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Research Article

Assessing Soil Quality Using Mesofauna as a Potential Bio-Indicator: A Case Study in Manthali Municipality, Nepal

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Abstract
Soil mesofauna is a key component of the terrestrial ecosystem that contributes to diverse soil and other ecological functions. Despite mesofauna having the potential to be used as indicators of soil quality, they are not frequently included in soil quality analysis. This study aimed to assess soil mesofauna's behavior and physico-chemical parameters under various land uses to better understand its effectiveness as a soil quality indicator. Soil samples were collected from 5 land-use types: Grazed Forest (F1), Ungrazed Forest (F2), Residential Area (Re), Upland Agricultural Area (UA), and Lowland Agricultural Area (LA) of Manthali Municipality, Nepal. For mesofauna, soil samples were collected using a quadrat along with the Berlese-Tullgren Funnel method for extraction and literature for identification. A total of 601 soil mesofauna were recorded, belonging to 8 classes. Oribatida and Collembola were the most abundant taxa, found in almost all land-use types, while few were specific to a particular land-use type. Shannon Wiener Diversity Index ranged from 0.82 (Re) to 1.22 (F1). Notably, Re showed high mesofaunal abundance but low diversity, highlighting an abundance-diversity trade-off under urban stress. The mesofaunal diversity was found to be influenced by soil moisture content, soil pH, temperature, and soil organic matter content. Among almost all soil parameters assessed, UA was superior to other land-use types, while Re had poor soil quality with the least mesofaunal diversity. In addition, Re had a high abundance of highly tolerant taxa like Oribatida and Collembola, indicating high stress in this land-use type. Moreover, the abundant number of mesofauna and the presence of Araneae in F2 possibly indicated healthy soil, as they play an important role in the soil food chain as predators. Thus, these findings provide important insights for incorporating soil mesofauna and other physico-chemical parameters to indicate soil quality.

Keywords: Bio-indicator, soil mesofauna, soil quality

Introduction

Soil quality, in general, is the potential of how well soil performs its productivity and environmental functions as a biologically active medium within ecosystem boundaries (Bastida et al., 2008; Garbisu et al., 2011; Fausak et al., 2024; Karlen et al., 1997; Karlen et al., 2008). Soil quality is commonly assessed using physical, chemical, and biological parameters (Abshiba et al., 2025; Parr et al., 1992). While key physical and chemical parameters such as moisture content, water holding capacity, infiltration, bulk density, total organic matter (OM), pH, available nitrogen (N), phosphorus (P), potassium (K), electrical conductivity, base saturation, and cation exchange capacity are frequently studied (Arnold et al., 2005; Bunemann et al., 2018; Lamsal et al., 2025; Navidi & Seyedmohammadi, 2020; Xu et al., 2019), biological indicators, on the other hand, remain comparatively underrepresented due to the complex and highly intricate interactions of organisms in the soil and a lack of sufficient baseline information (Andren et al., 2008; Howard, 1972; Mohkam-Singh & Nunes, 2025). While physical and chemical properties are important indicators of soil quality, they alone do not capture biological processes and ecosystem functioning. Therefore, there is a need to incorporate biological parameters for a holistic understanding of soil function and an accurate interpretation of soil quality status and management needs (Doran & Zeiss, 2000; Fan et al., 2025).

Among the biological parameters, soil invertebrates, particularly mesofauna, are a key indicator of soil quality (Heydari et al., 2020). They are among the most abundant, medium-sized (0.1 – 2 mm) organisms and are a significant part of terrestrial biodiversity (Briones, 2014; Dervash et al., 2018). They have a diverse range of ecological functions, including mineralization, mobilization, and regulation, especially of N and P, and serve as food sources for many macroinvertebrates (Chassain et al., 2021; Frouz, 2018; Koehler, 1997; Lakshmi et al., 2020). Mesofauna also has a wide range of feeding habits, with the majority being microbial feeders and some being plant feeders; a few are omnivorous and predators (Sauvadet et al., 2017). Because of their diverse feeding habits, mesofauna occupy nearly all trophic levels in the soil food web (Haynert et al., 2017). Their functions and interactions along the food chain highly influence soil health (George et al., 2017).

Furthermore, these organisms are sensitive to various natural and human-induced disturbances and exhibit rapid changes in spatial distribution, abundance, diversity, and even local species loss in some cases (Ekschmitt et al., 2003; Menta & Remelli, 2020). Many studies have concluded that intensive agricultural practices, heavy grazing, and urbanization reduce soil mesofauna because of soil compaction. At the same time, irrigation and fertilization in agroecosystems help to maintain high mesofaunal densities (Castro et al., 2015; Henneron et al., 2015; Moulin et al., 2019). Their

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wide range of taxonomic diversity, variety of life-history traits, and feeding patterns allow them to adapt to many habitats and situations, making them the best fit as soil quality indicators (Bellino et al., 2021; De Groot et al., 2016).

According to the United Nations, one-third of the world's fertile soil is being degraded, which is expected to continue as food demand and population grow (Watts, 2017). Anthropogenic activities like unsustainable agriculture, deforestation, overgrazing, construction, and urbanization are the major contributors to global soil degradation (Jie et al., 2002; Karlen & Rice, 2015; Lal, 2015), and a similar is the trend is observed in Nepal. High topographical variation, a range of climatic and ecological zones, and unique but geologically fragile landforms inherently characterize Nepal. With 83% of its total area covered by mountainous terrain, along with the added effect of high-intensity monsoon rainfall, Nepal is vulnerable to mass wasting processes and simultaneously to fertility and quality degradation (Chalise et al., 2019; Singh et al., 2021). Adding to these natural factors, land-use and land cover change driven by rapid urbanization, agricultural expansion, overgrazing, and infrastructural development have led to further decline in soil quality in Nepal (Rimal et al., 2018).

Over the past few decades, different studies have shown a significant change in cropland and forestland, followed by grassland, wetland, and others (MoFE, 2019). Along with the decrease in cultivable land, agricultural practices have also changed drastically (Raut et al., 2010). Cash crops and vegetables are preferred over cereal crops, which reflects market-oriented farming rather than subsistence farming (Dhakal, 2025; Raut et al., 2011). For this reason, farmers are performing excessive tilling, using chemical fertilizers, insecticides, pesticides, and heavy machinery, resulting in the degradation of soil properties. Studies show that the use of urea has doubled from 90,000 Metric Tons (MT) to 180,000 MT, and DAP from 20,000 MT to 100,000 MT between 1992 and 2015 (Pandey, 2017). Similarly, major pesticide use in agricultural areas has also increased from nearly 0 kg/ha in 1990 to 0.25 kg/ha in 2016 (Dhungana, 2020). While using agrochemicals has significantly helped in the production of several crops and in maintaining the soil fertility in different parts of Nepal, excessive and sometimes imbalanced use of them has led to several soil-related consequences, such as fertility loss, acidification, biodiversity loss, soil-borne diseases, reduced nutrient retention, aggregation loss, etc. (Chalise et al., 2019; GON, 2008; Karkee, 2004; Lamsal et al., 2025; Pilbeam et al., 2002; Raut & Sitaula, 2012). Increased productivity from intensified inputs must be balanced with long-term soil sustainability, especially regarding soil biological processes (Mridha et al., 2025). From the nutritional point of view, it is estimated that 60-70% of the soils of Nepal have low OM and low pH values, 23% have low P, and 18% have low K (Kharal et al., 2018).

The status of soil quality in Nepal seems to be still insufficiently assessed and understood. Some recent studies in Nepal show that soil mesofauna are sensitive to land-use changes, organic matter content, moisture regimes, and human disturbances, highlighting their importance as a potential indicator of soil health (Begum et al., 2011; Begum et al., 2014; Shrestha & Budha, 2022). Studies conducted in the mid-hills region of Nepal have indicated that mesofauna show a rapid response to agricultural intensification and land-use changes, often more clearly than physico-chemical parameters alone (Begum et al., 2011; Begum et al., 2014; Paudel & Tiwari, 2022). Despite showing a strong potential for incorporating mesofauna into soil quality assessment, such studies remain limited and site-specific. Therefore, this research aimed to assess different physical and chemical properties along with biological properties of soil under different land-use practices in one of the emerging cities, Manthali Municipality, in the mid-hills of Nepal.

Manthali lies within the rain shadow zone of the Mahabharat range, which provides it with a warm and subtropical climate, low annual rainfall, and recurring problems of drought and desertification. This region is also pocketed by two small rivers, which eventually end up in the Tamakoshi and are frequently prone to flooding. These climatic conditions and geographical allocation favor very distinct soil vegetations and the environment strongly influence soil properties of this study area. Manthali serves as a headquarters and market hub for the entire Ramechhap district; with this centralization, population growth and urbanization are inevitable. Moreover, with agriculture being one of the major occupations of the locality, which is phasing towards commercialization, agricultural practices have become more intensive (harsh tillage, excessive chemical fertilizer use, and land cover change). These activities have substantial potential in altering the soil properties, accelerating degradation, and eventually reducing the soil productivity.

This study will therefore provide a basis for understanding the ongoing changes and allow the beneficiaries of different land-use types within the municipality to evaluate the impact of their activities on soil and its functioning, and to adopt a suitable management strategy. Additionally, studying soil properties with mesofauna as a key indicator will not only be beneficial for the municipality but will also contribute to the border context by strengthening the mesofauna inventory of Nepal, which otherwise is not widely represented in soil research. The main objective of our study was to assess soil quality under different land-use types in Manthali municipality. Our specific objectives were to (i) to assess different physical and chemical properties of soil from different land-use, (ii) to assess mesofaunal assemblages, and (iii) to examine the relationship between mesofaunal metrics and soil environmental variables.

Materials and Methods

Study Area

The study was conducted in Manthali Municipality, the headquarters of Ramechhap district, which is located around 80 km east of Kathmandu Valley and connected via the BP highway (Fig. 1). The study area is characterized by valleys, ridges, and hill slopes distributed within the latitude ranging from 27°18' to 27°26' N and 85°58' to 86°09' E longitude and elevations ranging from 452 m to 2058 masl. This municipality lies in the rain shadow zone of the Mahabharat range, which provides it with a warm and subtropical climate, characterized by a mean annual temperature of 19°C. As a result, it receives less rainfall in comparison to other areas in the mid-hills of Nepal. Especially the southern part (annual rainfall: 1154.7 mm), which has led to severe problems of drought and semi-desertification. With one-third share each, agricultural land and forest dominate the study area; other land-use types include shrubland, residential areas, etc. (DFRS, 2018; Manthali Municipal Office, 2021).

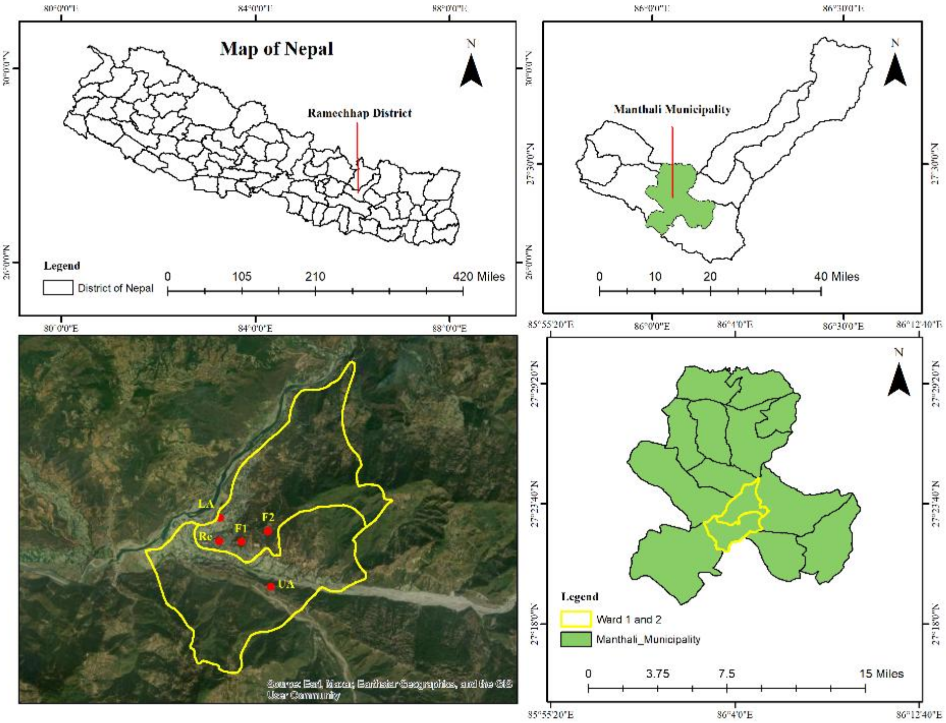

Figure 1. Map of the study area showing the location of the study site at different spatial scales, including the national, district, municipal, and ward levels, along with a satellite view indicating sampling locations.

Soil samples were collected from 5 different land-use types, namely Upland agricultural area (UA), Lowland agricultural area (LA), Grazed Forest (F1) (Sani Madhau Community Forest), Ungrazed Forest (F2) (Khok Community Forest), and Residential Area (Re). Agricultural areas were classified into UA and LA, based on topographical distribution, cropping, and irrigation systems. Higher-elevation agricultural lands with two crop rotations per year (maize, millet, and vegetables) were classified as UA. In comparison, lower-elevation agricultural lands with irrigated farming and three crop rotations per year (mustard, paddy, and maize) were classified as LA.

Forests were categorized as grazed and ungrazed based on livestock grazing. Khok community forest, which has been under livestock grazing for almost a decade (N. Shrestha, personal communication, March 27, 2022), was categorized as a grazed forest, and Sani Madhau CF, with no grazing at all (U. Subedi, personal communication, September 15, 2021), as an ungrazed forest. Both forests are a combination of natural and plantation forests and have a mix of different tree species such as *Pinus roxburghii* (Chir Pine), *Schima wallichii* (Chilaune), *Acacia catechu* (Khayar), *Royal poinciana* (Gulmohar), etc.

Soil Sampling

Four sets of samples, three for physico-chemical and one for mesofauna analysis, were collected with four replicates, making up a total of 80 samples. Soil is inherently highly variable, so enough replication helps with background variability and reduces the standard error, and 4 replications are a practical balance of precision and cost/time (Casler, 2015; Yan, 2021). These samples were collected at the end of the monsoon season (September 2021). The soil for mesofauna was sampled using a 10 x 10 cm quadrat at a depth of 5 cm. Many studies have shown that at this depth, the mesofaunal activities (especially arthropods) are high due to litter and humus concentration and declines in deeper layers (Onen & Koc, 2011; Seniczak et al., 2024). Samples for other parameters were collected from a depth of 0 – 15 cm using a core sampler, a hand trowel, a shovel, etc. Thus, these shallow soil sampling zones justify the practicality as well as the efficiency of the sampling. These samples were then collected in zip-lock bags, labeled, and transported to the laboratory for further analysis, as shown in Table 1. Soil mesofauna were extracted using the modified Berlese-Tullgren funnel method (Begum et al., 2010; Tullgren, 1918). Primarily, mesofauna were identified at the order level, which is appropriate for soil quality and bioindicator studies (Gallese et al., 2025). Standard taxonomic keys and regional literature were used for identification, and the specimens were cross-checked between the sample to ensure consistency. Where the identifications were uncertain, taxa were kept at a higher taxonomic level to avoid misclassification. The list of soil quality parameters measured is listed above, along with the methods adopted.

Table 1. Soil quality parameters measured, and the methods adopted

S. N.	Parameters	Apparatus/Methods	Reference
Physical parameters			
1	Temperature	Thermometer	
2	Moisture content (MC)	Gravimetric method	(Reynolds, 1970)
3	Bulk density (BD)	Core method	(Al-Shammary et al., 2018)
4	Soil texture	Hygrometer method	(Black, 1965)
Chemical parameters			
1	Nitrogen (N)	Kjeldahl method	(Bremner & Mulvaney, 1986)
2	Phosphorous (P)	Modified Olsen's method	(Kulkarni et al., 2014)
3	Potassium (K)	Flame Photometry	(Benren & Huizhen, 1985)
4	Organic carbon	Dry combustion method	(Nelson & Sommers, 2013)
5	pH	Glass calomel electrode method	(Mclean, 1982)
6	Soil organic matter (SOM)	Ash dry method	(Nelson & Sommers, 2013)
Biological parameters			
1	Mesofauna	Extraction: Berlese-Tullgren funnel. Identification: Standard, Available, and Regional Literature. Diversity: Shannon-Wiener Index	(Macfadyen, 1953; Spellerberg & Fedor, 2003)

Data analysis

SPSS version 20.0 was used for data analysis. Before statistical analyses, data were examined for normality and homogeneity of variance using the Shapiro-Wilk test and Levene's test. Statistical differences were tested using one-way ANOVA followed by a post hoc Tukey's test, whereas the relationship between soil physico-chemical and biological properties was determined using Pearson's correlation. The diversity of soil organisms was determined using the Shannon-Wiener diversity index (H). Statistical significance was considered at $p < 0.05$.

Results and Discussion

Land-use effects on soil physico-chemical parameters

To prevent speculative explanation, results are first presented descriptively, and interpretation is restricted to statistically supported patterns. Within the study area, soil quality parameters varied widely among the land-use types. Parameters like pH, MC, BD, SOM, and soil texture varied significantly among different land-use types ($p < 0.05$), while other parameters like temperature, N, P, and K were not significant. These variations suggest that land-use practices are strongly associated with soil structural and OM dynamics, which are key drivers of biological activity and soil functioning. Moderately acidic soil (LA) to slightly alkaline soil (Re) was found in the study area (Table 2). All the land-use types except for Re had a pH value that is considered suitable for plant growth, as it supports the optimum availability of nutrients essential for plant growth (Gentili et al., 2018).

In addition, the observed mean value of SOM ranged from 1.5–5%, which suggests medium (UA, F1, F2) to low SOM (Re, LA) in the study area (NARC, 1993) (Table 2). Together, soil pH and SOM are important factors related to soil biological processes across land-use types by affecting microbial activity, nutrient availability, and soil fauna habitat quality (Lal, 2025). The highest SOM in UA might be due to low crop rotation and excessive farmyard and animal manure use. At the same time, in F2, leaf litter, dead parts of forest vegetation, and faunal discharge may have aided in high SOM addition.

Loamy, clayey loam, sandy loam, and silty loam soils were found in the study area (Table 2). The dominance of phyllite and quartzite rocks in the study area might have resulted in this variety of soil texture (Covelo et al., 2017; EPP, 2021). N and P were highest in UA and positively correlated with SOM (Table 2). UA was subjected to less intensive agricultural activities with two crop rotations. However, this land-use type had a high input of N-based fertilizer, organic manure, and P-based fertilizers.

Thus, the observed higher N and P levels in UA may reflect fertilizer inputs exceeding crop demand. This may have resulted in a higher N and P residual in the soil (Lu et al., 2020; Sainju et al., 2019). Elevated nutrient levels may boost productivity in the short term, but nutrient buildup beyond crop demand often changes soil biological processes and raises the possibility of nutrient imbalance and environmental loss pathways (Wang et al., 2024). A similar study conducted by Wang et al. (2020) also showed an increase in N content in agricultural land after continuous application of organic manure for a few years.

However, the low N, P, and K concentrations in LA in comparison to UA are probably due to loss of nutrients because of excessive irrigation for paddy plantations, multiple crop rotation, and seasonal flooding (Alewell et al., 2020; Manu et al., 2021; Tolessa & Senbeta, 2018). Under intensive, water-managed agricultural systems, such nutrient depletion can limit soil biological activity and lower the soil's ability to support a variety of mesofaunal communities (Napoletano et al., 2025).

Table 2. Summary table for the value of physico-chemical parameters under different land-use types

Land-use	Temperature (°C)	MC (%)	BD (g/cm^3)	Textural Class	pH	SOM (%)	N (%)	P (mg/l)	K (mg/l)
F1	27±1.23^{abcde}	18.71^{abcd}	1.34 ± 0.15^{abcd}	Loam	6.20±0.23^{abcd}	3.07± 0.34^{abcde}	0.215 ± 0.029^{abcde}	0.14 ± 0.03^{abcd}	22.69 ± 7.05^{abcde}
F2	27±1.34^{abcde}	20.95^{abcd}	1.39 ± 0.13^{abcde}	Clay loam	6.07±0.36^{abcd}	4.01±0.36^{abcde}	0.186 ± 0.016^{abcde}	0.24 ± 0.15^{abcde}	26.90 ± 10.63^{abcde}
Re	28±1.81^{abcde}	22.74^{abcd}	1.64 ± 0.11^{de}	Sandy loam	7.86±0.17^{e}	2.17± 0.48^{abcd}	0.184 ± 0.047^{abcde}	0.36± 0.21^{abcde}	37.18 ± 29.46^{abcde}
UA	28±0.83^{abcde}	23.22^{abcd}	1.15 ± 0.17^{abcd}	Loam	6.34±0.49^{abcd}	5.10± 2.55^{cde}	0.297 ± 0.139^{abcde}	0.55 ± 0.31^{bcde}	34.59 ± 18.64^{abcde}
LA	27±0.78^{abcde}	40.96^{e}	1.35 ± 0.01^{dbcd}	Silt loam	5.67±5.67^{abcd}	1.87± 0.85^{abcd}	0.171 ± 0.046^{abcde}	0.22 ± 0.07^{abcde}	1.21 ± 0.81^{abcde}

*Different letters in a column represent the significant difference in the mean value of the analyzed parameter at $p < 0.05$, using One-Way ANOVA and the post hoc Tukey multiple comparison test.

A significant positive correlation between pH and BD ($r = 0.740$, $p < 0.01$) implies that higher soil pH tends to occur in soil with larger bulk density. There was a significant positive correlation ($r = 0.708$, $p < 0.01$) between sand content and BD, while a negative correlation with MC ($r = -0.55$, $p < 0.05$) was observed. Little pore space in sandy soil results in high BD and low water-holding capacity (USDA-NRCS, 2019; USDA-NRCS, 2000).

A similar result was reported by Nath and Krishna (2014) in the soil of the Dibrugarh district of Assam, India. Moreover, N and P were found to be significantly correlated with SOM (Table 2). SOM generally holds 90–95% of N and 80% of organic P in soil, which explains our finding. The results obtained are in line with the study conducted by Khadka (2016).

Soil mesofauna abundance under different land-use types

From all five land-use types studied, a total of 601 individuals of mesofauna were recorded belonging to 8 classes and 16 orders. Among these classes, the most abundant was Arachnida (74.5%), followed by Entognatha (14%), Insecta (7%), and Clitellata (4%). Order Oribatida had the highest number (447), followed by Collembola (80) and Haplotaxida (24) (Table 3). The dominance of the Oribatida in soil reflects the prevalence of detritivore-dominated communities, which are commonly associated with OM processing (Ojeda, 2025). The Oribatida and Collembola orders were found in all five land-use types. However, some mesofauna orders (Isopoda and Achatinoidea) were only found in one land-use type (UA and Re, respectively) (Table 3).

Table 3. Mesofaunal assemblages in different land-use systems

Class/Subclass	Order	Number of Individual					
		F1	**F2**	**Re**	**UA**	**LA**	**Total**
Arachnida	Araneae		6				6
	Mesostigmata	2			1		3
	Oribatida	4	129	273	12	19	437
	Trombidiformes		1				1
	Pseudoscorpiones					1	1
Chilopoda	Geophilomorpha		1				1
Clitellata	Haplotaxida	1	5	8	2	8	24
Entognatha	Collembola	8	21	23	21	5	78
	Diplura	3			3		6
Gastropoda	Achatinoidea			1			1
Insecta	Coleoptera	2	4			2	8
	Dermeptera				1	1	2
	Hemiptera		1			1	2
	Hymenoptera	3	1				4
	Thysanoptera		1		1		2
	Insecta1 indet.					1	1
	Insecta 2 indet.					1	1
	Insecta 3 indet.			1			1
	Insecta 4 indet.			1			1
	Insecta 5 indet.			2			2
	Insecta 6 indet.			1			1
	Insecta 7 indet.	1					1
	Insecta 8 indet.		1				1
	Insecta 9 indet.	2		2	4	4	12
Malacostraca	Isopoda				1		1
Symphyla		1		2			3
	Total	**27**	**171**	**314**	**46**	**43**	**601**

F2 had the highest number of orders that were not present in any other land-use type like Geophilomorpha, Araneae, Trombidiformes, etc. (Table 3). The restriction of certain taxa to specific land-use types indicates habitat filtering associated with soil conditions and disturbance regimes. Different studies have found that these orders prefer moist and OM-rich soil, which can usually be found in forests and pasture lands (Blackburn et al., 2002; Gudleifsson & Bjarnadottir, 2004; Ruas et al., 2015). The presence of these taxa, especially Araneae, is commonly indicative of healthy soil as they play an important role in the soil food chain as a predator (Pereira et al., 2020). Their diversity, as well as abundance, is highly dependent upon vegetation type, management practices, disturbance, and soil properties (Oxbrough et al., 2007; Da Rosa et al., 2019), thereby acting as a potential bioindicator. The presence of predatory and functionally diverse mesofauna in forest soils suggests a more complex soil food web, which enhances nutrient regulation, energy transfer, and ecosystem resilience.

Re had the highest number of mesofauna (314), followed by F2 (171) (Table 3), with the dominant taxa being Oribatida and Collembola. Oribatids are long-lived (3-4 years) organisms compared to other soil organisms, which live only for a few months, and they have slow metabolic rates, allowing them to survive periods of low food intake (Gergocs & Hufnagel, 2009; Pfingstl & Schatz, 2021). Also, because of their capacity to reproduce parthenogenetically, several of the Oribatida species can recover quickly in soil.

Similarly, Collembola possess morphological and physiological adaptations in the soil ecosystem, such as pigmented and large bodies with well-evolved locomotory organs, organs sensitive to air (silk) and light (eye), a high reproductive rate, and egg dormancy (Marx et al., 2009; Salmon et al., 2014; Susanti et al., 2024). Also, they have little to no ability to burrow in the soil, so they show better adaptability in sandy soil than in clay because of better habitable area (Beylich et al., 2010; Natalio et al., 2025; Oliveira et al., 2016). All of these characteristics allow Oribatida and Collembola to adapt easily even in disturbed soil, and a higher abundance of these taxa in Re may reflect high levels of disturbance (Battigelli, 2011; Heethoff, 2007; Lumley et al., 2023). This pattern suggests that a simplified soil food web and the dominance of a few stress-tolerant taxa are more likely to indicate degraded soil health. Such functional simplification under urban disturbance suggests that ecological stress and decreased soil system resilience, rather than high abundance alone, are indicators of good soil quality.

The second largest abundance of mesofauna was recorded in F2 (Fig. 2). Generally, forest soils, with high OM input, and fewer disturbances support greater mesofaunal abundance (Lin et al., 2024; Sharma et al., 2011). On the other hand, F1 had the lowest number of mesofauna (Table 3), which can be linked to high grazing pressure over this land-use. Continued overgrazing on land is commonly associated with low OM inputs since there are fewer plant biomass in the soil. In addition, there are chances of decreased operative depth of the soil due to increased susceptibility to erosion and compaction (Kairis et al., 2015). All these factors can be detrimental to soil life (Battigelli et al., 2011; Manu et al., 2025), and this further explains our findings.

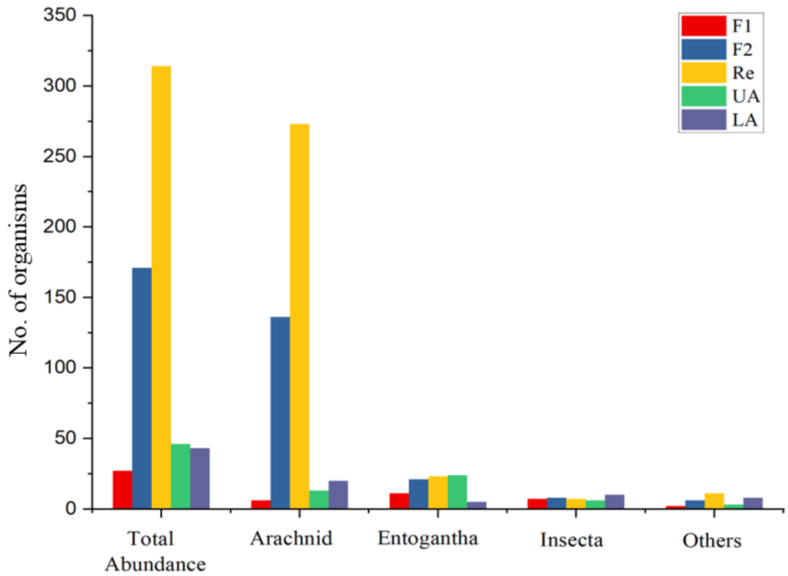

Figure 2. Abundance of soil mesofauna across different land-use types. Variation in abundance among different land-use types and among classes is evident. Re-recorded the highest abundance dominated by Arachnida, and the lowest in F1.

When it comes to agricultural areas, the LA's mesofaunal abundance was lower than that of the UA (Fig. 2). In contrast to the UA, the LA was subjected to more intensive farming methods supported by various activities (machinery use, excessive tillage, excessive fertilizer, and pesticide use) that are known to cause soil degradation. Soil compaction, aided by these activities, and the removal of plant biomass limit organic input into the soil, which may contribute to soil biota loss (Menta, 2012; Phillips et al., 2024; Raut et al., 2010). Similarly, excessive tillage can alter mesofauna abundance by affecting the distribution of residue material, the decomposition process, and nutrient mineralization, as well as by direct alteration in soil structure and by the erosion process (Giller et al., 1997; Van Oost et al., 2006).

In addition to that, pesticides used in the soil can potentially be toxic and have non-target effects on soil mesofauna, showing lethal to sublethal effects, including structural change, disorders in reproduction and growth, mortality, and changes in biodiversity and richness (Gunstone et al., 2021). Mesofaunal communities' capacity to recover and maintain their functional roles in decomposition and nutrient cycling is hampered by these management-induced disturbances, which collectively lower habitat quality and resource continuity in agricultural soils (Ma et al., 2024).

Shannon-Wiener diversity index

Shannon-Wiener diversity index (H) for the study area ranged from 0.82 (Re) to 1.22 (F1) (Fig. 6). F1, even though it is a forest with a high impact of overgrazing, was found to have the highest mesofaunal diversity compared to other land-use types. In ecology, the intermediate disturbance hypothesis (IDH) states that when a disturbance in a given system is neither too rare nor too frequent, local species diversity is maximized since species that flourish at both early and late successional stages may coexist in this scenario (Dial & Roughgarden, 1998; Nautiyal & Manish, 2024; Wilkinson, 1999), which is consistent with the observed pattern in F1. In the case of Re activities such as construction, landscaping, and contaminant inputs, degrading soil structure and nutrient unavailability may have made it less hospitable for a wide range of mesofauna.

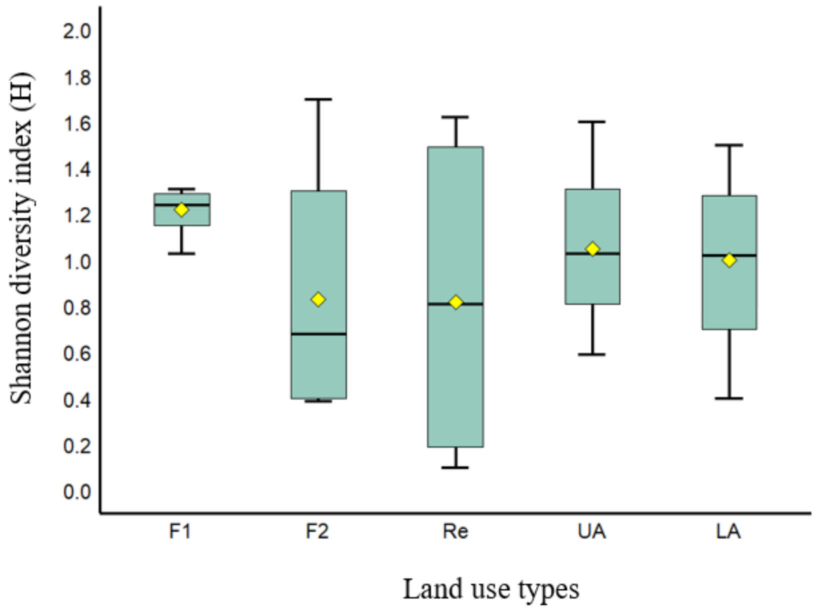

Figure 3. Shannon Diversity Index across different land-use types. The index was lowest value for Re and highest for F1, reflecting the influence of disturbance on community composition.

There was only a slight influence of moisture on mesofaunal diversity in this study, as indicated by H's weak negative correlation with MC (r = -0.11). However, the negative trend in our findings aligns with the study conducted by Santi et al. (2019). Studies have also mentioned that many mesofaunal communities are sensitive to changes in soil MC (Irmler, 2004; Zhang et al., 2021). On the other hand, mesofaunal diversity was positively correlated with temperature (r = 0.454). A similar result is reported by Santi et al. (2019). At higher temperatures, this pattern might be associated with increased biological interactions and decomposition rates, because increasing temperature may favor and accelerate decomposition. It may also increase interaction between the fauna of various trophic levels within the soil food web (Meyer- Kamczyc et al., 2022; Sierra et al., 2017; Wolfarth et al., 2021). Together, these correlations show how sensitive mesofaunal diversity is to microclimatic conditions, highlighting soil temperature and moisture as important regulators of soil food-web dynamics and biological functioning. However, our finding on the negative correlation between diversity and soil pH was in line with the findings of Begum et al. (2014). The presence of soil mesofauna highly depends on energy and food availability. SOM provides energy and food, and its availability in the soil can help in the development and diversity of mesofauna. However, in the current study, there was a positive trend between SOM and H, though this relationship was not statistically significant.

Overall, differences in soil functional capacity under varying degrees of anthropogenic pressure are reflected in mesofaunal diversity. While intensive urbanization and agricultural management simplify habitat structure and resource availability, resulting in decreased functional diversity (Bock et al., 2024), moderate disturbance, as seen in forest systems, may increase niche availability and support more diverse soil food webs (Guan et al., 2023). The significance of mesofaunal diversity as an integrative indicator of soil health in human-modified landscapes is highlighted by the potential for these changes to impair important soil processes, such as organic matter turnover and nutrient regulation (Remelli et al., 2024).

Conclusions

The study assessed the physicochemical and biological parameters of the soil under five different land-use systems. The result indicates that Re, a land-use type under continuous pressure of urbanization, had the highest mesofaunal abundance, dominated by highly tolerant taxa like Oribatida and Collembola. Meanwhile, the number of other mesofaunal communities was low, resulting in low mesofaunal diversity. Moreover, this land-use type exceeded the appropriate pH range for plant growth and had low SOM and N and high sand content. On the other hand, UA had moderate mesofaunal diversity, high SOM, weakly acidic pH, high N, and moderate P and K. In conclusion, the value for these parameters demonstrated that UA had good soil quality, whereas low soil quality was observed in Re. This implies that Manthali is facing serious stress across different land use types, especially as a consequence of urbanization. So, a land-use specific sustainable soil management practice should be adopted to restore and maintain soil quality. Furthermore, results also show that mesofauna are a useful indicator of soil quality, and a comprehensive understanding of soil health can be done by combining mesofaunal metrics with traditional physico-chemical parameters.

From a management standpoint, incorporating soil mesofauna into regular soil monitoring programs can facilitate early detection of soil degradation and can support sustainable land-use planning and soil conservation strategies, particularly in intensively managed and rapidly urbanizing landscapes like those found in Nepal. Nevertheless, this study is constrained by its spatial and temporal scope, as sampling was limited to Manthali Municipality's Ward 1 and was conducted during one season. Future study should be expanded to boarder context and time duration to capture the effect of seasonality on mesofauna and their abundance.

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