

Baseline Assessment of Soil Physico-Chemical Parameters and Macro-Invertebrate Distribution Across Urban and Agricultural Matrices in Punjab, Pakistan

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Research Article

Keywords: Edaphic parameters, Earthworms, Soil organic matter, Land-use matrices, Punjab, Soil ecology

Posted Date: October 29th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11530221/v1>

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Additional Declarations: The authors declare no competing interests.

Abstract

Purpose: Understanding the quantitative relationship between edaphic factors and soil fauna is vital for regional soil health monitoring. This study provides an empirical baseline assessment of soil physico-chemical parameters and macro-invertebrate (earthworm) abundance across four distinct urban and agricultural land-use matrices in Punjab, Pakistan.

Methods: Using a stratified random sampling design across four sites (LCWU Ground, an agricultural sugarcane field in Pattoki, Lawrence Gardens, and a site near Sagian Bypass), soil samples were collected in five replicates per site. Soil depth cores (6 inches) were evaluated for earthworm counts. Standard laboratory methods were employed to quantify organic matter (titration), moisture content (gravimetric), pH, electrical conductivity (EC), and available phosphorus (spectrophotometric acid digestion).

Results: Earthworm abundances varied significantly across matrices, ranging from means of 1.8 ± 0.8 at LCWU to 7.8 ± 0.65 in the agricultural sugarcane field. Organic matter percentages exceeded standard agricultural thresholds across all sites. Correlation analysis revealed a strong positive relationship between organic matter and earthworm abundance ($r = 0.8811$), whereas moisture content ($r = -0.1116$), pH ($r = 0.0523$), electrical conductivity ($r = -0.0598$), and available phosphorus ($r = -0.2930$) exhibited weak or negative correlations with earthworm numbers.

Conclusion: Soil organic matter serves as a primary reliable indicator for regional earthworm population distribution. While these empirical baselines offer valuable insights for sub-tropical land-use management, multi-season studies are recommended to further investigate mechanistic biochemical pathways.

1 Introduction

Soil is a vast ecosystem and has a huge diversity of micro and macro organisms all imparting their role in its unique properties and functions. The physical and chemical properties of soils have an important correlation with diversity of living organisms in soil. The diverse range of organisms and functions the macro-fauna community performs in the soil combines to produce a diversity in biogenic soil structures that help regulate soil physical properties, processes, and nutrient cycles, further providing a whole host of ecosystem services that help increase heterogeneity in soils and the soil ecosystem's resilience and resistance to ecological disequilibria (Pankhurst et al. 1997; Paoletti 1999).

Earthworms are among the most critical macro-organisms in soil ecosystems, acting as bio-indicators of soil health, fertility, and sustainability (Paoletti 1999). They mix soil layers, incorporate organic matter into the mineral matrix, and enhance nutrient availability for plant uptake (Chauhan 2014). Several key soil quality parameters influence the population density, distribution, abundance, and activity of earthworms, including soil pH, moisture content, temperature, soil texture, and organic matter content (Wood 1972; Lee 1985; Werner et al. 2005). Earthworms also play a vital role in nutrient availability

through the decomposition of organic matter and enhancement of soil physical structure (Aina 1984; Edwards and Bohlen 1996; Abdul Rida and Bouché 1997). Earthworm abundance is typically higher in undisturbed soil ecosystems compared to heavily cultivated and ploughed agricultural soils (Edwards and Bohlen 1996; Kladivko 2003; Brown et al. 2004).

Pakistan is predominantly a dry-land country where 80 percent of its land area is arid or semi-arid (GOP 2006). Out of a total geographical area of 79.61 million hectares (m ha), only 21.59 m ha is under cultivation, and merely 5.34 m ha (25 percent) is free from severe soil limitations and fit for intensive agriculture (Mian and Mirza 1993; Ahmad et al. 1998). Thus, three out of four hectares of cultivated land in Pakistan face health degradation, posing serious threats to sustainable agricultural growth (Ahmad et al. 1998).

Despite extensive global literature on earthworm biodiversity and ecology (Tsai et al. 1999, 2000; Blakemore 2000, 2002, 2003; Chang and Chen 2004, 2005a, b; Blakemore et al. 2006; Sautter et al. 2006), quantitative empirical evaluations connecting soil physico-chemical parameters with earthworm abundance across urban and agricultural matrices in Pakistan remain limited. Therefore, this study was conducted to determine the quantitative relationship between soil physico-chemical parameters (organic matter, moisture content, pH, electrical conductivity, and available phosphorus) and earthworm abundance across four distinct land-use matrices in Punjab, Pakistan.

2 Materials and Methods

2.1 Study Area and Research Design

This study employed a correlational research design to evaluate how the physical and chemical properties of soil affect the abundance of earthworms across four sampling sites in Lahore and surrounding districts, Punjab, Pakistan, over a four-month period (April to August 2016):

1. Garden in Lahore College for Women University (LCWU), Lahore (Institutional urban garden matrix).
2. Agricultural Field (Sugarcane crop) located in Lakhodair, District Pattoki (Commercial agricultural matrix).
3. Lawrence Garden, Lahore (Historic botanical garden matrix).
4. Land near Sagian Wala Bypass, Lahore (Urban-peri-urban roadside matrix).

2.2 Sampling Methodology and Earthworm Quantification

Soil sampling was conducted using a Stratified Random Sampling methodology. Each of the four study sites was divided into five distinct sub-sampling portions, yielding a total of 20 sampling locations. Earthworms were physically counted in situ by excavating soil blocks to a depth of 6 inches (15 cm) over a standardized surface unit area (Welke and Parkinson 2003). Following macro-invertebrate counting, soil samples were transferred to labeled zip-lock plastic bags and transported to the Environmental Science Laboratory at Lahore College for Women University for analytical testing.

2.3 Laboratory Analysis of Physico-Chemical Parameters

Soil samples were prepared through oven drying at 100°C for 12 hours, disaggregated using a mortar and pestle, and passed through a 2 mm stainless steel sieve to remove debris, roots, and coarse gravel.

Organic Matter (%): Soil organic matter was determined by Walkley-Black chromic acid wet oxidation titration (Walkley and Black 1934). Briefly, 1.0 g of sieved soil was treated with 10 mL of 1 N K₂Cr₂O₇ solution and 20 mL of concentrated H₂SO₄, left to stand for 30 minutes, and diluted to 200 mL with deionized water. After adding 10 mL H₃PO₄, 0.2 g NaF, and 10 drops of diphenylamine indicator, the solution was titrated against 0.5 N Ferrous Ammonium Sulfate until a sharp green endpoint appeared. Organic matter was calculated as:

Formula

$$\% \text{ Organic Matter} = 10 \times [1 - (S / B)] \times 0.67$$

where S is the sample titration volume (mL) and B is the blank titration volume (mL).

Moisture Content (%): Moisture content was determined gravimetrically (Black 1965). Soil samples (30 g) were weighed, oven-dried at 105°C for 24 hours, re-weighed, and calculated as:

Formula

$$\% \text{ Moisture Content} = [(Wet \text{ Mass} - Dry \text{ Mass}) / Dry \text{ Mass}] \times 100$$

pH and Electrical Conductivity (EC): Saturated soil pastes were prepared using air-dried soil and distilled water, stirred thoroughly, and allowed to equilibrate for 1 hour. Soil pH was measured directly using a calibrated digital pH meter (Model: pH 3110) (Black 1965). Electrical conductivity was determined on the saturated paste extract using a conductivity meter (wtw inoLab).

Available Phosphorus (ppm): Soil samples (1.0 g) underwent alkaline fusion acid digestion with Na₂CO₃ in a muffle furnace at 900°C for 2 hours (Nagornyy 2013). The cooled melt was dissolved in hot water and 6 N HCl, filtered through Whatman No. 5 filter paper into a 500 mL volumetric flask, and brought to volume. Colorimetric determination was performed on a UV-Vis Spectrophotometer (Evolution 300) at 710/880 nm using the ammonium molybdate-ascorbic acid method against a KH₂PO₄ standard calibration curve (0.2 to 8.0 ppm). Available phosphorus concentration (ppm) was calculated considering a dilution factor of 500.

2.4 Statistical Analysis

Data were compiled and analyzed statistically to determine Mean, Standard Error (SE), and Pearson Correlation Coefficients (r) between earthworm abundance and each measured soil physico-chemical parameter.

3 Results

The mean values and standard errors for earthworm counts and soil physico-chemical parameters across the four study sites are summarized in Table 1.

Table 1
Physico-chemical soil parameters and earthworm abundance (Mean $\pm$ SE) across study sites in Punjab, Pakistan.

Sampling Site	Earthworm Count (per 6")	Organic Matter (%)	Moisture Content (%)	pH	Electrical Cond. (μ S/cm)	Available P (ppm)
LCWU Ground	1.8 $\pm$ 0.80	7.54 $\pm$ 0.50	21.18 $\pm$ 2.94	7.85 $\pm$ 0.11	597.8 $\pm$ 68.12	288.0
Agricultural Field	7.8 $\pm$ 0.65	8.98 $\pm$ 0.14	12.66 $\pm$ 0.73	7.81 $\pm$ 0.03	569.2 $\pm$ 29.19	216.5
Lawrence Garden	4.4 $\pm$ 0.69	7.55 $\pm$ 0.52	16.42 $\pm$ 1.97	7.39 $\pm$ 0.11	743.8 $\pm$ 66.90	112.5
Sagian Bypass	4.4 $\pm$ 0.26	8.26 $\pm$ 0.76	136.36 $\pm$ 13.35	5.36 $\pm$ 0.18	351.6 $\pm$ 25.46	322.5
Overall Mean / Range	1.8–7.8	7.54–8.98	12.66–136.36	5.36–7.85	351.6–743.8	234.88 $\pm$ 27.97

3.1 Earthworm Abundance

The maximum mean earthworm abundance was recorded in the agricultural sugarcane field (7.8 $\pm$ 0.65 per 6" depth core; range 7 to 10), whereas the lowest count was observed at the LCWU institutional garden site (1.8 $\pm$ 0.80 per 6" depth core; range 0 to 6). Both Lawrence Garden and Sagian Bypass exhibited identical mean earthworm counts of 4.4 per core (SE $\pm$ 0.69 and $\pm$ 0.26, respectively).

3.2 Soil Organic Matter and Moisture Content

Organic matter percentages were highest in the agricultural sugarcane field (8.98 $\pm$ 0.14%), followed by Sagian Bypass (8.26 $\pm$ 0.76%), Lawrence Garden (7.55 $\pm$ 0.52%), and LCWU (7.54 $\pm$ 0.50%). Soil moisture content exhibited extreme variation, ranging from a minimum mean of 12.66 $\pm$ 0.73% in the agricultural field to a maximum mean of 136.36 $\pm$ 13.35% at the Sagian Bypass roadside site.

3.3 Soil pH, Electrical Conductivity, and Available Phosphorus

Soil pH was alkaline at LCWU (7.85 $\pm$ 0.11) and the Agricultural Field (7.81 $\pm$ 0.03), neutral at Lawrence Garden (7.39 $\pm$ 0.11), and moderately acidic at Sagian Bypass (5.36 $\pm$ 0.18). Electrical conductivity peaked at Lawrence Garden (743.8 $\pm$ 66.90 μ S/cm) and was lowest at Sagian Bypass (351.6 $\pm$ 25.46

μS/cm). Available phosphorus concentration ranged from 112.5 ppm at Lawrence Garden to 322.5 ppm at Sagian Bypass, with LCWU and Agricultural Field exhibiting 288.0 ppm and 216.5 ppm, respectively.

3.4 Correlation between Earthworm Abundance and Soil Parameters

Statistical Pearson correlation analysis revealed key quantitative relationships:

- Organic Matter vs. Earthworm Abundance: Strong positive correlation ($r = 0.8811$).
- Soil pH vs. Earthworm Abundance: Weak positive correlation ($r = 0.0523$).
- Moisture Content vs. Earthworm Abundance: Weak negative correlation ($r = -0.1116$).
- Electrical Conductivity vs. Earthworm Abundance: Very weak negative correlation ($r = -0.0598$).
- Available Phosphorus vs. Earthworm Abundance: Weak negative correlation ($r = -0.2930$).

4 Discussion

The results of this study establish that soil organic matter is the primary edaphic factor positively governing earthworm abundance across different land-use matrices in Punjab, Pakistan. The agricultural sugarcane field supported both the highest organic matter content (8.98%) and the greatest earthworm density (7.8 individuals/core). This strong positive correlation ($r = 0.8811$) corroborates earlier findings by Hendrix et al. (1992) and Valchovski (2016), who reported that soil organic carbon directly favors Lumbricidae population density and biomass by serving as a primary nutritive substrate.

Conversely, soil moisture content exhibited a weak inverse relationship with earthworm abundance ($r = -0.1116$). Although adequate soil moisture is essential for earthworm cutaneous respiration and metabolic activity (Eckert and Randall 1988), excessive waterlogging—such as that observed at the Sagian Bypass site (136.36% moisture)—creates hypoxic or anaerobic soil conditions, displacing dissolved oxygen and forcing earthworms to migrate or perish (Mariappan et al. 2013).

Soil pH demonstrated a weak positive correlation ($r = 0.0523$). Most earthworm species are neutrophilic, preferring pH levels between 6.0 and 7.0 (Karmegam and Daniel 2007; Salehi et al. 2013). The mildly acidic conditions at Sagian Bypass (pH 5.36) and the slightly alkaline conditions at LCWU (pH 7.85) highlight local environmental thresholds beyond which species richness and density may decline.

Electrical conductivity (EC) and available phosphorus showed weak negative correlations with earthworm count ($r = -0.0598$ and $r = -0.2930$, respectively). High electrical conductivity indicates elevated soil salinity, which increases osmotic stress on soft-bodied macro-invertebrates (Karmegam and Daniel 2007). Similarly, high available phosphorus levels—often stemming from intensive agrochemical application or urban runoff—can negatively impact earthworm biomass and survival (Iordache and Borza 2010). Overall, organic matter content remains the single most reliable biophysical indicator for macro-invertebrate abundance in these sub-tropical soil matrices.

5 Conclusion

This study provides an empirical baseline assessment of soil physico-chemical parameters and macro-invertebrate (earthworm) abundance across four urban and agricultural matrices in Punjab, Pakistan. Soil organic matter was identified as the critical driver positively influencing earthworm populations ($r = 0.8811$). In contrast, excessive moisture content, elevated electrical conductivity, extreme pH shifts, and high available phosphorus levels exerted neutral to negative influences on earthworm density. Sustainable soil management in regional agroecosystems should prioritize organic amendments, balanced fertilization, and minimal mechanical disturbance to maintain soil faunal biodiversity and long-term soil health.

Declarations

Competing Interests:

The authors declare that they have no competing financial or non-financial interests that are directly or indirectly related to the work submitted for publication.

Funding:

No external funding was received for conducting this study.

Author Contributions:

Affifa Noor designed the study, conducted field sampling, performed laboratory analyses, analyzed data, and wrote the manuscript. Zaira Ahmad contributed to study co-supervision, methodological verification.

Acknowledgements

The authors gratefully acknowledge the Department of Environmental Sciences, Lahore College for Women University (LCWU), Lahore, Pakistan, for providing laboratory facilities, analytical instruments, and logistical support for this research project.

Data Availability:

The data supporting the findings of this study are available within the article.

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