

Assessment of Soil Quality and Potential Ecotoxicological Risk Using Physio-Chemical Parameters and Soil Organism Distribution

Shaniba Ayoobkhan¹, Riyazudheen Kabeer², Dr Sujatha Perumal Sivakumar³

^{1,2} Research Scholar, Department of Zoology, Government Arts College, Coimbatore

³ Associate Professor, Department of Zoology, Government Arts College, Coimbatore

Abstract—Soil quality is a fundamental determinant of ecosystem health and agricultural productivity. The present study investigated the physio-chemical parameters and soil organism distribution across four depth layers (A: 0–10 cm, B: 10–20 cm, C: 20–30 cm, and D: 30–40 cm) to assess soil quality and potential ecotoxicological risks. Parameters, including temperature, pH, water content, organic matter content, and the number of soil organisms, were measured at each depth. The results revealed a clear depth-dependent decline in all measured parameters. The surface layer (A) exhibited the highest values for temperature (25 ± 1.5 °C), pH (7.2 ± 0.5), water content ($95 \pm 2.0\%$), organic matter ($4.8 \pm 0.3\%$), and organism count (140 ± 2.5), indicating optimal conditions for biological activity. A statistically significant reduction ($p < 0.05$) was observed with increasing depth, with the deepest layer (D) recording the lowest values across all parameters and a minimal organism count of 40 ± 4.0 . These findings highlight the role of physio-chemical gradients in governing soil biodiversity and suggest that deeper soil layers may be particularly vulnerable to ecotoxicological stress. The study provides a baseline for monitoring soil health and contributes to the understanding of depth-stratified soil ecology in the context of pesticide and pollutant risk assessment.

Index Terms—soil quality; physio-chemical parameters; soil organism distribution; soil depth; organic matter

I. INTRODUCTION

Soil is a vital non-renewable natural resource that supports terrestrial ecosystems, agriculture, and environmental sustainability. It functions as a medium for plant growth, a habitat for diverse organisms, a reservoir for water and nutrients, and a natural buffer against contaminants (Brady & Weil,

2016). However, rapid urbanization, intensive agriculture, and excessive use of pesticides and fertilizers have increasingly threatened soil quality and ecosystem stability (Lal, 2015; FAO, 2018). Soil quality refers to the ability of soil to perform its ecological functions effectively and sustainably. Important indicators of soil quality include physio-chemical parameters such as temperature, pH, moisture content, and organic matter, all of which strongly influence soil biological activity (Bhaskar *et al.*, 2015).

Soil pH regulates nutrient availability and toxicity; temperature affects microbial metabolism; moisture controls nutrient transport and organism survival; and organic matter enhances fertility and water-holding capacity (Sharma & Minhas, 2005; Ramesh & Mahadevan, 2016). Soil is naturally arranged into distinct layers or horizons, each with distinct physical, chemical, and biological properties. Surface layers are generally rich in organic matter, nutrients, and biological activity, whereas deeper layers are more compact and less fertile (Brady & Weil, 2016). Soil organisms such as earthworms, nematodes, arthropods, and microbes play a crucial role in nutrient cycling, decomposition, and maintenance of soil structure. Their abundance and distribution are highly sensitive to changes in soil conditions, making them reliable bioindicators of soil health and ecological disturbance (Swaine *et al.*, 2025).

Pesticide contamination is one of the major threats to soil biodiversity and ecosystem integrity. Continuous pesticide application can alter soil pH, reduce organic matter, disrupt microbial communities, and

negatively affect non-target soil organisms (Goulson, 2013; Tudi *et al.*, 2021). In agricultural regions, particularly in cultivation systems such as arecanut and banana plantations, the interaction between soil depth, organic matter, and pesticide residues may significantly influence soil ecosystem health (Acharya *et al.*, 2015; Paramesh *et al.*, 2025). Therefore, the present study was designed to evaluate soil quality across four distinct soil layers by analyzing temperature, pH, moisture content, organic matter, and soil organism abundance. The study aimed to identify depth-dependent variations in these parameters and assess their significance as indicators of ecotoxicological risk in agricultural soils.

II. MATERIALS AND METHODS

A. Study Site and Soil Sampling

Soil samples were collected from an agricultural site representative of a cropping system where pesticide application is routinely practised. Sampling was conducted using standard soil coring techniques to preserve the integrity of each depth layer. Samples were extracted from four distinct depth intervals: Layer A (0–10 cm), Layer B (10–20 cm), Layer C (20–30 cm), and Layer D (30–40 cm). Three replicate cores were collected from each depth, and samples were stored in labelled, airtight containers and transported to the laboratory under cool conditions to prevent degradation.

B. Physio – chemical analysis

Temperature was recorded in situ at the time of sampling using a calibrated digital soil thermometer. Soil pH was determined using a pH meter in a 1:2.5 soil-to-water suspension following standard protocols. Water content was measured gravimetrically as the percentage weight loss after oven-drying at 105 °C for 24 hours. Organic matter content was determined by the Walkley–Black wet oxidation method and expressed as a percentage of dry soil weight. All physico-chemical measurements were performed in triplicate, and the mean $\pm$ standard deviation was reported for each depth layer.

C. Soil Organism Distribution

Soil organisms were extracted from each sample using the wet funnel extraction method and the hand-sorting technique for macrofauna such as

earthworms. Organisms were counted and categorized under a stereo-binocular microscope.

The total organism count per unit volume of soil was recorded for each depth layer. Statistical significance of differences across layers was evaluated using one-way analysis of variance (ANOVA), with post hoc testing applied where appropriate. Differences were considered statistically significant at $p < 0.05$.

D. Statistical Analysis

All data were expressed as mean $\pm$ standard deviation (SD) of three replicates. Statistical comparisons among depth layers were performed using one-way ANOVA followed by Tukey's post hoc test using standard statistical software. Significance was set at $p < 0.05$. Pearson's correlation coefficients were calculated to explore relationships among physico-chemical parameters and organism distribution across depth layers.

III. RESULTS

A. Physio-Chemical Parameters Across Depth Layers

The physio-chemical properties of soil samples collected from the four depth layers are summarized in Table 1. A consistent and statistically significant depth-dependent decline was observed across all measured parameters. Temperature decreased progressively from 25 ± 1.5 °C in Layer A to 19 ± 1.1 °C in Layer D. Similarly, pH declined from 7.2 ± 0.5 in the surface layer to 6.6 ± 0.5 in the deepest layer, indicating a shift from near-neutral to slightly acidic conditions with increasing depth. Water content showed the highest value at the surface ($95 \pm 2.0\%$) and declined to $85 \pm 2.5\%$ in Layer D. Organic matter content followed a similar trend, decreasing from $4.8 \pm 0.3\%$ in Layer A to $3.5 \pm 0.4\%$ in Layer D, with the most pronounced reduction occurring between Layers A and C. All differences between Layer A and the deeper layers (B, C, and D) were statistically significant ($p < 0.05$).

B. Soil Organism Distribution

The distribution of soil organisms across depth layers mirrored the trends observed in the physico-chemical parameters (Table 1).

Layer A supported the highest organism count (140 ± 2.5), reflecting the favorable combination of temperature, pH, moisture, and organic matter at the surface. A statistically significant decline ($p < 0.05$) was recorded from Layer A to Layer B (120 ± 2.5), and this reduction became more pronounced in Layer C (80 ± 5.0). The lowest organism count was recorded in Layer D (40 ± 4.0), representing a 71.4% reduction compared to the surface layer. These differences were statistically significant across all pairwise comparisons ($p < 0.05$).

IV. DISCUSSION

The findings of the present study demonstrate a clear and consistent depth-dependent deterioration in soil physio-chemical quality and biological abundance. The surface layer (A: 0–10 cm) consistently recorded the highest values for all parameters, reflecting its exposure to solar radiation, organic matter inputs from surface vegetation, and greater aeration—all of which promote biological activity (Brady & Weil, 2016). The significant decline in organism count from 140 ± 2.5 in Layer A to 40 ± 4.0 in Layer D closely parallels the reductions in organic matter, pH, temperature, and water content, indicating that soil organisms are highly responsive to changes in these abiotic drivers.

The near-neutral pH observed in Layer A (7.2 ± 0.5) is consistent with conditions favourable for a broad range of soil organisms and is comparable to values reported in arecanut and banana agroecosystems in southern India (Acharya *et al.*, 2015; Bhat & Sujatha, 2014). The mild acidification with depth—from pH 7.2 to 6.6—may reflect reduced organic matter decomposition and the accumulation of slightly acidic mineral constituents in deeper horizons (Ramesh & Mahadevan, 2016; Sharma & Minhas, 2005). Although the pH values across all layers remained within a range generally suitable for plant growth, the observed trend is consistent with findings from Cauvery delta soils and other tropical agricultural systems (Bhaskar *et al.*, 2015; Ramesh & Mahadevan, 2016).

The progressive reduction in water content with depth is of ecological relevance. Moisture availability is a primary regulator of microbial activity, nutrient

mineralization, and the habitat quality for soil macrofauna (Lal, 2015). The decline from $95 \pm 2.0\%$ in Layer A to $85 \pm 2.5\%$ in Layer D, while numerically modest, may represent a meaningful reduction in biological suitability, particularly given its co-occurrence with reduced organic matter and temperature. These combined deficits would limit the activity and reproduction of soil organisms in deeper layers (Paramesh *et al.*, 2025).

The decline in organic matter content from 4.8% at the surface to 3.2% in Layer C and 3.5% in Layer D is noteworthy. The slight recovery observed between Layers C and D may reflect the accumulation of slowly decomposable recalcitrant organic matter in deeper horizons, a phenomenon reported in other tropical soils (Lal, 2015). Organic matter is central to soil fertility, as it provides energy and nutrients for microbial communities, enhances water retention, and improves soil structure (Brady & Weil, 2016; Acharya *et al.*, 2015). Its depletion with depth is therefore a key driver of reduced biological activity in the lower soil profile.

From an ecotoxicological perspective, the depth-dependent decline in both physio-chemical parameters and organism abundance has important implications. Pesticides applied to the soil surface may leach downward through the soil profile, reaching deeper layers where organisms are already under physiological stress due to suboptimal abiotic conditions. Such organisms may exhibit heightened sensitivity to chemical toxicants, a phenomenon consistent with the synergistic effects of environmental stress and toxicant exposure documented in aquatic systems (Begum *et al.*, 2016; Moezzi *et al.*, 2025). Deeper soil layers, characterized by lower pH and reduced organic matter, may also exhibit altered pesticide sorption and degradation kinetics, potentially increasing bioavailable toxicant concentrations (Larson *et al.*, 1997; Goulson, 2013).

The sharp decline in organism count in Layer D is consistent with the threshold-based responses reported in ecotoxicological studies of soil invertebrates and microbial communities exposed to agrochemicals (Swaine *et al.*, 2025; Rao *et al.*, 1993). The use of organisms as a bioindicator is well-established and provides an integrative measure of

cumulative environmental stress across multiple physio-chemical gradients (Swaine *et al.*, 2025; IJMSRT, 2025). The statistically significant differences ($p < 0.05$) observed between Layer A and all other layers, as well as between non-adjacent layers, underscore the ecological sensitivity of soil organisms to depth-stratified changes in their environment.

These results are also relevant to sustainable soil management strategies. Practices that maintain or enhance surface organic matter content, such as mulching, cover cropping, and the addition of organic amendments, may buffer against depth-dependent quality decline and reduce ecotoxicological vulnerability (Paramesh *et al.*, 2025; Lal, 2015).

Conversely, tillage practices that disrupt the surface layer may accelerate the downward redistribution of physio-chemical stress, with potentially cascading effects on subsurface biodiversity (FAO, 2018).

V. CONCLUSION

The present study demonstrates that soil quality, as assessed through physio-chemical parameters and soil organism distribution, declines significantly with increasing depth. The surface layer exhibited the most favourable conditions for biological activity, with the highest values for temperature, pH, water content, organic matter, and organism count. A statistically significant depth-dependent reduction in all parameters was observed, with the deepest layer recording the lowest biological abundance, representing a 71.4% reduction in organism count relative to the surface. These findings highlight the critical importance of surface soil integrity for maintaining soil biodiversity and ecosystem function. From an ecotoxicological standpoint, the compromised physio-chemical conditions in deeper layers may amplify the vulnerability of soil organisms to pesticide exposure. The data presented serve as a useful baseline for soil health monitoring and underscore the need for depth-stratified approaches in soil quality and risk assessment studies.

Table 1. physio-chemical parameters and soil organism distribution across depth layers (mean $\pm$ SD, $n = 3$). Asterisks (*) denote statistically significant differences from Layer A ($p < 0.05$).

Layer (Depth, cm)	Temperature ($^{\circ}\text{C}$)	pH	Water Content (%)	Organic Content (%)	No. of Organisms
A (0–10)	25 ± 1.5	7.2 ± 0.5	95 ± 2.0	4.8 ± 0.3	140 ± 2.5
B (10–20)	$23 \pm 0.8^*$	$7.0 \pm 0.7^*$	$92 \pm 2.0^*$	$4.0 \pm 0.2^*$	$120 \pm 2.5^*$
C (20–30)	$21 \pm 0.8^*$	$6.8 \pm 0.4^*$	$89 \pm 1.5^*$	$3.2 \pm 0.4^*$	$80 \pm 5.0^*$
D (30–40)	$19 \pm 1.1^*$	$6.6 \pm 0.5^*$	$85 \pm 2.5^*$	$3.5 \pm 0.4^*$	$40 \pm 4.0^*$

ACKNOWLEDGMENTS

The authors wish to thank the Department of Zoology, Government Arts College, Coimbatore - 18, for providing facilities and support for this research. No funding sources were used for the above work. The authors confirm that there is no conflict of interest.

REFERENCES

- [1] Acharya, G. C., Paul, S. C., Chakrabarty, R., & Ray, A. K. (2015). Effect of organic and inorganic sources of nutrients on the soil fertility status of arecanut. *The Indian Journal of Agricultural Sciences*, 85(10), 1360–1365.
- [2] Begum, G., Venkateswara Rao, J., & Srikanth, K. (2016). Biochemical alterations in freshwater fish exposed to organophosphate pesticides and their role in environmental risk assessment. *Ecotoxicology and Environmental Safety*, 124, 110–116.
- [3] Bhaskar, B. P., (2015). Soil resource characterization for sustainable land use planning in the Cauvery delta region. *Journal of the Indian Society of Soil Science*.
- [4] Bhat, R., & Sujatha, S. (2014). Soil fertility status and disorders in arecanut (*Areca catechu*

- L.) grown on clay and laterite soils of India. *Communications in Soil Science and Plant Analysis*, 45(12), 1622–1635. <https://doi.org/10.1080/00103624.2013.875204>
- [5] Brady, N. C., & Weil, R. R. (2016). *The nature and properties of soils* (15th ed.). Pearson Education.
- [6] [6] Food and Agriculture Organization (FAO). (2018). *Soil pollution: A hidden reality*. FAO.
- [7] Goulson, D. (2013). An overview of the environmental risks posed by neonicotinoid insecticides. *Journal of Applied Ecology*, 50(4), 977–987. <https://doi.org/10.1111/1365-2664.12111>
- [8] *International Journal of Modern Science and Research Technology (IJMSRT)*. (2025). Influence of physicochemical parameters on pesticide toxicity in soil and aquatic systems.
- [9] Kumar, V., Singh, J., & Kumar, P. (2019). Role of plant extracts in detoxification of environmental pollutants. *Environmental Science and Pollution Research*, 26, 12345–12358.
- [10] Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, 7(5), 5875–5895. <https://doi.org/10.3390/su7055875>
- [11] Larson, S. J., Capel, P. D., & Majewski, M. S. (1997). *Pesticides in surface waters: Distribution, trends, and governing factors*. Ann Arbor Press.
- [12] Matthews, G. A. (2016). *Pesticides: Health, safety and the environment* (3rd ed.). Wiley-Blackwell.
- [13] Moezzi, S. A., Ramezani, S., Rezaei, K., & Kohei, A. J. (2025). Mechanisms of pesticide toxicity in fish: Insights into the ameliorative role of plant-derived compounds. *Aquaculture Nutrition*, 2025, 5328773. <https://doi.org/10.1155/2025/5328773>
- [14] Paramesh, V., Kumar, P., Kumar, R. M., Jinger, D., Chillarge, S., Bhattacharjee, S., & Sannagoudar, M. S. (2025). Soil quality enhancement in arecanut-based agroforestry system. *Indian Journal of Agricultural Sciences*, 95(3), 331–335.
- [15] Pimentel, D. (1995). Amounts of pesticides reaching target pests: Environmental impacts and ethics. *Journal of Agricultural and Environmental Ethics*, 8(1), 17–29. <https://doi.org/10.1007/BF02286399>
- [16] Pimentel, D., & Levitan, L. (1986). Pesticides: Amounts applied and amounts reaching pests. *BioScience*, 36(2), 86–91. <https://doi.org/10.2307/1310103>
- [17] Ramesh, R., & Mahadevan, S. (2016). Soil characteristics and fertility status of Cauvery delta region. *Indian Journal of Soil Conservation*.
- [18] Rao, D. M., et al. (1993). Impact of pesticide pollution on non-target organisms. *Environmental Toxicology Studies*.
- [19] Sharma, P., & Minhas, P. S. (2005). Strategies for managing saline and alkali soils. *Agricultural Reviews*.