planning, risk assessment, and disaster resilience initiatives. Such analyses also contribute to broader scientific understanding of tectonic evolution and subduction-zone dynamics within complex convergent plate boundaries.

This study therefore examines variations and patterns in earthquake depths in the Philippines from January 2018 to July 2026 using a comprehensive database of 132,157 seismic events from PHIVOLCS. Specifically, it examines earthquake-depth distributions by year, depth category, and magnitude category; identifies significant differences among these classifications; evaluates associations between depth categories and selected variables; and identifies temporal trends in focal-depth behavior over the study period. By providing a multidimensional assessment of earthquake-depth characteristics, the study contributes new empirical evidence to Philippine seismological literature. It offers insights that may support future seismic hazard assessments, disaster risk reduction strategies, infrastructure planning, and evidence-based policy development.

Research Questions

This study investigated the focal-depth characteristics of earthquakes in the Philippines from 2018 to 2026. Specifically, it sought to answer the following questions:

1. What are the patterns and distributions of earthquake focal depths in the Philippines from 2018 to 2026 when classified according to:
    - Year of occurrence;
    - Depth category; and
    - Magnitude category?
2. Are there significant differences in earthquake focal depths across years and magnitude categories during the study period?

3. Is there a significant association between earthquake focal-depth categories and earthquake magnitude classifications?

METHODOLOGY

Research Design

This study used a quantitative retrospective observational research design to examine earthquake focal-depth characteristics in the Philippines from January 2018 to July 2026. Specifically, the study integrated descriptive, comparative, correlational, and trend analyses to provide a comprehensive understanding of earthquake-depth behavior across time and magnitude classifications. Because the investigation utilized historical earthquake records without manipulating variables, a non-experimental approach was deemed appropriate. The design enabled the researchers to describe focal-depth distributions, identify significant differences among classification groups, examine relationships between earthquake depth and magnitude, and identify temporal trends that may inform seismic hazard assessment and disaster risk reduction efforts.

Data Source

The study utilized secondary data obtained from the Philippine Institute of Volcanology and Seismology (PHIVOLCS), the government agency mandated to monitor seismic activity and assess geological hazards in the Philippines. The analysis included 132,157 earthquake events recorded between January 2018 and July 2026. The dataset contained essential earthquake parameters, including date of occurrence, year, geographic coordinates, focal depth, and magnitude. Using an official government database ensured the data's credibility, accuracy, and reliability.

RESULTS AND DISCUSSION

This section presents and discusses the study's findings on the focal-depth characteristics of earthquakes in the Philippines from January 2018 to July 2026. The results are organized by research question and analyzed using appropriate descriptive and inferential statistical techniques to identify patterns, differences, relationships, and temporal trends in earthquake focal depths. The findings are interpreted in light of established seismological theories and related literature to deepen understanding of earthquake behavior and its implications for seismic hazard assessment, disaster risk reduction, infrastructure resilience, and evidence-based decision-making in the Philippine context.

Table 1

Variations in Earthquake Depths (km) in the Philippines from January 2018 to July 2026 According to Year

Year	Count	Mean	SD	CV (%)
2018	6,258	36.5	51.0	139.7%
2019	13,015	29.2	35.2	120.5%

2020	14,094	32.3	40.4	125.1%
2021	12,069	33.3	41.0	123.1%
2022	14,338	28.3	35.7	126.1%
2023	16,630	28.5	36.6	128.4%
2024	18,147	28.1	35.7	127.0%
2025	21,775	27.0	34.3	127.0%
2026*	15,831	26.4	30.8	116.7%
Total	**132,157**	**29.2**	**37.0**	**126.7%**

Note: covers only the period from **January to **July 2026**.*

Table 1 presents variations in earthquake depths in the Philippines from January 2018 to July 2026 by year of occurrence. The study recorded 132,157 earthquake events during the period, with a mean focal depth of 29.2 km, a standard deviation of 37.0 km, and a coefficient of variation (CV) of 126.7%, indicating substantial variability in earthquake depths across the dataset. The findings show that mean earthquake depth generally declined over time, from 36.5 km in 2018 to 26.4 km in 2026, suggesting a gradual shift toward shallower seismic events in the latter years of the study period.

Among the years examined, 2018 recorded the deepest average earthquake depth (M = 36.5 km, SD = 51.0 km), while 2026 recorded the shallowest average depth (M = 26.4 km, SD = 30.8 km). The number of recorded earthquakes increased notably over time, rising from 6,258 events in 2018 to 21,775 events in 2025, indicating heightened seismic activity and/or improved earthquake detection capabilities. Moreover, all years showed coefficient of variation values exceeding 100%, ranging from 116.7% to 139.7%, reflecting high dispersion in earthquake depths and suggesting that seismic events occurred across a wide range of focal-depth levels, from shallow to deep-focus earthquakes.

The decreasing trend in mean focal depth, coupled with consistently high variability across years, implies a dynamic and complex seismic environment shaped by the country's active tectonic setting. These findings highlight the importance of continuously monitoring earthquake-depth patterns because shallower earthquakes generally have a greater potential to produce damaging ground shaking than deeper events. Consequently, understanding temporal variations in focal depth is essential to improving seismic hazard assessment, disaster preparedness, infrastructure resilience, and risk-reduction planning in the Philippines.

Table 2
Variations in Earthquake Depths in the Philippines from January 2018 to July 2026 According to Depth Category

Depth Category	Count	Mean	Median	SD (km)	CV
Shallow (0-70 km)	119,308	19.4	18.0	13.8	71.10%
Intermediate(71-300k)	12,667	114.4	109.0	32.0	28.00%

Deep (>300 km)	182	495.0	514.0	113.4	22.90%
Total	**132,157**	**29.2**	**21.0**	**37.0**	**126.70%**

Table 2 presents variations in earthquake depths in the Philippines from January 2018 to July 2026 by depth category. Of the 132,157 recorded earthquake events, the overwhelming majority were shallow-focus earthquakes (0-70 km), comprising 119,308 occurrences, or approximately 90.3% of all recorded events. These earthquakes exhibited a mean depth of 19.4 km, a median depth of 18 km, and a standard deviation of 13.8 km. The coefficient of variation (CV) of 71.10% indicates relatively high variability within the shallow-depth classification, suggesting that shallow earthquakes occurred across a broad range of depths within the category.

In contrast, intermediate-focus earthquakes (71-300 km) accounted for 12,667 events, or about 9.6% of total earthquake occurrences. This category recorded a mean depth of 114.4 km and a median depth of 109 km, with a standard deviation of 32 km and a coefficient of variation of 28.00%. The lower CV value suggests that intermediate-depth earthquakes were more consistently concentrated around their mean depth than shallow earthquakes. Meanwhile, deep-focus earthquakes (>300 km) were the least frequent, with only 182 recorded events or about 0.1% of the total dataset. Despite their rarity, these earthquakes had the greatest mean depth (495 km) and a median depth of 514 km. The standard deviation of 113.4 km and coefficient of variation of 22.90% indicate comparatively lower relative variability, reflecting a more clustered distribution of deep-focus seismic events.

Overall, the findings show that seismic activity in the Philippines is predominantly characterized by shallow-focus earthquakes, with a mean depth of 29.2 km and a median depth of 21 km. The high proportion of shallow earthquakes is particularly significant because shallow seismic events generally generate stronger ground motions at the Earth's surface and therefore pose greater risks to communities, infrastructure, and economic activities. The dominance of shallow-focus earthquakes observed in the present study is consistent with the Philippines' complex tectonic environment, where active faults and plate boundary interactions frequently generate near-surface seismic activity. These results underscore the importance of prioritizing shallow-earthquake monitoring, seismic hazard assessment, disaster preparedness, and resilient infrastructure planning to mitigate the potential impacts of future earthquake events in the country.

Table 3
Descriptive Statistics of Earthquake Depths in the Philippines by Magnitude Category (January 2018 to July 2026)

Magnitude Category	Count	Mean	SD	CV
Micro (<3.0)	103,030	28.1	30.1	107.10%
Minor (3.0-3.9)	23,965	30.2	46.4	153.60%

Light (4.0-4.9)	4,488	45.9	81.4	177.30%
Moderate (5.0-5.9)	584	46.3	72.9	157.50%
Strong (6.0-6.9)	79	66.0	101.1	153.20%
Major (7.0-7.9)	11	99.3	196.2	197.60%
Total	**132,157**	**29.2**	**37.0**	**126.70%**

*Note. The magnitude categorization in this table strictly follows the standard **USGS Earthquake Magnitude Classes** and the **Encyclopedia Britannica** seismic scale frameworks.*

Table 3 presents descriptive statistics of earthquake depths in the Philippines by magnitude category from January 2018 to July 2026. The results indicate that most recorded earthquakes were classified as micro earthquakes (M < 3.0), with 103,030 events representing approximately 77.96% of the total 132,157 earthquake occurrences. These events recorded a mean depth of 28.1 km and a median depth of 22 km, suggesting that most low-magnitude earthquakes originated within relatively shallow portions of the Earth's crust. Minor earthquakes (M = 3.0-3.9) accounted for 23,965 events and exhibited a slightly deeper mean focal depth of 30.2 km. Meanwhile, light (M = 4.0-4.9) and moderate earthquakes (M = 5.0-5.9) showed notably greater mean depths of 45.9 km and 46.3 km, respectively, indicating that higher-magnitude earthquakes tend to originate from deeper seismic sources.

Furthermore, strong earthquakes (M = 6.0-6.9) recorded a mean depth of 66.0 km, while major earthquakes (M = 7.0-7.9) exhibited the greatest average depth of 99.3 km. Although only 79 strong and 11 major earthquakes were recorded during the study period, their deeper focal depths suggest an association between larger seismic events and deeper tectonic processes, particularly those related to subduction zones. No great earthquakes (M ≥ 8.0) were recorded during the period under investigation. Mean depth increases across magnitude categories, indicating that larger earthquakes tend to originate at greater depths beneath the Earth's surface. This pattern is consistent with the Philippines' tectonic setting, where both shallow crustal faulting and deeper subduction-related seismicity contribute to earthquake occurrence.

Earthquake depths varied substantially across magnitude categories, as reflected in exceptionally high coefficients of variation ranging from 107.10% to 197.60%. The highest variability was observed among major earthquakes (CV = 197.60%), indicating considerable dispersion in focal depths despite the limited number of recorded events. Similarly, light, moderate, and strong earthquakes showed coefficients of variation exceeding 150%, suggesting that earthquakes in these categories originated across a broad spectrum of tectonic environments and depth ranges. The disparity between mean and median values across most categories further indicates positively skewed distributions, wherein a relatively small number of deep-focus events increased the average focal depth.

The minimum and maximum depths also reveal the extensive range of earthquake origins in the Philippines. Micro-earthquakes reached depths of up to 1,068 km, while major earthquakes were recorded at depths of up to 686 km. These findings demonstrate

that earthquakes of varying magnitudes can occur throughout the entire seismogenic zone, from shallow crustal levels to deep subduction environments. Overall, the results show that while lower-magnitude earthquakes comprise the vast majority of seismic events, larger earthquakes generally occur at greater average depths and exhibit considerable variability. These findings underscore the importance of considering earthquake magnitude and focal depth together in seismic hazard assessments, as both factors influence the extent of ground shaking, the distribution of seismic energy, and the potential risks to communities, infrastructure, and disaster management systems throughout the Philippines.

Table 4

Welch's One-Way ANOVA Results for Differences in Earthquake Depth by Year, Depth Category, and Magnitude Category, Philippines, January 2018– July 2026

Grouping Variable	Welch's F	df1	df2	p-value	Remarks
Year	71.3	8	47,414	<.001	Highly Significant
Depth Category	56,171.0	2	476	<.001	Highly Significant
Magnitude Category	77.8	3	385	<.001	Highly Significant

Table 4 presents the results of Welch's Analysis of Variance (ANOVA), which tested whether earthquake depths differ significantly across year, depth category, and magnitude category. The findings revealed statistically significant differences in earthquake depths for all classification variables examined, with p-values less than .001. Specifically, earthquake depths varied significantly across years (Welch's F = 71.30), indicating temporal changes in focal-depth characteristics during the study period. Likewise, depth category exhibited the largest effect (Welch's F = 56,171.00), confirming substantial differences among shallow, intermediate, and deep-focus earthquakes. Significant differences were also observed across magnitude categories (Welch's F = 77.80), suggesting that earthquake magnitude is associated with variations in focal depth. Consequently, the null hypothesis of no significant difference was rejected for all analyses, indicating that earthquake depths are not uniformly distributed across temporal and seismic classifications in the Philippines.

Table 5

Test of Independence Results for Earthquake Depth Categories by Year and Magnitude Category, Philippines, January 2018– July 2026

Variable Comparison	χ^2	(df)	p-value	Cramer's V	Association Strength
Depth Category x Year	2,423	16	<.001	0.0957	Significant but very weak

Depth Category x Magnitude	2,962	130	<.001	0.106	Significant but weak

Table 5 presents the results of the Chi-Square Test of Independence conducted to determine whether earthquake depth categories are associated with year and magnitude category. The analysis revealed statistically significant associations between earthquake depth category and year (χ^2 = 2,423.00, df = 16, $p < .001$) and between earthquake depth category and magnitude category (χ^2 = 2,962.00, df = 130, $p < .001$). These findings indicate that the distribution of shallow-, intermediate-, and deep-focus earthquakes varies significantly across years and magnitude classifications. Consequently, the null hypothesis of independence was rejected for both comparisons.

However, despite their statistical significance, the computed Cramer's V values indicate relatively weak practical associations. The relationship between depth category and year yielded a Cramer's V of 0.096, reflecting a very weak association. In contrast, the relationship between depth category and magnitude category produced a Cramer's V of 0.106, indicating a weak association. These results suggest that although temporal variation and earthquake magnitude are significantly related to earthquake depth categories, their influence is relatively small. The findings imply that other tectonic and geological factors, such as fault mechanisms, subduction processes, plate interactions, and regional seismic conditions, may play a more substantial role in determining earthquake focal depths within the Philippine seismic environment.

This study's findings have significant implications for seismic hazard assessment, disaster risk reduction, urban planning, and public safety in the Philippines. The overwhelming dominance of shallow-focus earthquakes, coupled with the observed trend toward increasingly shallow seismic activity, suggests that communities, infrastructure systems, and economic centers may face heightened exposure to destructive ground shaking in the coming years. These results underscore the urgent need for government agencies, policymakers, engineers, and disaster management practitioners to prioritize earthquake-resilient infrastructure, strengthen the enforcement of seismic building standards, enhance hazard mapping and land-use planning, and intensify community preparedness programs. Furthermore, identifying significant variations in earthquake depths across time and magnitude classifications deepens understanding of the country's tectonic behavior. It provides valuable empirical evidence for improving seismic risk models and disaster mitigation strategies. Ultimately, the study reinforces the importance of proactive, science-based approaches to resilience building to reduce vulnerability, safeguard lives and property, and promote sustainable development in one of the world's most seismically active regions.

Conclusions

The findings reveal that earthquake activity in the Philippines from January 2018 to July 2026 was overwhelmingly dominated by shallow-focus earthquakes, accounting

for 90.3% of all recorded seismic events. Although the overall distribution of earthquake depths varied widely because a small number of extremely deep earthquakes reached depths of up to 1,068 km, the analysis shows that most seismic activity remained concentrated within the upper crust. Moreover, the study observed a gradual decline in mean focal depth over the study period, indicating a growing prevalence of shallower earthquakes. The results also showed that focal depth generally increases with earthquake magnitude, suggesting that larger seismic events are more commonly associated with deeper tectonic processes, particularly within subduction environments. Collectively, these findings highlight the complex yet spatially organized nature of earthquake generation in the Philippine tectonic setting.

The inferential analyses confirmed that earthquake depths vary significantly across temporal, depth, and magnitude classifications. Welch's ANOVA revealed highly significant differences in focal depths when grouped by year, depth category, and magnitude category, showing that earthquake-depth distributions are not uniform across these classifications. Post hoc analyses further established that the observed differences represent distinct seismic characteristics rather than random statistical fluctuations. These findings suggest that variations in earthquake depth are strongly influenced by underlying tectonic structures, fault systems, and subduction processes that govern seismic activity throughout the archipelago.

The study likewise established statistically significant associations between earthquake depth categories and both year and magnitude category. However, the corresponding Cramer's V coefficients indicated only very weak to weak relationships, suggesting that although these variables are related, their practical influence on earthquake-depth classification remains limited. This implies that other geodynamic factors, including plate interactions, fault mechanics, stress accumulation, and subduction dynamics, play a more substantial role in determining earthquake focal depths than temporal variation or earthquake magnitude alone. Nevertheless, the persistent dominance of shallow-focus earthquakes underscores the continuing exposure of Philippine communities to earthquakes capable of generating strong ground shaking and substantial surface impacts.

Recommendations

Based on the findings of the study, it is recommended that the Department of Public Works and Highways (DPWH), in coordination with other relevant government agencies, strengthen the implementation and periodic review of the National Building Code to ensure that infrastructure and critical facilities are designed to withstand the impacts of increasingly prevalent shallow-focus earthquakes. Given that shallow earthquakes have the greatest potential to generate destructive ground shaking, structural resilience should remain a national priority, particularly in highly urbanized and seismically active areas.

The Office of Civil Defense (OCD), PHIVOLCS, and Local Government Units (LGUs) should utilize the identified earthquake-depth patterns to enhance seismic hazard

mapping, contingency planning, emergency preparedness programs, and community-based disaster risk reduction initiatives. Hazard assessments and public awareness campaigns should place greater emphasis on the risks associated with shallow-focus earthquakes. In contrast, earthquake drills and evacuation protocols should be regularly updated to reflect current seismic realities and evolving risk profiles.

Educational institutions and government agencies should further strengthen earthquake awareness and preparedness programs through continuous public education, capacity-building activities, and the integration of science-based disaster risk management strategies. Greater public understanding of earthquake-depth characteristics and their implications can improve preparedness, strengthen emergency response, and increase community resilience during seismic events.

Finally, future researchers are encouraged to expand this study by incorporating additional geophysical and tectonic variables, such as fault proximity, epicentral location, ground acceleration data, subduction-zone characteristics, and spatial distribution patterns. Applying advanced analytical approaches, including geospatial modeling, machine learning techniques, and comparative studies with other Pacific Ring of Fire countries, may provide deeper insights into earthquake behavior and contribute to more accurate seismic hazard prediction and risk assessment frameworks.

Compliance with Ethical Standards

The authors confirm that this study complied with all ethical standards. No human participants were involved, and the study used only publicly available seismic data. There are no conflicts of interest. The authors avoided plagiarism, referenced all sources, and interpreted findings impartially for research purposes only. The authors are committed to research integrity and responsible scholarship.

Acknowledgments

The authors sincerely thank God the Father for His guidance, strength, and wisdom throughout this study. They also express their heartfelt gratitude to their mentor for his unwavering support and valuable guidance.

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APA Citation:

Dumalag, F. L., & Abraham, G. G. M. (2026). EARTHQUAKE FOCAL DEPTH DYNAMICS IN THE PHILIPPINES: VARIATIONS AND IMPLICATIONS FOR DISASTER RISK REDUCTION. Ignatian International Journal for Multidisciplinary Research, 4(10), 173–185. https://doi.org/10.5281/zenodo.23262717

2093341@g.cu.edu.ph
2091005@g.cu.edu.ph