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Formicidae Ant Diversity and Its Association with Environmental Variables in a Traditional Oil Mining Area of Wonocolo, Indonesia

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ABSTRACT

This study aims to explore the diversity of Formicidae ants in the oil mining area of Wonocolo and evaluate the relationship between ant diversity and environmental factors. This research was conducted in a traditional oil mining area in Bojonegoro, East Java, Indonesia. Pitfall traps were used to collect ant samples, and a total of 11 ant species from 8 genera were identified. The Shannon–Wiener diversity index (H') ranged from 0.03 to 1.49, the Simpson dominance index (C) ranged from 0.26 to 0.99, and the evenness index (E) ranged from 0.04 to 0.97, indicating low diversity with varying levels of dominance and community stability. The high-density mining area was strongly dominated by *Monomorium pharaonis*, resulting in high dominance and low community evenness. Simple linear regression analysis showed that ant diversity was statistically associated with several environmental variables, with soil temperature showing the strongest association ($R^2 = 0.4016$), followed by air pressure ($R^2 = 0.2917$), dry air temperature ($R^2 = 0.2649$), altitude ($R^2 = 0.0929$), wet air temperature ($R^2 = 0.0002$), and air humidity ($R^2 = 0.0538$). These findings provide baseline information on Formicidae diversity and highlight the potential of ant communities as ecological indicators for biodiversity monitoring and environmental management in traditional oil mining ecosystems.

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INTRODUCTION

Biodiversity is a crucial component of ecosystem stability and functioning (Delgado-Baquerizo et al. 2020; Oktafitria et al. 2019a; Oktafitria et al. 2019b). Among the various groups

of animals, ants from the Formicidae family play a significant role in many ecosystems, including petroleum mining areas (Delgado-Baquerizo et al. 2020; Landis 2018; Rahmawati et al. 2024). Ants not only act as decomposers (Hani & Suhaendah, 2019; Landis, 2018; Majeed et al., 2021), but also contribute to soil aeration (Klimek et al., 2022; Landis, 2018), seed dispersal (CaraDonna et al., 2021; Landis, 2018), and pest control (Aristizábal & Metzger, 2019; Landis, 2018). Due to their poikilothermic nature, ants are greatly influenced by the temperature of their surrounding environment (Calixto et al., 2021; Parr & Bishop, 2022). Research on ant diversity and its relationship with environmental conditions is becoming increasingly relevant, especially in areas that are disturbed by human activities such as petroleum mining (Oktafitria 2019a, Ardianita 2024).

The Wonocolo petroleum mining area, located in Bojonegoro Regency, East Java, has been exploited using conventional methods since the Dutch colonial period (Rahmawati et al. 2021a; 2021b; 2024; Sari and Trihadiningrum 2018). Click or tap here to enter text.Click or tap here to enter text.Click or tap here to enter text.Click or tap here to enter text.Click or tap here to enter text.Long-term mining activities have resulted in soil contamination by petroleum hydrocarbons (TPH) and heavy metals, altering soil properties and habitat quality (Sari et al. 2018; Rahmawati et al. 2024). Such environmental changes may influence the structure and diversity of soil-dwelling organisms, including Formicidae ants, by modifying the microhabitat conditions necessary for their survival and foraging activities.

The Wonocolo petroleum mining area has experienced continuous environmental disturbance due to long-term oil exploration and extraction activities. These disturbances can affect the natural habitat of ants and other species that depend on the ecosystem (Rahmawati et al. 2024). The various air and soil temperature in this area can affect the behavior and survival of ants and will even affect the diversity of their species (Roeder et al. 2021). According to research by Latumahina et al. (2015), the optimum temperature for ant activity ranges from 24°C to 32°C, while the supportive humidity ranges from 85% to 88%. Temperatures that are too high or too low can interfere with physiological processes such as reproduction and metabolism of ants (Roeder et al. 2021).

Environmental variables, including soil temperature (Haroon et al., 2026; Henine-Maouche et al., 2026; Pérochon et al., 2026), air temperature (Bochenski et al., 2025; Pérochon et al., 2026), humidity (Bochenski et al., 2025; Haroon et al., 2026; Henine-Maouche et al., 2026), altitude (Henine-Maouche et al., 2026), and other habitat characteristics, are important ecological drivers that influence ant activity, species distribution, colony establishment, and community composition. Variations in these environmental conditions caused by long-term mining disturbance may alter

habitat suitability and consequently affect ant diversity within the ecosystem. Therefore, understanding the association between environmental variables and ant diversity is essential for evaluating ecological responses to anthropogenic disturbance.

Previous studies in the Wonocolo traditional oil mining area have mainly focused on environmental pollution, including total petroleum hydrocarbons (TPH), heavy metal contamination, and water quality (Sari et al. 2018; Rahmawati et al. 2021b; Rahmawati et al. 2024). However, studies investigating Formicidae biodiversity and its association with environmental variables in this traditional oil mining ecosystem remain very limited. In particular, the relationship between ant diversity and variations in soil temperature, air temperature, altitude, and air pressure has not been systematically evaluated. This represents an important knowledge gap because ants are widely recognized as ecological indicators of environmental change and habitat quality. The novelty of this study lies in examining the association between Formicidae ant diversity and multiple environmental variables within a long-established traditional oil mining ecosystem, thereby providing baseline ecological information for biodiversity monitoring in disturbed landscapes.

This study aims to investigate the diversity of Formicidae ant species in the Wonosolo petroleum mining area and examine its association with environmental variables, including soil temperature, air temperature, altitude, and air pressure. The findings are expected to improve our understanding of how environmental variation influences ant communities and provide scientific information to support biodiversity monitoring and ecosystem management in traditional oil mining areas.

RESEARCH METHODS

This research was conducted in the traditional oil mining area of Wonocolo Village, Kedewan District, Bojonegoro Regency, East Java, Indonesia (latitude 7° 20 LS, longitude 111° 38 E), with an average altitude of more than 200 meters above sea level, on an area of 50 hectares. To facilitate the collection of research data, the distribution area of traditional oil wells is divided into several plots and then grouped based on the density of oil well distribution per hectare. Nine sampling points were established using a purposive sampling approach to represent the major habitat conditions within the traditional oil mining area. Sampling locations were classified into three categories based on oil well density, namely high-density (D), medium-density (M), and low-density (R) areas, with three independent sampling points assigned to each category (Rahmawati et al., 2024a). This stratified sampling design was intended to capture environmental heterogeneity associated with different levels of mining disturbance rather than to provide complete spatial

coverage of the study area. (Rahmawati et al. 2024)Nine sampling points were determined representing high-density well areas (D), medium-density well areas (M), and low-density well areas (R). Two pitfall traps were installed at each sampling point, with a distance of 5 m between traps to reduce trap interference and increase sampling coverage (Rahmawati et al. 2024).

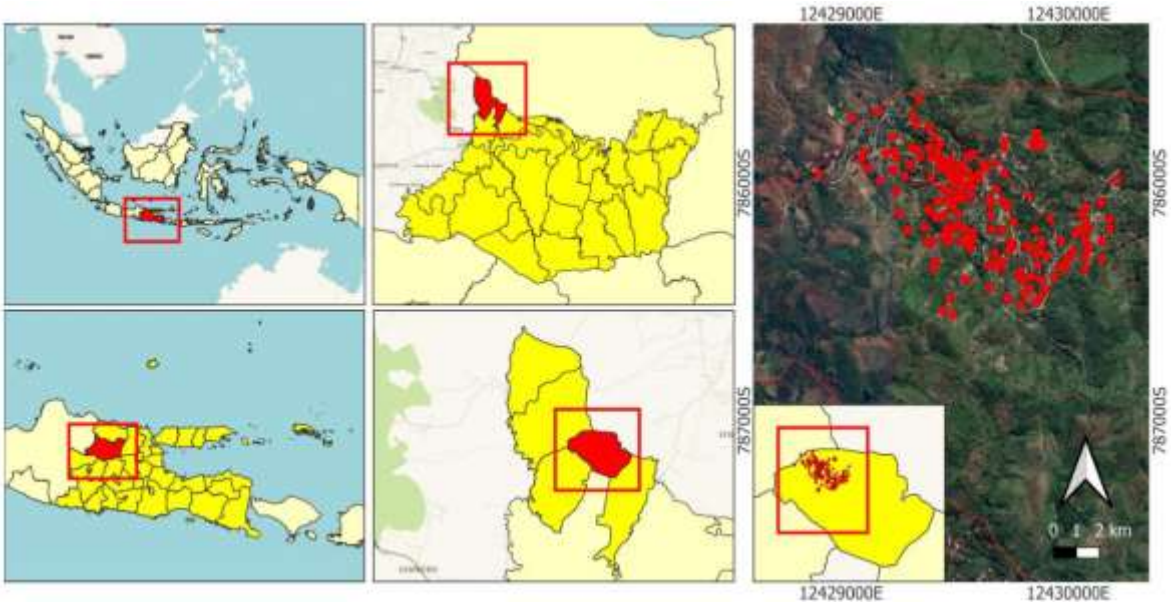


Figure 1. The research location is Wonocolo Village, Kadewan District, Bojonegoro Regency, East Java, Indonesia (Rahmawati et al. 2024)

The pitfall trap method is used to sample soil ants active on the ground surface. A plastic cup is buried at each sampling point, with its top covered by a plastic plate to protect it from rain and sunlight (Oktafitria et al. 2019b; Oktafitria et al. 2019a). The cup is filled with a 70% alcohol solution (100 ml) to preserve the ants. Pitfall traps were operated continuously for three consecutive days. This sampling duration followed commonly applied rapid biodiversity assessment protocols for ground-dwelling ants and was considered sufficient to compare ant community structure among the different mining disturbance categories while minimizing disturbance to the traps and specimen degradation. Traps are checked daily for three days, and the collected ants are preserved for identification and counting (Rahmawati et al. 2024). The collected specimens were identified to the lowest possible taxonomic level based on external morphological characters using the identification key presented in An Introduction to the Study of Insects (Borror, Triplehorn, & Johnson, 1992). Species identification was conducted using morphological characteristics observable under laboratory conditions.. Various biodiversity indices—Shannon Wiener diversity index, species evenness, and Simpson dominance index—are calculated to assess the ant community's structure (Vasconcellos et al., 2013). Based on these indices, community diversity, stability, and dominance were categorized (Rahmawati et al. 2024).

Environmental variables measured at each sampling point included soil temperature, dry air temperature, wet air temperature, altitude, and air pressure. These variables were selected because they represent important microclimatic factors that influence the activity, distribution, and diversity of ground-dwelling ants. The relationship between the Shannon–Wiener diversity index (H') and each environmental variable was analyzed using simple linear regression. The coefficient of determination (R^2) was used to evaluate the strength of the association between ant diversity and environmental variables.

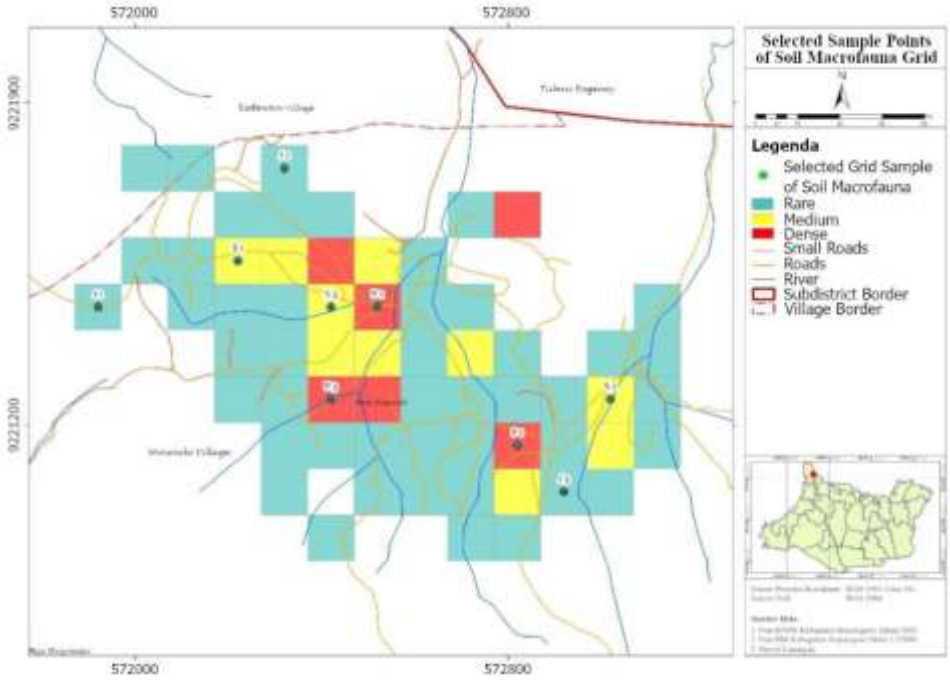


Figure 2. Ant sampling point in Wonocolo Traditional Oil Mining Area (Rahmawati et al. 2024)

RESEARCH RESULT

Based on the collection of ants by the pitfall trap method, 8 genera from the Formicidae family with 11 species of ants were obtained (Table 1). In the area of the high-density well (D1, D2, D3), 7 species of ants were found. In the area of the medium-density well (M1, M2, M3), 8 species of ants were found. In the low-density well area (R1, R2, R3), 4 species were found.

The ant species that have the largest number of individuals and number more than 100 in the Wonocolo oil drilling well area are *Monomorium pharaonis* (399 individuals) and *Camponotus sp* (277 individuals). Although the medium-density mining area contained a slightly higher number of species than the high-density area, the community structure differed markedly between the two habitat categories. The high-density well area was strongly dominated by *Monomorium pharaonis*, particularly at sampling point D1 (350 individuals), resulting in a highly uneven distribution of individuals among species (Figure 3).

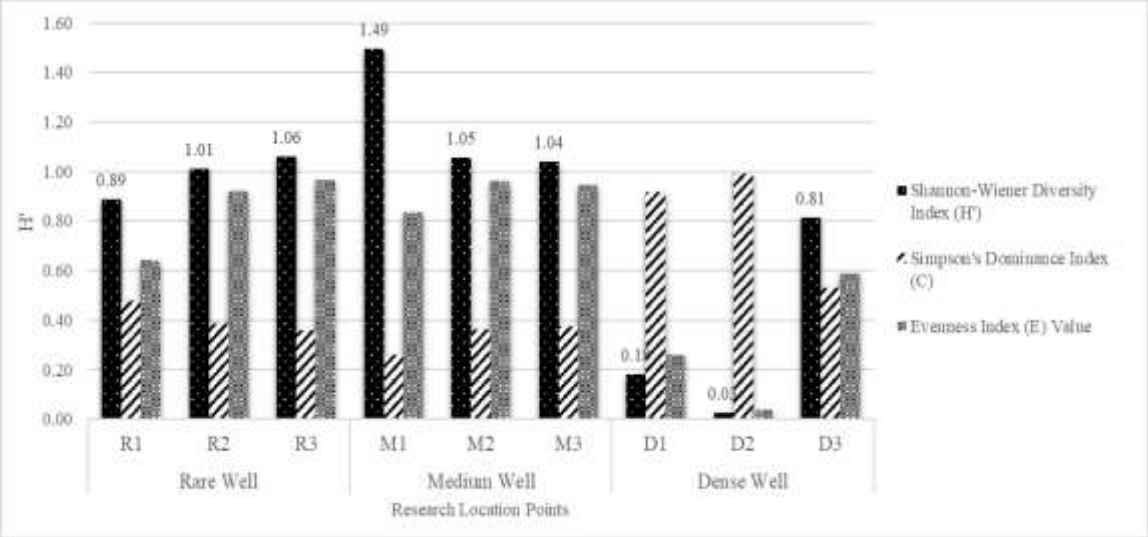


Figure 3. Ant community structure in the Wonocolo oil mining area, Bojonegoro, Indonesia

The ant communities structure in the low-density well area (R) was characterized by low diversity (mean H'=0.987), low dominance (mean C=0.41) and relatively stable community (mean E=0.84). Similarly, the medium density well area (M) showed low diversity (mean H'=1.193), low dominance (mean C=0.33) and high evenness (mean E=0.91). Although the high density well area (D) contained seven ant species, its community was characterized by low diversity (mean H'=1.02), high dominance (mean C=0.81) and depressed ant communities (mean E=0.21). This pattern indicates that the community was heavily dominated by a single species, *Monomorium pharaonis*, resulting in an uneven distribution of individuals despite the presence of several ant species.

In addition to the ant sampling, environmental variables measured at each sampling point included soil temperature, dry air temperature, wet air temperature, altitude, and air pressure (Table 2). Soil temperature range from 26.90 to 35.45 °C, while the reported optimum range for ant activity is 25 - 32 °C (Latumahina et al. 2015). Dry air temperature range from 25 to 32.33 °C, whereas the reported optimum range for ant is 25 - 29 °C (Latumahina et al. 2015; Putri et al. 2022). Wet air temperature range from 23.67 to 27 °C, while previous studies reported an optimum range of 28 – 30 °C (Indrayani et al. 2022). Altitude range from 148.33 to 220.33 m above sea level, which falls within the reported distribution range of many ant species (100-375 masl) (Latumahina et al., 2015). Air pressure range from 990.73 to 995.83 Pa.

Table 1. List of Ant Species in Wonocolo Traditional Oil Mining Area, Kadewan District, Bojonegoro Regency, East Java, Indonesia

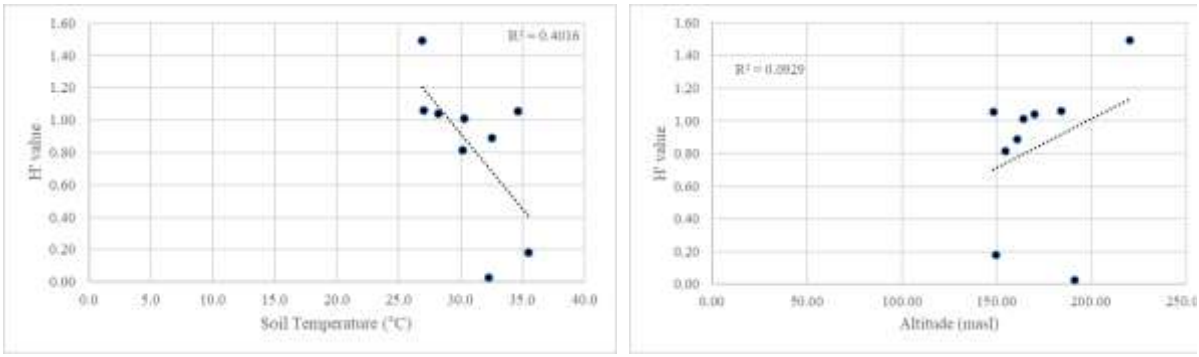
Order	Family	Genus	Species	Ni								
				Low Density Wells			Medium Density Wells			High Density Wells		
				R1	R2	R3	M1	M2	M3	D1	D2	D3
Hymenoptera	Formicidae	*Anoplolepis*	*Anoplolepis gracilipes*	0	0	0	30	0	0	0	0	25
		Camponotus	*Camponotus consobrinus*	1	0	0	0	0	0	0	0	0
			Camponotus sp	0	0	0	0	4	1	16	256	0
		Crematogaster	*Crematogaster claudiae*	0	0	0	0	0	0	0	1	0
			Crematogaster levior	0	0	0	21	0	0	0	0	0
		Lasius	*Lasius niger*	63	9	3	0	2	1	0	0	1
		Monomorium	*Monomorium pharaonis*	31	3	4	5	4	2	350	0	0
		Odontoponera	*Odontoponera denticulata*	7	8	2	1	0	0	0	0	1
		Oecophylla	*Oecophylla smaragdina*	0	0	0	13	0	0	0	0	0
		Solenopsis	*Solenopsis invicta*	0	0	0	9	0	0	0	0	0
			Solenopsis sp	0	0	0	0	0	0	0	0	10
Total Individuals				**102**	**20**	**9**	**79**	**10**	**4**	**366**	**257**	**37**
Total Species				**4**	**3**	**3**	**6**	**3**	**3**	**2**	**2**	**4**
Shannon-Wiener Diversity Index Value (H')				**0.89**	**1.01**	**1.06**	**1.49**	**1.05**	**1.04**	**0.18**	**0.03**	**0.81**
Simpson Dominance Index Value (C)				**0.48**	**0.39**	**0.36**	**0.26**	**0.36**	**0.38**	**0.92**	**0.99**	**0.53**
Evenness Index Value (E)				**0.64**	**0.92**	**0.97**	**0.83**	**0.96**	**0.95**	**0.26**	**0.04**	**0.59**

Table 2. Environmental Parameter Measurement Results

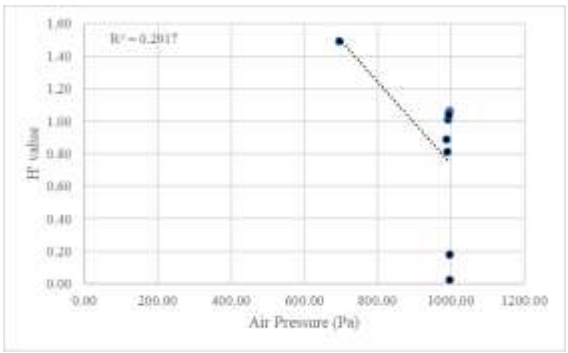
Parameters	R1	R2	R3	M1	M2	M3	D1	D2	D3
Soil Temperature (°C)	32.55	30.30	27.00	26.90	34.65	28.20	35.45	32.25	30.15
Dry Air Temperature (°C)	32.00	28.17	30.00	31.33	29.33	32.33	31.00	25.00	31.17
Wet Air Temperature (°C)	24.50	23.67	25.17	25.50	24.67	26.00	27.00	23.67	25.00
Altitude (masl)	220.33	184.00	148.33	170.00	164.00	160.67	154.67	149.67	191.33
Air pressure (Pa)	987.27	991.63	995.83	995.30	993.97	994.40	995.10	995.73	990.73

The relationship between the Shannon–Wiener diversity index (H') and environmental variables was evaluated using simple linear regression analysis. The coefficient of determination (R^2) was used to describe the proportion of variation in H' associated with each environmental variable. Based on Figure 4a, 4b, and 4c, simple linear regression analysis showed a negative relationship between soil temperature and the Shannon–Wiener diversity index ($R^2 = 0.4016$), indicating that approximately 40.16% of the observed variation in H' was associated with soil temperature (Figure 4a). A weak positive relationship was observed between H' and altitude ($R^2 = 0.0929$) (Figure 4b). In addition, a moderate negative relationship was found between H' and air pressure ($R^2 = 0.2917$) (Figure 4a).

Similarly, simple linear regression analysis indicated weak positive relationships between H' and wet air temperature ($R^2 = 0.0002$), dry air temperature ($R^2 = 0.2649$), and air humidity ($R^2 = 0.0538$) (Figures 5a–5c). These R^2 values indicate the proportion of variation in ant diversity associated with each environmental variable and should be interpreted as statistical associations rather than evidence of causal relationships. Considering that the analysis was based on nine sampling sites, the observed relationships should be regarded as exploratory and interpreted with caution (Landsman and Thiel 2021; Lin et al. 2023; Putri et al. 2021).

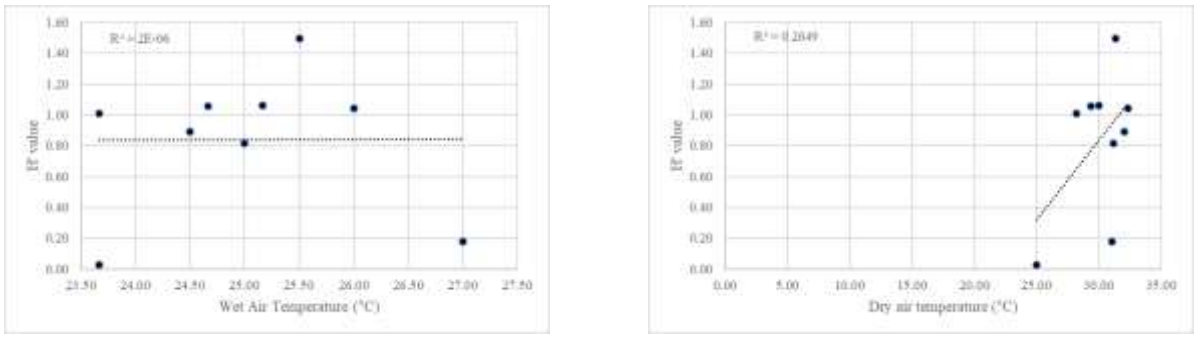


(a) (b)



(c)

Figure 4. Graph of the relationship between H' value and soil temperature (a); Graph of the relationship between H' value and altitude (b); and Graph of the relationship between H' value and air pressure (c) in the Wonocolo oil mining area, Bojonegoro, Indonesia.



(a) (b)

Figure 5. Graph of the relationship between H' value and wet air temperature (a) and Graph of relationship between H' value and dry air temperature (b) in Wonocolo oil field, Bojonegoro, Indonesia

DISCUSSION

Based on the research results, several important facts were obtained, including the fact that the largest number found in the Wonocolo oil drilling well area are *Monomorium pharaonis* (399 individuals) and *Camponotus* sp. (277 individuals). The dominance of *Monomorium pharaonis*, particularly in the high-density oil well area, suggests that this species is well adapted to disturbed habitats associated with long-term traditional oil mining activities. As an invasive and opportunistic species, *M. pharaonis* is widely recognized as an indicator of anthropogenically disturbed environments because of its high ecological plasticity and ability to exploit a wide range of food resources ((Hasin & Tasen, 2020; Rosas-Mejía et al., 2021; Warner et al., 2018). The high dominance of this species is consistent with the low evenness (E = 0.21) and high dominance index (C = 0.81) observed in the high-density mining area, indicating that although several ant species were present, the community was largely dominated by a single species.

Monomorium pharaonis, known as Pharaoh's ant, is a species of small ant ca. 2 mm long (Vail & Williams, 2021) that originated in the equatorial region of Africa and has spread throughout the world as one of the most important pest species (Rosas-Mejía et al., 2021) and an invasive species . Its ability to colonize disturbed habitats, including mining areas, is attributed to its broad dietary preferences and high tolerance to environmental disturbance rather than to specific physiological adaptations measured in this study. Therefore, the dominance of *M. pharaonis* in Wonocolo is more appropriately interpreted as an ecological response to habitat disturbance than as direct evidence of physiological adaptation.

Camponotus sp. was the second most abundant taxon recorded in the study area. Members of the genus *Camponotus* are common components of tropical ant communities and are known to occupy a wide range of habitats, including disturbed environments. Because species-level identification could not be confirmed using the available morphological characters, the specimens were conservatively identified as *Camponotus* sp. Consequently, the present study focuses on the ecological role of the genus rather than species-specific biological characteristics. Their relatively high abundance indicates that this genus is capable of persisting under the microclimatic conditions of the traditional oil mining landscape.

Simple linear regression analysis indicated that soil temperature was associated with the largest proportion of variation in the Shannon–Wiener diversity index ($R^2 = 0.4016$) (Figure 4a). This finding suggests that differences in soil temperature may contribute to differences in ant community structure across sampling sites. Unlike the previous interpretation, the present results do not indicate that ant diversity affects soil temperature. Instead, soil temperature is more likely

to act as an environmental driver influencing the distribution and composition of ant communities. The soil temperature in the Wonocolo oil mining area ranged from 26.90 to 35.45°C, which is close to the reported optimum range for many ground-dwelling ants (25–32°C) (Putra et al., 2021; Putra et al., 2018). The relatively high soil temperature observed in several sampling sites may be related to heat generated by oil extraction activities and reduced vegetation cover surrounding the wells, both of which can alter local microclimatic conditions.

Altitude showed only a weak positive association with ant diversity (R^2 = 0.0929) (Figure 4b), suggesting that elevation alone explained only a small proportion of the observed variation in community diversity. This relatively weak relationship is expected because the elevation range among sampling sites (148.33–220.33 m above sea level) was relatively narrow. Nevertheless, elevation may indirectly influence ant communities through its effects on local temperature, humidity, and vegetation characteristics, as reported in previous studies (Addo-Bediako et al., 2000; Putra et al., 2021; Putra et al., 2018). This is consistent with the occurrence of genera such as *Camponotus* sp., *Odontoponera denticulata*, and *Solenopsis* spp. in the Wonocolo oil mining area.

Air pressure exhibited a moderate negative association with ant diversity (R^2 = 0.2917) (Figure 4c). However, this relationship should be interpreted cautiously because air pressure is unlikely to directly determine ant diversity. Instead, air pressure may reflect broader microclimatic conditions that covary with other environmental factors, including temperature and humidity. Therefore, the observed relationship represents a statistical association rather than a direct causal effect. Similarly, the relationships between ant diversity and wet air temperature, dry air temperature, and air humidity were relatively weak (R^2 = 0.0002, 0.2649, and 0.0538, respectively). These results suggest that variation in ant diversity was associated with multiple microclimatic variables rather than being determined by a single environmental factor.

Because this study was based on only nine sampling points, the regression analyses should be regarded as exploratory. Additional studies incorporating larger sample sizes, seasonal observations, vegetation characteristics, soil properties, and petroleum contamination (e.g., TPH and heavy metals) are needed to provide a more comprehensive understanding of the environmental factors influencing ant communities in traditional oil mining ecosystems.

CONCLUSION

From this research it can be concluded that Formicidae ants in the Wonocolo petroleum mining area consist of 8 genera and 11 species, with overall low ant diversity, varying levels of species dominance, and community evenness ranging from depressed to stable conditions. The

high-density mining area was characterized by strong dominance of *Monomorium pharaonis*, indicating that habitat disturbance associated with traditional oil mining may favor opportunistic and disturbance-tolerant ant species. The study further demonstrates that ant diversity was statistically associated with several microclimatic variables, particularly soil temperature, air pressure, altitude, and air temperature. Among these variables, soil temperature showed the strongest association with ant diversity, suggesting that local microclimatic conditions may play an important role in shaping ant community structure in traditional oil mining ecosystems. However, these relationships should be interpreted as statistical associations rather than causal effects because of the limited number of sampling sites. These findings provide baseline information on Formicidae diversity in the Wonocolo traditional oil mining area and highlight the potential use of ant communities as ecological indicators for biodiversity monitoring and environmental management in disturbed mining landscapes. Future studies incorporating additional environmental variables, such as vegetation characteristics, soil properties, and petroleum contamination, are recommended to improve understanding of the factors influencing ant community dynamics.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

L.A. Rahmawati: conceptualization, methodology, validation, writing original draft, writing review & editing, supervision. D. Oktafitria: methodology, validation, investigating, writing original draft. N.N Rodhi: Formal analysis, investigation, visualization. D. Setyaningrum: Resources, data curation, project administration.

DECLARATION OF THE USE OF AI

During the preparation of this work the authors used Chat-GPT Pro in order to language alignment and reducing typographical errors in the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

REFERENCE

Addo-Bediako, A., Chown, S. L., & Gaston, K. J. (2000). Thermal tolerance, climatic variability and latitude. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *267*(1445), 739–745. https://doi.org/10.1098/rspb.2000.1065

Aristizábal, N., & Metzger, J. P. (2019). Landscape structure regulates pest control provided by ants in sun coffee farms. *Journal of Applied Ecology*, *56*(1), 21–30. https://doi.org/10.1111/1365-2664.13283

Bochenski, W. S., Vicente, R. E., Bishop, T. R., & Izzo, T. J. (2025). Ant brightness and size influence the seasonal vegetation use by ground-dwelling ants (Hymenoptera: Formicidae) in an Amazonia-Cerrado transition zone. *Ecological Entomology*, *50*(6), 1082–1095. https://doi.org/10.1111/een.70000

Calixto, E. S., Novaes, L. R., dos Santos, D. F. B., Lange, D., Moreira, X., & Del-Claro, K. (2021). Climate seasonality drives ant–plant–herbivore interactions via plant phenology in an extrafloral nectary-bearing plant community. *Journal of Ecology*, *109*(2), 639–651. https://doi.org/10.1111/1365-2745.13492

CaraDonna, P. J., Burkle, L. A., Schwarz, B., Resasco, J., Knight, T. M., Benadi, G., Blüthgen, N., Dormann, C. F., Fang, Q., Fründ, J., Gauzens, B., Kaiser-Bunbury, C. N., Winfree, R., & Vázquez, D. P. (2021). Seeing through the static: the temporal dimension of plant–animal mutualistic interactions. *Ecology Letters*, *24*(1), 149–161. https://doi.org/10.1111/ele.13623

Delgado-Baquerizo, M., Reich, P. B., Trivedi, C., Eldridge, D. J., Abades, S., Alfaro, F. D., Bastida, F., Berhe, A. A., Cutler, N. A., Gallardo, A., García-Velázquez, L., Hart, S. C., Hayes, P. E., He, J.-Z., Hseu, Z.-Y., Hu, H.-W., Kirchmair, M., Neuhauser, S., Pérez, C. A., … Singh, B.

K. (2020). Multiple elements of soil biodiversity drive ecosystem functions across biomes. *Nature Ecology & Evolution*, *4*(2), 210–220. https://doi.org/10.1038/s41559-019-1084-y

Elvania, N. C., Margianti, Y. S., Tiara, S. A., & Nugroho, D. B. (2023). Analisis Kesuburan Tanah di Pertambangan Minyak Tradisional Desa Wonocolo Kecamatan Kedewan, Kabupaten Bojonegoro. *Media Ilmiah Teknik Lingkungan*, *8*(2), 42–49. https://doi.org/10.33084/mitl.v8i2.5350

Hani, A., & Suhaendah, E. (2019). Diversity of Soil Macro Fauna and Its Role On Soil Fertility in Manglid Agroforestry. *Indonesian Journal of Forestry Research*, *6*(1), 61–68. https://doi.org/10.20886/ijfr.2019.6.1.61-68

Haroon, H., Hussain, R., Wang, C., & Zhang, S. (2026). Invasive risk of Solenopsis invicta (Hymenoptera: Formicidae) in China under current and future climate change scenarios. *European Journal of Entomology*, *123*, 136–147. https://doi.org/10.14411/eje.2026.014

Hasin, S., & Tasen, W. (2020). Ant community composition in urban areas of Bangkok, Thailand. *Agriculture and Natural Resources*, *54*, 507–514. https://doi.org/10.34044/j.anres.2020.54.5.07

Henine-Maouche, A., Moulaï, R., Belahbib, M., Mazioua, F., & Bozdoğan, H. (2026). Can environmental factors influence the assemblage of ants (Formicidae) in Mediterranean matorrals in Algeria? *Biologia*, *81*(6), 138. https://doi.org/10.1007/s11756-026-02190-9

Indrayani, Y., Wardenaar, E., & Ahmad Dandi. (2022). Keanekaragaman Jenis Semut Arboreal Di Kebun Raya Sambas Kalimantan Barat. *Jurnal Hutan Lestari*, *10*(3), 695–703.

Klimek, B., Poliwka-Modliborek, H., & Grześ, I. M. (2022). Ant nests as a microbial hot spots in a long-term heavy metal-contaminated soils. *Environmental Science and Pollution Research*, *29*, 10848–108457. https://doi.org/10.1007/s11356-021-16384-y/Published

Landis, B. D. W. D. A. (2018). The role of ants in north temperate grasslands : a review. *Oecologia*, *186*(2), 323–338. https://doi.org/10.1007/s00442-017-4007-0

Landsman, A. P., & Thiel, C. R. (2021). Habitat characteristics and climatic factors influence microhabitat selection and arthropod community structure in a globally rare central Appalachian shale barren. *Ecology and Evolution*, *11*(24), 18169–18180. https://doi.org/10.1002/ece3.8413

Latumahina, F. (2016). Respon Semut Terhadap Kerusakan Antropogenik Pada Hutan Lindung Sirimau, Ambon. *Agrologia*, *5*(2), 53–66.

Latumahina, F., Musyafa, M., Sumardi, S., & Putra, N. S. (2015). Respon Semut Terhadap Kerusakan Antropogenik Dalam Hutan Lindung Sirimau Ambon (Ants Response to Damage Anthropogenic in Sirimau Forest Ambon). *Jurnal Manusia Dan Lingkungan*, *22*(2), 169. https://doi.org/10.22146/jml.18739

Lin, Y. J., Yeh, C. H., Wu, C. Z., & Wu, L. H. (2023). Climate and Wolbachia Impacts on Anoplolepis gracilipes (Hymenoptera: Formicidae). *Biology*, *12*(12), 1–14. https://doi.org/10.3390/biology12121482

Majeed, W., Khawaja, M., & Rana, N. (2021). *Assessing fluctuation of ant populations in a distinct ecological habitat to track climate change effects*. *22*(5), 2722–2727. https://doi.org/10.13057/biodiv/d220533

Oktafitria, D., Febriyantiningrum, K., Jadid, N., Nurfitria, N., Rahmadani, F., Amrullah, A., & Hidayati, D. (2019). Short Communication: Assessment of reclamation success of former limestone quarries in Tuban, Indonesia, based on soil arthropod diversity and soil organic carbon content. *Biodiversitas Journal of Biological Diversity*, *20*(6). https://doi.org/10.13057/biodiv/d200634

Oktafitria, D., Hidayati, D., & Purnomo, E. (2019). Diversitas Serangga Tanah Di Berbagai Tipe Tanah Pada Lahan Reklamasi Bekas Tambang Kapur Kabupaten Tuban. *Florea : Jurnal Biologi Dan Pembelajarannya*, *6*(1), 28. https://doi.org/10.25273/florea.v6i1.4367

Parr, C. L., & Bishop, T. R. (2022). The response of ants to climate change. *Global Change Biology*, *28*(10), 3188–3205. https://doi.org/10.1111/gcb.16140

Pérochon, E., Guénard, B., Gippet, J. M. W., Klaftenberger, T., Ollier, S., & Bertelsmeier, C. (2026). Environmental conditions shape the global distribution of ant societies. *Proceedings of the National Academy of Sciences*, *123*(6). https://doi.org/10.1073/pnas.2530826123

Putra, I., Luqmana, I., Setiawan, H., & Suprihatini, N. (2021). Keanekaragaman Jenis Semut (Hymenoptera: Formicidae) Di Sekitar Kampus 4 Universitas Ahmad Dahlan Yogyakarta. *Biospecies*, *14*(2), 20–30. https://doi.org/10.22437/biospecies.v14i2.12905

Putra, I. M., Hadi, M., & Rahadian, R. (2018). Struktur Komunitas Semut (Hymenoptera : Formicidae) di Lahan Pertanian Organik dan Anorganik Desa Batur, Kecamatan Getasan, Kabupaten Semarang. *Bioma : Berkala Ilmiah Biologi*, *19*(2), 170. https://doi.org/10.14710/bioma.19.2.170-176

Putri, A. R., Rahmawitra, C. D., Nurfalinda, S., Surya, A., Hilmy, M. N., Satria, R., & Fitriana, N. (2022). Inventarisasi Semut Arboreal (Hymenoptera: Formicidae) di Kawasan Air Terjun Sarasah Uwak. *Prosiding Semnas Bio 2022 UIN Syarif Hidayatullah Jakarta*, 180–186.

Putri, F. A., Yulminarti, Herwina, H., Janra, M. N., & Satria, R. (2021). Ant Community (Hymenoptera: Formicidae) at the Forest Park of Sultan Syarif Hasyim, Riau. *IOP Conference Series: Earth and Environmental Science*, *757*(1), 012079. https://doi.org/10.1088/1755-1315/757/1/012079

Rahmawati, L. A., Afiati, N., & Putranto, T. T. (2021a). Impacts of the Covid-19 pandemic on traditional oil mining at Wonocolo Village Kedewan Sub-District Bojonegoro Regency East Java. *IOP Conference Series: Earth and Environmental Science*, *623*(1), 1–6. https://doi.org/10.1088/1755-1315/623/1/012019

Rahmawati, L. A., Afiati, N., & Putranto, T. T. (2021b). River Water Quality Based on Macrozoobentic Bioindicators in the Wonocolo Traditional Oil Mining Area. *Jurnal Ilmu Lingkungan*, *19*(1), 29–35. https://doi.org/10.14710/jil.19.1.29-35

Rahmawati, L. A., Afiati, N., & Putranto, T. T. (2024a). Diversity of soil macrofauna in traditional oil mining of Wonocolo Geosite, Bojonegoro Geopark, East Java, Indonesia. *Biodiversitas*, *25*(5), 2148–2160. https://doi.org/10.13057/biodiv/d250533

Roeder, K. A., Roeder, D. V, & Bujan, J. (2021). Ant Thermal Tolerance: A Review of Methods, Hypotheses, and Sources of Variation. *Annals of the Entomological Society of America*, *114*(4), 459–469. https://doi.org/10.1093/aesa/saab018

Rosas-Mejía, M., Guénard, B., Aguilar-Méndez, M. J., Ghilardi, A., Vásquez-Bolaños, M., Economo, E. P., & Janda, M. (2021). Alien ants (Hymenoptera: Formicidae) in Mexico: the first database of records. *Biological Invasions*, *23*(6), 1669–1680. https://doi.org/10.1007/s10530-020-02423-1

Sari, G. L., & Trihadiningrum, Y. (2018). Petroleum Hydrocarbon Pollution in Soil and Surface Water by Public Oil Petroleum Hydrocarbon Pollution in Soil and Surface Water by Public Oil Fields in Wonocolo Sub-district , Indonesia. *Journal of Ecological Engineering*, *19*(2), 184–193. https://doi.org/10.12911/22998993/82800

Sari, G. L., Trihadiningrum, Y., Suci, F. C., & Hadining, A. F. (2018). Identification of total petroleum hydrocarbon and heavy metals levels in crude oil contaminated soil at wonocolo public mining. *EnvironmentAsia*, *11*(2), 109–117. https://doi.org/10.14456/ea.2018.26

Vail, K. M., & Williams, D. F. (2021). Foraging of the Pharaoh Ant, Monomorium Pharaonis: An Exotic in the Urban Environment. In *Exotic Ants* (pp. 228–239). CRC Press. https://doi.org/10.1201/9780429040795-20

Vasconcellos, R. L. F., Segat, J. C., Bon, J. A., & Baretta, D. (2013). Soil macrofauna as an indicator of soil quality in an undisturbed riparian forest and recovering sites of different ages. *European Journal of Soil Biology Journal*, *58*, 105–112.

Warner, M. R., Lipponen, J., & Linksvayer, T. A. (2018). Pharaoh ant colonies dynamically regulate reproductive allocation based on colony demography. *Behavioral Ecology and Sociobiology*, *72*(3), 31. https://doi.org/10.1007/s00265-017-2430-1

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