Scientific Research Publishing

Journal of Geoscience and Environment Protection, 2026, 14(4), 337-350
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Satellite-Based Assessment of Quarry-Induced Vegetation Degradation at Kaseve Quarry, Machakos County, Kenya (2015-2024)

Charles Ngala Kithome[1]*, Julian A. Ogondo[2], Mary Mwangi[1]

[1]Department of Geology and Meteorology, School of Agriculture, Environment, Water and Natural Resources, South Eastern Kenya University, Kitui, Kenya
[2]Department of Geography and Natural Resource Management, School of Arts and Social Sciences, Maseno University, Kisumu, Kenya
Email: *charliekithome@gmail.com

How to cite this paper: Kithome, C. N., Ogondo, J. A., & Mwangi, M. (2026). Satellite-Based Assessment of Quarry-Induced Vegetation Degradation at Kaseve Quarry, Machakos County, Kenya (2015-2024). *Journal of Geoscience and Environment Protection, 14,* 337-350.
https://doi.org/10.4236/gep.2026.144018

Received: March 31, 2026
Accepted: April 25, 2026
Published: April 28, 2026

Abstract

Quarrying activities are a significant driver of vegetation degradation globally, yet quantitative assessments of their ecological impacts remain limited, particularly in Sub-Saharan Africa. This study evaluates vegetation loss at Kaseve Quarry in Machakos County, Kenya, using Normalized Difference Vegetation Index (NDVI) analysis derived from Landsat-8 and Sentinel-2 satellite imagery spanning 2015 to 2024. The research employed a descriptive and quantitative design, processing multi-temporal satellite data through Google Earth Engine to generate annual NDVI composites. Spatial analysis was conducted across distance-based zones (0 - 250 m, 250 - 500 m, 500 - 750 m, 750 - 1000 m, and >1000 m reference zone) and directional sectors around the quarry boundary. Ground-truthing validated satellite-derived indices. Results revealed a substantial 49.1% decline in NDVI values within the quarry area (from 0.55 in 2015 to 0.28 in 2024), while the reference area maintained stable values (0.55 - 0.58). Linear regression analysis demonstrated a highly significant negative trend (−0.0297 NDVI units/year, $R^2 = 0.984$, $p < 0.001$). Spatial analysis showed a clear distance-decay pattern, with the most severe impacts within 250 m of quarry operations (NDVI = 0.24) and near-baseline conditions beyond 1 km (NDVI = 0.57). Directional analysis revealed anisotropic impacts, with greatest vegetation loss in the southeast sector (56%), consistent with prevailing wind patterns. Rainfall variability showed no consistent correlation with NDVI decline, confirming quarrying activities as the primary driver of degradation. These findings provide the first spatially explicit, quantitative evidence of quarry-induced vegetation degradation at Kaseve, demonstrating the effectiveness of satellite-based NDVI monitoring for environmental assessment and supporting evidence-based regulation and rehabilitation planning in quarrying zones.

Keywords

Quarrying, Vegetation Degradation, NDVI, Remote Sensing, Landsat-8, Sentinel-2, Machakos County

1. Introduction

Quarrying activities represent a critical component of economic development globally, providing essential raw materials for construction, infrastructure, and industrial applications. However, these operations are increasingly recognized as significant drivers of environmental degradation, particularly in terms of vegetation loss, soil disturbance, and ecosystem disruption (Avkopashvili, 2004; Darwish, 2011). In Sub-Saharan Africa, where regulatory frameworks are often weak and enforcement mechanisms limited, unregulated quarrying has led to widespread ecological damage, including unrehabilitated extraction sites, unstable slopes, contaminated water sources, and substantial biodiversity loss (Darwish, 2011; Gromnicki, 2025). Kenya, and specifically Machakos County, has emerged as a quarrying hotspot where unregulated extraction activities have caused extensive vegetation degradation and associated environmental hazards. Kaseve Quarry, located in Machakos County, exemplifies these challenges. Despite visible environmental impacts and community concerns, no comprehensive scientific assessment had quantified the extent and spatial patterns of vegetation degradation at this site prior to this study. This knowledge gap has hindered evidence-based environmental management, regulatory oversight, and rehabilitation planning.

Remote sensing technologies, particularly satellite-based vegetation indices such as the Normalized Difference Vegetation Index (NDVI), offer powerful tools for quantifying and monitoring vegetation changes over time (Li et al., 2024; Nkonya, 2016). NDVI analysis has been successfully applied to assess mining and quarrying impacts globally, providing spatially explicit, temporally consistent, and cost-effective measurements of vegetation health and productivity (Nkonya, 2016). The availability of freely accessible satellite imagery from Landsat-8 and Sentinel-2 missions, combined with cloud-based processing platforms like Google Earth Engine, has democratized environmental monitoring capabilities, making rigorous scientific assessments feasible even in resource-constrained contexts.

2. Methodology

2.1. Study Area

The study area encompasses a 1 km^2 grid centered at UTM Zone 37 M, 314111.00

m E and 9831121.00 m·S, covering both active and abandoned sections of Kaseve Quarry. The spatial analysis extent was expanded to include concentric buffer zones up to 1000 m from the quarry boundary to ensure a robust comparison with undisturbed conditions. Climatically, Machakos County experiences a temperate highland tropical climate (Köppen Cwb) due to its elevation of approximately 1600 m above sea level (Kenya Meteorological Department). Average annual temperatures range between 18.9˚C - 20.5˚C, with daytime highs of 23˚C - 26˚C and cooler nights around 13˚C - 16˚C. Humidity levels fluctuate between 66% - 84%, reflecting seasonal rainfall and dry periods. Rainfall follows a bimodal pattern, with long rains occurring from March to May and short rains from October to December, averaging between 500 - 1300 mm annually (Indiatsy, 2018). The dry season, typically June to September, is marked by reduced precipitation, soil erosion, and water scarcity, while rainfall remains highly variable and unpredictable.

Geologically, the study area lies within the Eastern Mozambique Belt Segment (EMBS), part of the extensive Mozambique belt east of the Rift System. This belt stretches nearly the full length of Kenya, with the study site situated in the Central sub-area II northeast of Nairobi, bounded by towns such as Thika, Machakos, Embu, Chuka, Kitui, and Mwingi (Fritz, 2013). The surface rocks are predominantly Precambrian metamorphic formations overlain by the Yatta Plateau to the south. Historically, the region was composed of crystalline basement rocks of the Mozambique belt, which were metamorphosed, exposed, and eroded (Dodson, 1953). During the Miocene, phonolite eruptions formed the Yatta Plateau, while earlier Archaean compression led to folding, tilting, and transformation of rock successions into schists, gneisses, and granulites (Mathu, 1992).

Hydrogeologically, the area is characterized by complex basement rocks with scarce water-bearing formations. Groundwater occurs mainly in temporary aquifers and fractures, influenced by structural deformations such as the Yatta shear zone (Nyamai, 2004).

2.2. Satellite Data Processing Workflow

Satellite imagery from Landsat-8 (30 m spatial resolution) and Sentinel-2 (10 m spatial resolution) was acquired for the period 2015-2024 using Google Earth Engine (GEE). Images were selected primarily from peak vegetation periods (March-May and October-December) to minimize seasonal variability. Cloud filtering was applied using a threshold of less than 10% cloud cover. Cloud and shadow masking were implemented using the QA60 band for Sentinel-2 and the pixel band for Landsat-8 imagery. Annual NDVI composites were generated using a median reducer to minimize atmospheric noise and residual cloud contamination. To ensure consistency between datasets, Sentinel-2 imagery was resampled to 30 m resolution to match Landsat-8. Cross-sensor harmonization was performed using linear regression calibration based on overlapping acquisition dates. The Normalized Difference Vegetation Index (NDVI) was computed using the standard expression:

$$NDVI = (NIR - Red)/(NIR + Red)$$

where NIR represents near-infrared reflectance and Red represents red band reflectance. All processed outputs were standardized to a spatial resolution of 30 m and exported for subsequent spatial and statistical analysis.

2.3. Sampling Technique

For NDVI validation, sampling locations were stratified into four distance bands from the quarry boundary: 0 - 250 m (high-impact zone), 250 - 500 m (moderate impact), 500 - 750 m (low-impact transitional zone), and a reference zone located beyond 1000 m. The quarry boundary was manually digitized using high-resolution 2024 imagery from Google Earth Pro. The reference zone is consistently defined as the area beyond 1000 m from the quarry perimeter. This zone was selected for its lack of quarry disturbance and comparable topographic and geological characteristics.

The reference zone was consistently defined as areas located beyond 1000 m from the quarry boundary. This threshold was selected to minimize the influence of quarry-related disturbances while ensuring comparable environmental conditions in terms of elevation, geology, and land-use characteristics.

2.4. Ground Validation Design

Ground validation was conducted through field reconnaissance undertaken in February 2025 to verify the spatial patterns observed in satellite-derived NDVI data.

Field data collected in 2025 across 50 sampling points, distributed over five distance zones, was evaluated using a vegetation scoring rubric ranging from 1 (bare soil/high degradation) to 5 (dense/healthy canopy). A Pearson correlation analysis between the 2024 NDVI values and the 2025 field scores yielded a strong positive relationship ($r = 0.82$), underscoring the reliability of the satellite-derived vegetation indices. Although the field survey was conducted after the 2015-2024 satellite time series, the results provide a robust baseline of land-cover stability in undisturbed zones and confirm the physical drivers of change such as dust deposition and clearing identified in the remote sensing record. This alignment between field observations and satellite data strengthens confidence in the long-term interpretation of vegetation dynamics across the study area.

2.5. Spatial Analysis

The methodology involved acquiring Landsat 8 and Sentinel-2 images spanning 2015-2024, which were processed in Google Earth Engine through cloud masking, yearly composite generation, and NDVI computation. NDVI statistics were then extracted for both the quarry polygon and a designated control area to enable comparative analysis. To capture spatial variability, directional and distance-based sampling was conducted across zones of 0 - 250 m, 250 - 500 m, 500 - 750 m, and 750 - 1000 m from the quarry boundary. Finally, ground-truthing was carried out using handheld Global Positioning System units and direct vegetation scoring, ensuring that satellite-derived indices were validated against field observations for accuracy and reliability.

2.6. Statistical Analysis

NDVI data was analyzed primarily using linear regression to quantify long-term trends in vegetation cover between 2015 and 2024. This method allowed assessment of the rate and direction of vegetation change within the quarry influence zone over time. NDVI values from the quarry area were compared descriptively with those from a surrounding reference area located beyond the zone of disturbance to evaluate spatial differences attributable to quarry activities.

To evaluate differences in vegetation condition between quarry and reference areas, an Independent Samples t-test was applied:

$$t = \left(\overline{X}_1 - \overline{X}_2\right) \Big/ \sqrt{\left[\left(s_1^2/n_1\right) + \left(s_2^2/n_2\right)\right]}$$

where $\overline{X}_1$ and $\overline{X}_2$ represent mean NDVI values, s_1 and s_2 represent standard deviations, and n_1 and n_2 represent sample sizes. The test results (t = 8.42, p < 0.001) indicate a statistically significant difference between vegetation conditions in the quarry and reference zones.

Vegetation Loss (%): Defined as

$$\left(\left(\text{NDVI\_baseline} - \text{NDVI\_current}\right) / \text{NDVI\_baseline}\right) * 100,$$

where the 2015 NDVI value serves as the baseline.

Annual rainfall data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) dataset, selected for its spatial completeness and reliability in East African climate studies.

The relationship between rainfall and NDVI was evaluated using the Pearson correlation coefficient:

$$r = \left[\sum\left(\text{NDVI}_i - \overline{\text{NDVI}}\right)\left(\text{Rain}_i - \overline{\text{Rain}}\right)\right] \Big/ \sqrt{\sum\left(\text{NDVI}_i - \overline{\text{NDVI}}\right)^2 \sum\left(\text{Rain}_i - \overline{\text{Rain}}\right)^2}$$

The analysis yielded a weak and statistically non-significant relationship (r = 0.48, p > 0.05), indicating that rainfall variability does not explain the observed decline in vegetation condition.

Annual rainfall totals were used as a proxy for cumulative biomass productivity, although it is acknowledged that this approach may not fully capture intra-annual variability associated with bimodal rainfall regimes.

3. Results and Findings

3.1. Temporal NDVI Trends (2015-2024)

Table 1 presents annual NDVI values for the quarry area and the reference area, together with annual rainfall totals extracted from the CHIRPS dataset for the Kaseve study area. The rainfall series is included as a climatic control variable to evaluate whether observed vegetation changes could be attributed to rainfall variability rather than quarry disturbance.

The results indicate a clear and progressive decline in vegetation health within the quarry area over the study period. As shown in **Figure 1** and **Figure 2**, NDVI values decreased from 0.55 in 2015 to 0.28 in 2024, representing an approximate 49% reduction in vegetation vigor. In contrast, the reference area maintained relatively stable NDVI values ranging between 0.55 and 0.58 throughout the same period, indicating minimal long-term ecological disturbance.

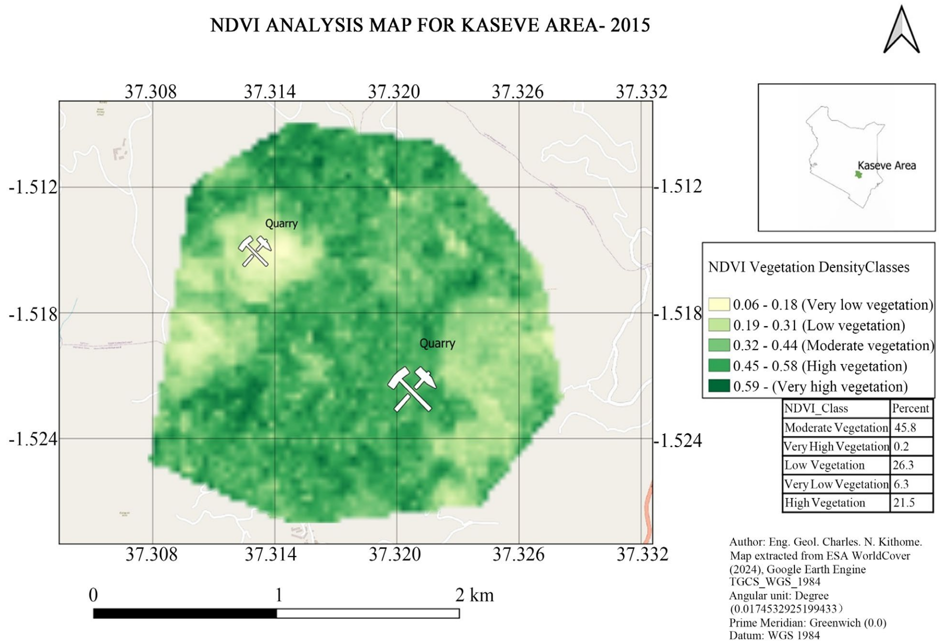

Figure 1. NDVI analysis map for kaseve area, 2015.

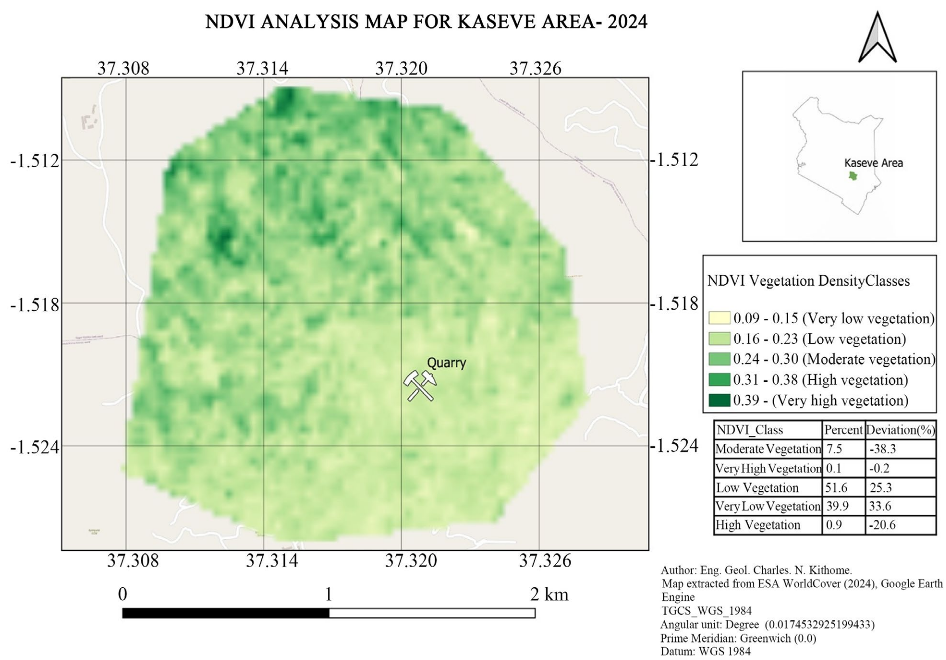

Figure 2. NDVI analysis map for kaseve area, 2024.

The difference in NDVI between the quarry and reference areas widened consistently over time, from −0.01 in 2015 to −0.29 in 2024, demonstrating increasing divergence in vegetation condition as shown in **Figure 3**. This progressive separation strongly suggests that quarry operations have had a cumulative impact on surrounding vegetation (**Table 1**).

Rainfall variability during the study period did not exhibit a consistent relationship with NDVI decline. Years with higher rainfall did not correspond to improved vegetation conditions within the quarry zone, indicating that climatic factors alone cannot explain the observed degradation. The rainfall data therefore serve primarily as contextual control variables rather than direct drivers of vegetation change. Overall, the stability of NDVI in the reference area, combined with the pronounced decline within the quarry zone, supports the interpretation that vegetation loss is primarily associated with quarry-related disturbances such as blasting, dust deposition, land clearing, and surface modification rather than natural environmental variability.

Table 1. NDVI values for quarry and control areas (2015-2024).

Year	Quarry Area NDVI	Control Area NDVI	Difference	Annual Rainfall (mm)
2015	0.55	0.56	−0.01	945
2016	0.52	0.57	−0.05	1020
2017	0.48	0.55	−0.07	780
2018	0.44	0.58	−0.14	890
2019	0.41	0.56	−0.15	720
2020	0.38	0.57	−0.19	850
2021	0.35	0.58	−0.23	920
2022	0.32	0.57	−0.25	880
2023	0.29	0.56	−0.27	810
2024	0.28	0.57	−0.29	900

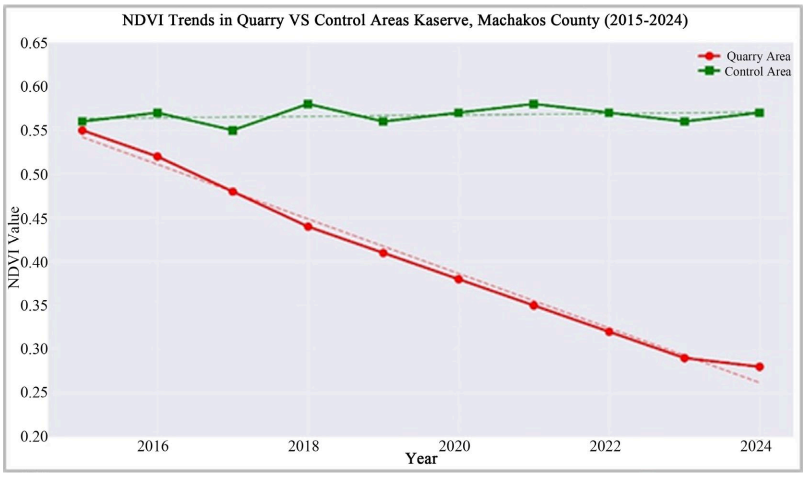

Figure 3. NDVI trends in quarry vs control areas—kaseve, machakos county (2015-2024).

Linear regression analysis of NDVI within the quarry area revealed a highly significant negative trend, with vegetation cover declining at a rate of −0.0297 NDVI units per year. The model demonstrated a very strong fit, indicated by an R^2 value of 0.984, confirming that the regression explains nearly all the observed variation in NDVI over time. The p-value of less than 0.001 further underscores the statistical significance of this decline, providing robust evidence that quarry activities have caused consistent and measurable vegetation loss across the 2015-2024 period.

3.2. Statistical Comparison of Quarry vs Control Areas

A statistical comparison of NDVI values between the quarry and reference areas over the study period confirms substantial differences in vegetation condition. The quarry area exhibited markedly lower NDVI values (mean = 0.402 ± 0.096) compared to the reference area (mean = 0.567 ± 0.010), indicating declined vegetation health within the zone affected by quarry activities.

The persistent disparity between the two areas across all years demonstrates that vegetation degradation in the quarry zone is systematic rather than episodic. The stability of NDVI values in the reference area further supports the interpretation that the observed decline within the quarry area is attributable to localized disturbances rather than regional environmental variability.

These findings provide strong evidence that quarry operations have produced measurable and sustained impacts on vegetation cover, likely through mechanisms such as land clearing, dust deposition, blasting vibrations, and alteration of soil properties.

3.3. Correlation with Rainfall Variability

An assessment of the relationship between annual rainfall and NDVI was conducted to determine whether climatic variability could account for the observed vegetation decline. The analysis indicated no consistent correspondence between rainfall fluctuations and vegetation condition within the quarry area.

Periods of relatively high rainfall did not result in measurable recovery of vegetation indices in the disturbed zone, suggesting that climatic factors alone cannot explain the observed degradation. In contrast, vegetation in the surrounding reference area remained stable across varying rainfall conditions, indicating greater ecological resilience in undisturbed environments.

These results suggest that quarry-related disturbances are the dominant driver of vegetation decline, while rainfall variability plays a secondary or limited role.

These results demonstrate that rainfall variability does not explain the NDVI decline observed in the quarry area. While some positive correlation exists (r = 0.48), it is not statistically significant and accounts for only 23% of variance (r^2 = 0.23) (**Figure 4**). In contrast, the temporal trend (declining NDVI independent of rainfall) explains 98.4% of variance. This strongly suggests that quarrying activities, rather than rainfall, are the primary driver of vegetation degradation.

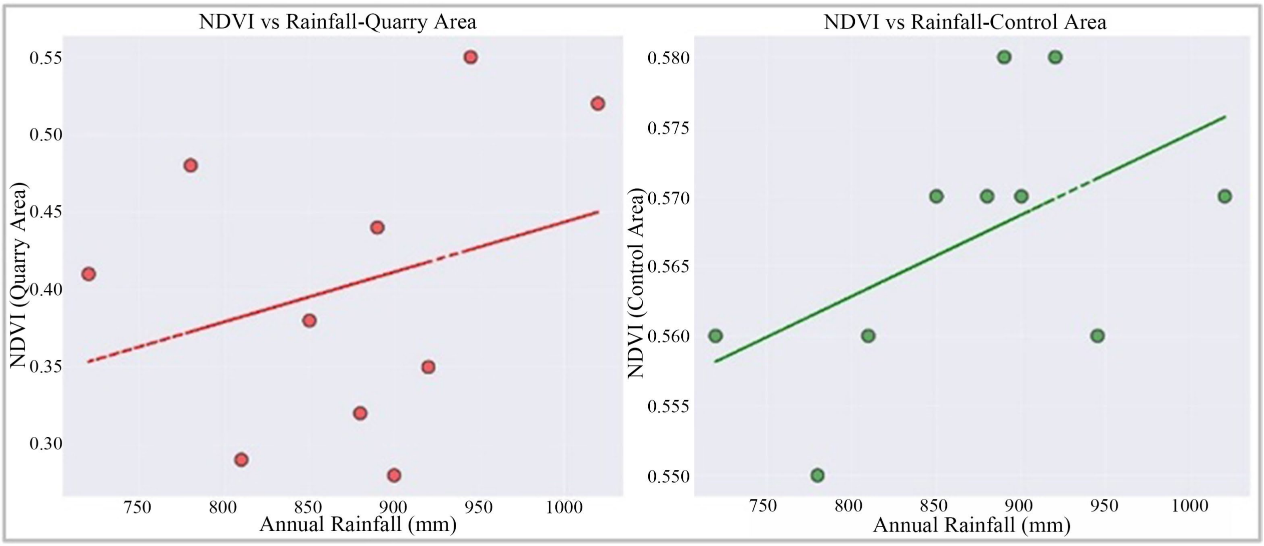

Figure 4. Correlation between NDVI and annual rainfall for quarry and control areas.

The surrounding area proximity shows essentially no relationship between rainfall and NDVI ($r = 0.12$), indicating that the vegetation in undisturbed areas maintains stable health across the range of rainfall variability observed during the study period.

3.4. Spatial Distribution of Vegetation Impacts

Spatial analysis of NDVI values at different distances from the quarry perimeter reveals a clear distance-decay pattern of impacts (Table 2).

Table 2. Mean NDVI values by distance from quarry (2015-2024 multi-year composite).

Distance Zone from Quarry	Mean NDVI	Standard Deviation	Number of pixels/Sample Points
0 - 250 m	0.24	0.08	45
250 - 500 m	0.32	0.11	38
500 - 750 m	0.41	0.09	32
750 - 1000 m	0.48	0.07	28
>1000 m (control)	0.57	0.05	40

The NDVI values presented in Table 2 represent a multi-year composite derived from Landsat-8 and Sentinel-2 imagery for the period 2015-2024. Using a composite dataset minimizes short-term climatic variability and provides a more reliable assessment of long-term quarry impacts on vegetation. These data therefore constitute secondary remote-sensing observations validated through field reconnaissance conducted in 2025.

Distance zones were generated using concentric buffer analysis from the quarry boundary within a GIS environment. NDVI values were extracted from all valid vegetation pixels within each buffer, and the reported sample size corresponds to the number of pixels used in statistical calculations. The reference zone (>1000 m) was selected to represent areas with similar elevation, soil characteristics, and land-use conditions but without observable quarry disturbance, ensuring meaningful comparison between impacted and non-impacted areas.

The progressive increase in mean NDVI with distance from the quarry indicates a clear spatial gradient of environmental impact, with the lowest vegetation health occurring within 250 m of active quarry operations and near-baseline conditions observed beyond 1 km.

3.5. Directional Analysis of Vegetation Impacts

Analysis of NDVI patterns in different directions from the quarry reveals anisotropic (directionally dependent) impacts consistent with prevailing wind patterns (Table 3).

Table 3. Mean NDVI values by direction from quarry (Within 500 m buffer, 2015-2024 composite).

Direction	Mean NDVI	Vegetation Loss (%)	Relative wind position
North	0.34	40%	Upwind
Northeast	0.31	46%	Cross-wind
East	0.29	49%	Cross-wind
Southeast	0.25	56%	Downwind
South	0.27	53%	Downwind
Southwest	0.28	51%	Downwind
West	0.32	44%	Cross-wind

The NDVI values presented in Table 3 represent multi-temporal averages derived from Landsat-8 and Sentinel-2 imagery covering the period 2015-2024, rather than a single year. This composite approach minimizes the influence of short-term climatic variability and provides a more robust representation of long-term vegetation conditions associated with quarry activities. Although field investigations were conducted in 2025, the satellite data analyzed correspond to the operational history of the quarry during 2015-2024, ensuring temporal alignment with the study objectives.

Sampling locations were established using a stratified distance-based design centered on the quarry boundary. Concentric buffer zones at 250 m intervals were generated in a GIS environment, and sampling points were distributed systematically within each zone to ensure spatial representativeness. Ground reconnaissance in 2025 was undertaken to validate land-cover conditions, confirm accessibility, and verify the absence of confounding disturbances unrelated to quarry operations.

The reference area (>1000 m) was selected following field inspection and satellite image assessment to identify locations with intact vegetation cover, comparable elevation, soil characteristics, and land-use patterns but without visible quarry influence. This ensured that differences in NDVI across zones reflect the environmental impact of quarry activities rather than natural spatial variability.

Overall, the results demonstrate a clear gradient of vegetation condition with increasing distance from the quarry. The lowest NDVI values occur within 250 m of the extraction area, indicating severe vegetation stress, while values progressively increase toward the reference zone, suggesting attenuation of quarry-related disturbances with distance.

4. Discussion

4.1. Vegetation Degradation Patterns and Mechanisms

4.1.1. Magnitude of Vegetation Decline

The remote sensing analysis indicates substantial deterioration of vegetation condition in the vicinity of Kaseve Quarry between 2015 and 2024. Mean NDVI values declined from approximately 0.55 in 2015 to about 0.28 in 2024, representing a reduction of roughly 49.1 percent over the nine-year period. This decline reflects a pronounced reduction in vegetation greenness and productivity within the quarry influence zone.

Spatial analysis shows that the greatest reductions occurred within the immediate operational footprint of the quarry and progressively decreased with distance from the extraction area. Areas located outside the zone of quarry activity exhibited comparatively stable NDVI values during the same period, indicating localized disturbance rather than region-wide vegetation change.

The rate of decline, estimated at approximately 5.5 percent per year, falls toward the upper range reported in quarry environments globally. Comparable studies in mining regions have documented significant reductions in vegetation indices associated with land surface disturbance and removal of vegetative cover. The magnitude of change observed at Kaseve therefore reflects substantial alteration of surface conditions within the study area.

The observed patterns directly address the study objective concerning vegetation degradation and provide quantitative evidence that vegetation condition deteriorated markedly over the monitoring period. These findings are consistent with the study hypothesis that quarrying activities are associated with measurable loss of vegetation cover.

4.1.2. Spatial Extent of Impacts

The spatial analysis of NDVI values indicates that vegetation degradation associated with quarrying activities at Kaseve extends considerably beyond the immediate excavation area. Results presented in Chapter Three show a clear distance-decay pattern, with mean NDVI values increasing progressively from 0.24 within 0 - 250 m of the quarry to 0.48 at 750 - 1000 m and stabilizing at 0.57 in the reference zone located beyond 1000 m. This gradient demonstrates that the most severe impacts occur in close proximity to quarry operations, while vegetation condition improves with increasing distance, indicating attenuation of disturbance effects away from the source.

Directional analysis further reveals that impacts are not uniformly distributed around the quarry. NDVI reductions are greatest within the southeast sector (56% vegetation loss), followed by the south and southwest sectors (53% and 51% respectively), while comparatively lower reductions occur in the northern sectors, particularly northwest (39%). This anisotropic pattern confirms that vegetation degradation is spatially heterogeneous rather than evenly distributed.

Rainfall data presented in Section 3.1 indicate that annual precipitation during the study period ranged between approximately 720 mm and 1020 mm, values consistent with the normal climatic variability of Machakos County. Despite this variability, NDVI decline within the quarry influence zone followed a consistent downward trend independent of rainfall fluctuations, while vegetation in the reference area remained stable across the same period. This suggests that the spatial pattern of degradation is unlikely to be explained by rainfall differences alone.

The observed directional differences are therefore interpreted as reflecting localized environmental disturbance associated with quarry operations rather than regional climatic controls. Factors such as excavation intensity, land clearing, dust deposition, and surface modification may vary around the quarry perimeter depending on operational layout and site conditions, producing uneven spatial impacts on surrounding vegetation.

Overall, the findings demonstrate that quarry-related disturbances at Kaseve extend up to approximately 750 m from the excavation area, with the severity of impacts declining with distance and varying by direction. These results provide strong evidence that vegetation degradation is primarily driven by site-specific quarry activities rather than uniform environmental factors.

4.1.3. Rainfall-NDVI Relationships

The annual precipitation in the Kaseve area during the study period ranged between approximately 720 mm and 1020 mm, reflecting normal interannual variability typical of semi-arid environments in Machakos County. Despite this variability, the NDVI analysis showed a persistent downward trend in vegetation condition within the quarry influence zone between 2015 and 2024. In contrast, NDVI values in the reference area outside the quarry influence remained relatively stable over the same period.

The absence of a consistent temporal correspondence between annual rainfall fluctuations and NDVI decline in the quarry zone suggests that rainfall variability alone does not explain the observed vegetation degradation. If rainfall were the dominant control, similar declines would be expected in the reference area subjected to the same regional climatic conditions. The stability of vegetation indices outside the quarry footprint therefore indicates that local site disturbances play a more significant role than regional precipitation patterns.

4.1.4. Alignment with Land Degradation Theory

The decline in NDVI values documented at Kaseve Quarry provides empirical evidence consistent with the principles of Land Degradation Theory, which describes how sustained land disturbance can reduce vegetation productivity and ecosystem function. In this study, vegetation condition declined substantially within the quarry influence zone between 2015 and 2024, while comparatively stable NDVI values were observed in areas beyond the immediate operational footprint. This spatial contrast indicates that degradation is localized rather than regionally uniform.

Land Degradation Theory does not attribute ecological deterioration to a single factor but to cumulative land surface disturbances that modify soil properties, surface cover, and moisture retention capacity. The remote sensing analysis revealed a progressive shift from moderate and high vegetation density classes toward low and very low classes within the quarry zone, reflecting reduced canopy cover and biomass over time. Such transitions are characteristic of disturbed landscapes where surface materials are exposed and vegetative recovery is limited.

The spatial gradient identified in this study, with the most pronounced NDVI reductions occurring near active quarry areas and diminishing outward toward buffer and reference zones, further supports the interpretation of localized land degradation processes. This pattern suggests that the observed vegetation decline is associated with site-specific land surface disturbance rather than broad environmental change. However, the study did not directly quantify individual disturbance mechanisms such as dust deposition, soil compaction, or vegetation removal, and therefore causal attribution to specific operational activities cannot be conclusively established. Within this framework, Kaseve Quarry represents a landscape undergoing measurable ecological alteration as a result of intensive land use. The findings demonstrate how prolonged surface disturbance can lead to progressive vegetation decline and reduced ecological resilience. The results therefore align with Land Degradation Theory by illustrating the cumulative effects of localized land modification on vegetation condition, without requiring assumptions about processes that were not directly investigated.

Acknowledgements

We thank the Almighty God for the gift of life and knowledge to undertake this study. Second, I would like to express my deepest gratitude to my supervisors and lecturers, Dr. Mary Mwangi and Dr. Julian Awuor Ogondo for their tireless guidance to this end. To my family, I am grateful for your unwavering support, time and encouragement. Finally, I am grateful to my classmates and friends for their contribution.

Conflicts of Interest

The authors declare no conflict of interest.

References

Avkopashvili, M., Avkopashvili, I., Avkopashvili, G., & Ayo-Bali, A. E. (2024). 50 Years of

Mining-Induced Environmental Changes: Topography, Hydrology, and Vegetation Health in Kazreti, Georgia. *Environmental Research Communications, 6,* Article ID: 085008. https://doi.org/10.1088/2515-7620/ad6b06

Darwish, T., Khater, C., Jomaa, I., Stehouwer, R., Shaban, A., & Hamzé, M. (2011). Environmental Impact of Quarries on Natural Resources in Lebanon. *Land Degradation & Development, 22,* 345-358. https://doi.org/10.1002/ldr.1011

Dodson, R. G. (1953). *Geology of the South-East Machakos Area: Degree Sheet 52, SE Quadrant (with Coloured Map) (No. 25).* Government Printer.

Fritz, H., Abdelsalam, M., Ali, K. A., Bingen, B., Collins, A. S., Fowler, A. R. et al. (2013). Orogen Styles in the East African Orogen: A Review of the Neoproterozoic to Cambrian Tectonic Evolution. *Journal of African Earth Sciences, 86,* 65-106. https://doi.org/10.1016/j.jafrearsci.2013.06.004

Gromnicki, K., & Chudy, K. (2025). Impact Assessment of Mining Dewatering on Vegetation Based on Satellite Image Analysis and the NDVI Index—A Case Study of a Chalk Mine. *Resources, 14,* Article 134. https://doi.org/10.3390/resources14090134

Indiatsy, C. M. (2018). Analysis of Historical Monthly, Seasonal and Annual Rainfall Variability (1990-2014) in Machakos Sub County, Kenya. *International Journal of Multidisciplinary and Current Research, 6,* 24-41. https://doi.org/10.14741/ijmcr.v6i01.10904

Kenya Meteorological Department. *Climate of Machakos County.* Government of Kenya.

Li, N., Guo, Y., Wang, L., Wang, Q., Yan, D., Zhao, S. et al. (2024). Evaluation and Quantitative Characterization for the Ecological Environment Impact of Open Pit Mining on Vegetation Destruction from Landsat Time Series: A Case Study of Wulishan Limestone Mine. *Ecological Indicators, 158,* Article ID: 111371. https://doi.org/10.1016/j.ecolind.2023.111371

Mathu, E. M. (1992). The Mutito and Ikoo Faults in the Pan-African Mozambique Belt, Eastern Kenya. In R. Mason (Ed.), *Basement Tectonics 7* (pp. 61-69). Springer. https://doi.org/10.1007/978-94-017-0833-3_5

Nkonya, M. (2016). *Economics of Land Degradation and Improvement—A Global Assessment for Sustainable Development.* Springer.

Nyamai, C., Mathu, E., Opiyo-Akech, N., & Wallbrecher, E. (2004). A Reappraaisal of the Geology, Geochemistry, Structures and Tectonics of the Mozambique Belt in Kenya, East of the Rift System. *African Journal of Science and Technology, 4,* 51-71. https://doi.org/10.4314/ajst.v4i2.15306