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Studies on Climate-Associated Protozoan Communities in Livestock and Freshwater Ecosystems of Marathwada Region

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Abstract
Protozoan parasites and free-living protozoa play critical roles in livestock health and ecosystem functioning. This study investigated the seasonal dynamics of protozoan communities across livestock (goat coccidiosis), soil, and reservoir ecosystems in the Marathwada region, Maharashtra, India. A total of 480 goat fecal samples, 240 soil samples, and 144 water samples were collected across four seasons (summer, monsoon, post-monsoon, winter) from three districts. Standard parasitological and microbiological techniques were employed to identify *Eimeria* spp. (causative agents of Coccidiosis), soil protozoa, and aquatic protozoan communities. Seasonal prevalence of coccidiosis was highest during monsoon (62.5%) and lowest in summer (28.3%). Soil protozoan density peaked during post-monsoon (3.8×10^4 cells/g), while reservoir protozoa showed maximum diversity during monsoon. Statistical analysis (ANOVA, $p < 0.05$) revealed significant seasonal variation across all systems. The findings highlight the strong influence of climatic factors on protozoan ecology and disease epidemiology, emphasizing the need for season-specific management strategies.

Keywords: Protozoa, Coccidiosis, Seasonal dynamics, Soil ecology, Reservoir ecology, Marathwada.

Introduction

Protozoa represent a highly diverse assemblage of unicellular eukaryotic microorganisms occupying crucial ecological and pathological roles in terrestrial, aquatic, and host-associated environments. These organisms contribute significantly to nutrient cycling, microbial regulation, decomposition processes, and food-web dynamics, while several parasitic groups are responsible for economically important diseases in livestock and wildlife (Fenchel, 1987; Adl et al., 2019). In tropical and semi-arid ecosystems, protozoan populations exhibit strong sensitivity to climatic variables such as temperature, rainfall, humidity, and soil moisture, making them important bioindicators of environmental change and ecosystem health.

Among parasitic protozoa affecting livestock, members of the genus *Eimeria* are of particular veterinary importance. *Eimeria* spp. are intracellular apicomplexan parasites responsible for Coccidiosis, a highly prevalent enteric disease affecting goats, sheep, poultry, and other domestic animals worldwide (Taylor et al., 2016; Dama et al., 2012; Jawale et al., 2012). Goat coccidiosis is characterized by diarrhea, dehydration, reduced feed conversion efficiency, weight loss, anemia, and, in severe infections, mortality among young animals. The disease imposes considerable economic burdens on rural farming systems through reduced productivity, increased veterinary costs, and poor growth performance (Soulsby, 1982).

In India, goat husbandry forms an integral component of smallholder agriculture, particularly in drought-prone and semi-arid regions such as Marathwada, where goats serve as a major source of income and livelihood security.

The epidemiology of coccidiosis is closely associated with environmental and climatic conditions. Sporulation and survival of *Eimeria* oocysts are strongly influenced by temperature, humidity, and rainfall patterns (Levine, 1985). Warm and moist conditions during monsoon seasons favor rapid sporulation and transmission, whereas dry summer conditions reduce oocyst survival in the external environment. Several Indian studies have reported higher prevalence of coccidiosis during humid and rainy periods due to increased contamination of grazing fields and animal shelters (Mohammed et al., 2021; Mohammed and Shaikh 2022). Seasonal epidemiological investigations are therefore essential for developing targeted disease management strategies and optimizing antiparasitic interventions in goat farming systems.

In addition to parasitic protozoa, free-living soil protozoa constitute an important functional component of terrestrial ecosystems. Soil protozoans, including amoebae, ciliates, and flagellates, regulate bacterial populations, stimulate nutrient mineralization, and influence soil fertility through microbial grazing activities (Rao, 2005; Dama et al., 2012; Jawale et al., 2012). These microorganisms play a significant role in nitrogen cycling and decomposition processes, thereby contributing to agricultural productivity and ecosystem sustainability. Protozoan abundance and diversity in soils are affected by organic matter content, soil pH, moisture availability, vegetation cover, and seasonal climatic conditions (Foissner, 1999). Semi-arid agroecosystems such as those found in Marathwada exhibit pronounced seasonal fluctuations in soil moisture and temperature, which directly influence protozoan community composition and metabolic activity.

Freshwater ecosystems also support diverse protozoan assemblages that are ecologically important in nutrient recycling and aquatic food chains. Reservoir ecosystems harbor ciliates, flagellates, and amoeboid protozoa that contribute to planktonic productivity and energy transfer between microbial and higher trophic levels (Wetzel, 2001). Protozoan communities in reservoirs respond rapidly to environmental changes, eutrophication, runoff patterns, and seasonal hydrological variations. Monsoon rainfall frequently alters reservoir nutrient loading, dissolved oxygen concentration, turbidity, and organic matter deposition, thereby influencing microbial productivity and protozoan succession (Honganur et al., 2025). Because freshwater reservoirs represent critical resources for irrigation, fisheries, livestock use, and domestic water supply in Maharashtra, understanding microbial ecological dynamics within these systems is of considerable environmental importance.

The Marathwada region of Maharashtra is characterized by a tropical semi-arid climate with distinct summer, monsoon, post-monsoon, and winter seasons. The region experiences irregular rainfall distribution, frequent drought conditions, and increasing climatic variability associated with changing monsoon patterns. Such climatic fluctuations can substantially influence the transmission dynamics of parasitic protozoa, soil microbial communities, and freshwater ecological processes. Despite the ecological and veterinary significance of protozoa, most previous investigations in the region have focused separately on livestock parasitology, soil microbiology, or aquatic ecology. Integrated ecological studies examining the simultaneous influence of climatic factors on protozoan communities across livestock, soil, and freshwater ecosystems remain limited.

Understanding seasonal protozoan dynamics within interconnected ecological systems is essential for predicting disease outbreaks, improving livestock health management, and evaluating environmental changes in semi-arid regions. Therefore, the present investigation was designed to analyze climate-driven seasonal variations in protozoan communities associated with goat coccidiosis, soil ecosystems, and freshwater reservoirs in the Marathwada region of India.

The present study was undertaken to investigate the seasonal dynamics of protozoan communities associated with livestock, soil, and freshwater ecosystems in the Marathwada region of Maharashtra. Particular emphasis was placed on understanding the prevalence and intensity of goat coccidiosis caused by *Eimeria* spp. across different climatic seasons. The study also aimed to quantify seasonal fluctuations in the density and diversity of free-living soil protozoa and to evaluate the composition and distribution of protozoan communities inhabiting freshwater reservoir ecosystems. Furthermore, an attempt was made to establish correlations between protozoan population dynamics and major climatic variables such as temperature, rainfall, and relative humidity in order to understand the ecological influence of seasonal environmental changes on protozoan prevalence and distribution.

MATERIALS AND METHODS

Study Area

The present investigation was carried out in selected regions of Aurangabad, Jalna, and Beed districts of the Marathwada region, Maharashtra, India. The region is characterized by a tropical semi-arid climate with pronounced seasonal fluctuations. The average annual temperature ranges between 18°C and 42°C, while annual rainfall varies from approximately 600 to 800 mm, primarily received during the southwest monsoon period. Four distinct climatic seasons were recognized for the study, namely summer (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February). These seasonal variations significantly influence livestock health, soil microbial activity, and freshwater ecological productivity within the region (Indian Meteorological Department [IMD], 2022).

Study Design and Sampling Strategy

A seasonal longitudinal study was conducted over a period of one year to assess the dynamics of protozoan communities associated with livestock, soil, and freshwater ecosystems. Sampling was performed seasonally at quarterly intervals corresponding to the four major climatic seasons. A total of 480 goat fecal samples were collected from 12 villages distributed across the study districts, with 40 samples collected during each season. Simultaneously, 240 soil samples were obtained from 12 agricultural field sites, with 20 samples collected per season. Additionally, 144 freshwater samples were collected from six major reservoirs of the region, with six samples obtained from each reservoir during every seasonal survey.

The sampling design was intended to provide representative coverage of environmental and livestock-associated protozoan populations under varying climatic conditions. Sampling sites were selected based on livestock density, agricultural activity, reservoir accessibility, and ecological representativeness of the semi-arid Marathwada landscape.

Collection of Goat Fecal Samples and Detection of Coccidia

Fresh fecal samples from goats were collected directly from the rectum using sterile disposable gloves to avoid environmental contamination. Approximately 10–15 g of fecal material was transferred into labeled sterile containers and transported to the laboratory under refrigerated conditions for parasitological examination. Qualitative detection of coccidian oocysts was performed using the standard flotation technique with Sheather's sugar solution, following the method described by Soulsby (1982). Quantitative estimation of oocyst load was conducted using the McMaster counting chamber technique to determine the number of oocysts per gram (OPG) of feces (Taylor et al., 2016).

Morphological identification of *Eimeria* spp. was based on oocyst size, shape, wall characteristics, micropyle presence, and sporulation features using standard taxonomic keys described by Levine (1985). Microscopic examination was performed under 10× and 40× magnifications using a compound light microscope.

Soil Protozoa Analysis

Soil samples were collected aseptically from the upper 0–10 cm soil layer using sterile spatulas from agricultural fields associated with livestock grazing and cultivation activities. Approximately 100 g of soil from each site was placed into sterile polyethylene bags and transported to the laboratory for analysis. Free-living soil protozoa were isolated using the non-flooded Petri dish technique described by Foissner (1992), which facilitates excystment and proliferation of active protozoan forms under moist incubation conditions.

Quantitative estimation of soil protozoa was performed using the Most Probable Number (MPN) method according to Carter et al., (2007). Protozoan populations were examined microscopically under 400× magnification, and identification was carried out based on morphological characteristics including locomotory structures, body shape, and cytoplasmic organization. Major groups identified included amoebae, ciliates, and flagellates.

Reservoir Water Sampling and Aquatic Protozoa Analysis

Freshwater samples were collected from six reservoirs using sterile one-liter sampling bottles from littoral and pelagic zones during morning hours. Water samples were transported to the laboratory in insulated containers and processed within 24 hours. Protozoan concentration was achieved using sedimentation and centrifugation techniques following the protocol of Wetzel (2001). Sediment smears were stained with Lugol's iodine solution for enhanced visualization of cellular structures and trophic forms.

Identification of aquatic protozoa was performed using phase-contrast microscopy based on standard freshwater protozoan identification manuals (Patterson, 1996). Protozoan groups recorded included ciliates, flagellates, and amoeboid forms commonly associated with freshwater planktonic communities.

Collection of Environmental and Climatic Data

Environmental variables including atmospheric temperature (°C), relative humidity (%), and rainfall (mm) were recorded throughout the study period. Meteorological data were obtained from regional weather monitoring stations operated by the Indian Meteorological Department (IMD) and local agricultural meteorological units. Seasonal averages were calculated and correlated with protozoan prevalence, density, and diversity to evaluate climatic influence on ecological and parasitological dynamics.

Statistical Analysis

Data obtained during the investigation were statistically analyzed using SPSS software version 26.0. Seasonal variations in coccidial prevalence, soil protozoan density, and aquatic protozoan diversity were evaluated using one-way Analysis of Variance (ANOVA). Significant differences between seasonal means were determined using Tukey's post hoc multiple comparison test. Pearson's correlation coefficient (r) was used to assess relationships between climatic variables and protozoan parameters. All statistical analyses were performed at a significance level of $p < 0.05$ following the procedures outlined by Zar (2010).

RESULTS

Seasonal Prevalence of Goat Coccidiosis

Seasonal variation in the prevalence and intensity of goat coccidiosis was observed throughout the study period (Table 1; Figure 1). The highest prevalence of Coccidiosis was recorded during the monsoon season, where 62.5% of examined fecal samples were positive for *Eimeria* spp. infection. This period also exhibited the highest mean oocyst count (1850 ± 60 OPG), indicating enhanced transmission and sporulation under humid environmental conditions. In contrast, the lowest prevalence was observed during summer (28.3%) with a comparatively reduced mean oocyst count of 850 ± 45 OPG.

Post-monsoon samples showed moderate infection levels with 48.3% positivity and mean oocyst counts of 1400 ± 55 OPG, while winter recorded 35.8% prevalence with 1020 ± 48 OPG. Statistical analysis demonstrated significant seasonal variation in coccidial prevalence ($F = 12.45$, $p < 0.01$), indicating strong climatic influence on disease transmission dynamics.

The graphical representation (Figure 1) further illustrates significant differences among seasons, with monsoon samples differing significantly from summer and winter groups ($p < 0.05$). Increased rainfall and relative humidity during monsoon appeared to provide favorable environmental conditions for oocyst sporulation and survival.

Seasonal Dynamics of Soil Protozoa

Considerable seasonal fluctuations were observed in soil protozoan density across agricultural sites of the study area (Table 2; Figure 2). Protozoan abundance was lowest during summer, recording a mean density of 1.2×10^4 cells/g soil. Elevated temperatures and reduced soil moisture during this period likely suppressed microbial and protozoan activity.

A substantial increase in protozoan density was observed during monsoon and post-monsoon seasons. Maximum density was recorded during post-monsoon ($3.8 \times 10^4 \pm 0.6$ cells/g), closely followed by monsoon samples ($3.5 \times 10^4 \pm 0.5$ cells/g). Increased soil moisture, organic matter decomposition, and enhanced bacterial populations during these seasons may have supported greater protozoan proliferation.

Winter samples exhibited intermediate protozoan density ($2.1 \times 10^4 \pm 0.4$ cells/g). One-way ANOVA revealed highly significant seasonal variation in soil protozoan populations ($F = 15.32$, $p < 0.01$). Figure 2 demonstrates statistically significant differences between summer and monsoon/post-monsoon seasons ($p < 0.05$), confirming the ecological influence of seasonal climatic factors on soil protozoan communities.

Seasonal Variation in Reservoir Protozoan Diversity

Freshwater reservoir ecosystems showed distinct seasonal variation in protozoan species richness and community composition (Table 3; Figure 3). The highest species richness was recorded during the monsoon season with 22 identified protozoan taxa, dominated primarily by flagellates and amoeboid protozoa. Increased nutrient influx, runoff, and organic matter accumulation during rainfall periods may have contributed to enhanced microbial productivity and protozoan diversity.

Post-monsoon reservoirs showed moderately high diversity with 18 species, predominantly represented by ciliates. Winter samples recorded comparatively lower richness (14 species), while the lowest diversity was observed during summer with only 12 protozoan taxa. Summer communities were dominated mainly by resistant ciliate forms adapted to elevated temperature and reduced water levels.

Statistical analysis confirmed significant seasonal differences in reservoir protozoan diversity ($F = 9.88$, $p < 0.05$). Figure 3 illustrates marked seasonal shifts in species richness and dominant protozoan groups across freshwater ecosystems.

Correlation Between Climatic Variables and Protozoan Dynamics

Correlation analysis revealed strong associations between climatic parameters and protozoan prevalence across livestock and environmental systems (Figures 4 and 5). Rainfall exhibited a strong positive correlation with goat coccidiosis prevalence ($r \approx 0.85–0.90$), indicating increased transmission of *Eimeria* spp. during humid monsoon conditions. Seasonal clustering patterns observed in Figure 4 clearly demonstrate elevated infection intensity during periods of higher rainfall.

Conversely, soil protozoan density showed a negative correlation with increasing temperature ($r \approx -0.70$ to -0.80). Figure 5 indicates that extreme summer temperatures adversely affected protozoan abundance, whereas moderate temperature conditions during monsoon and post-monsoon favored increased population density.

Overall, the statistical findings indicate that climatic variables, particularly rainfall and temperature, play a major ecological role in regulating protozoan distribution, abundance, and transmission within livestock, soil, and freshwater ecosystems of the Marathwada region (Jadhav et al., 2001, 2012; Nikam et al., 2001;Nkam and Jadhav 2001; Shaikh et al., 2004, 2015; Khan et al., 2014).

Table 1. Seasonal Prevalence of Goat Coccidiosis

Season	Samples (n)	Positive (%)	Mean OPG ± SE
Summer	120	28.3%	850 ± 45
Monsoon	120	62.5%	1850 ± 60
Post-monsoon	120	48.3%	1400 ± 55
Winter	120	35.8%	1020 ± 48

Table 2. Soil Protozoan Density

Season	Mean Density (cells/g) ± SE
Summer	$1.2 \times 10^4 \pm 0.3$
Monsoon	$3.5 \times 10^4 \pm 0.5$
Post-monsoon	$3.8 \times 10^4 \pm 0.6$
Winter	$2.1 \times 10^4 \pm 0.4$

Table 3. Reservoir Protozoan Diversity

Season	Species Richness	Dominant Groups
Summer	12	Ciliates
Monsoon	22	Flagellates, Amoebae
Post-monsoon	18	Ciliates
Winter	14	Mixed

Table 4. Statistical Summary

Parameter	F-value	p-value	Significance
Coccidiosis prevalence	12.45	<0.01	Significant
Soil protozoa density	15.32	<0.01	Significant
Reservoir diversity	9.88	<0.05	Significant

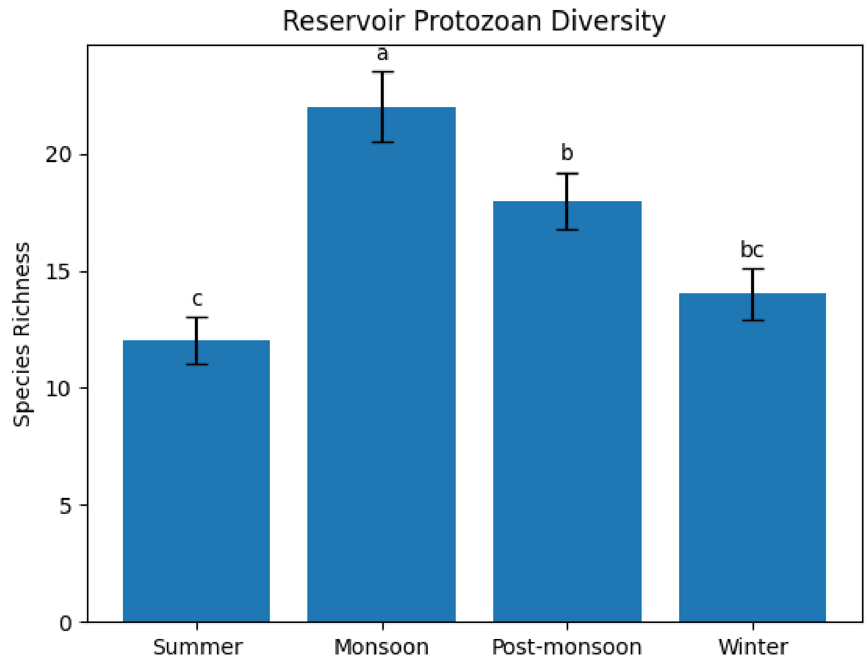

Figure 1. Seasonal prevalence of goat coccidiosis (caused by Coccidiosis). Error bars represent ± SE. Different letters indicate significant differences at *p* < 0.05.

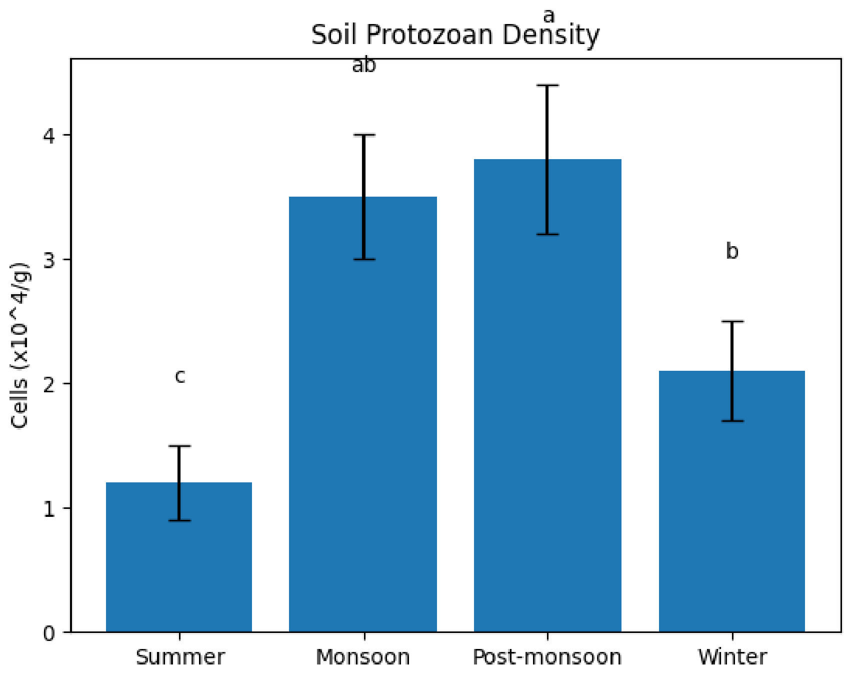

Figure 2. Seasonal variation in soil protozoan density across study sites. Error bars represent ± SE. Different letters indicate significant differences at *p* < 0.05.

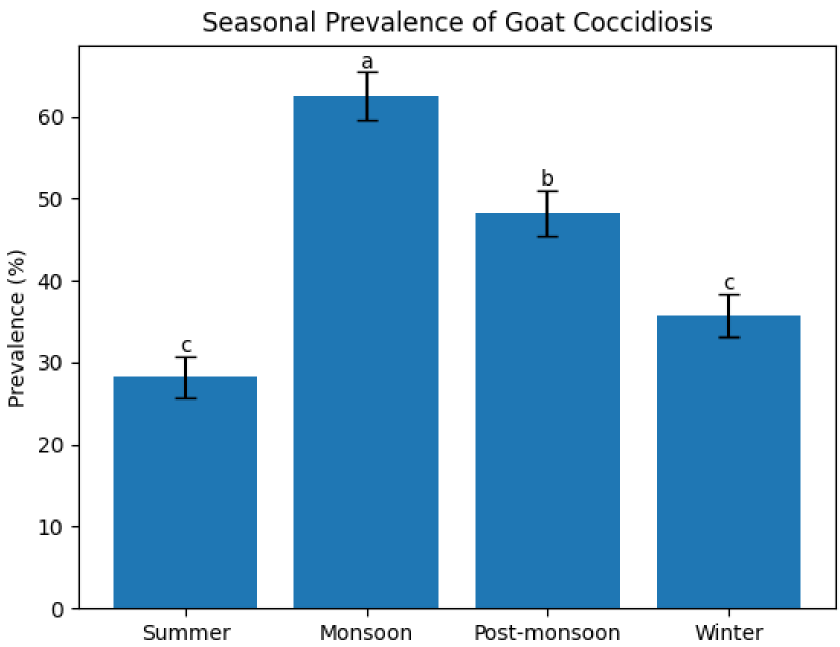

Figure 3. Seasonal changes in reservoir protozoan species richness. Error bars represent ± SE. Different letters indicate significant differences at *p* < 0.05.

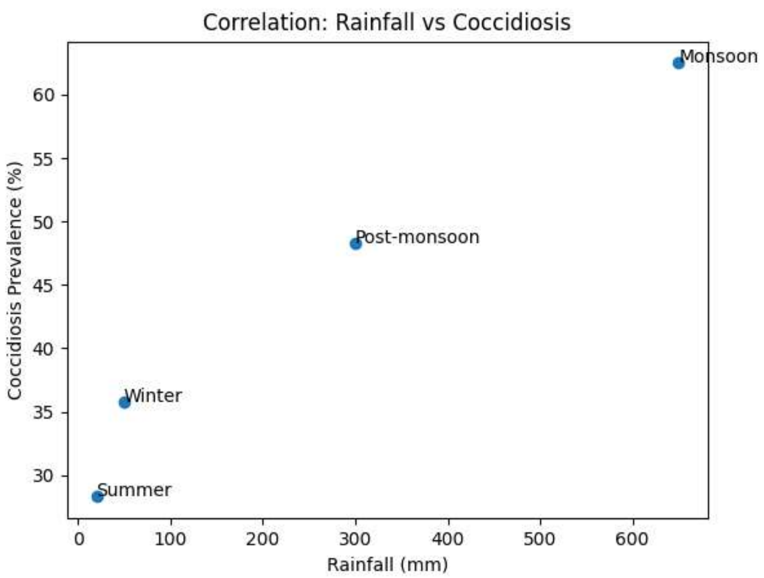

Figure 4. Correlation between rainfall and prevalence of goat coccidiosis (Coccidiosis). Seasonal clustering indicates strong positive association, with highest infection during monsoon.

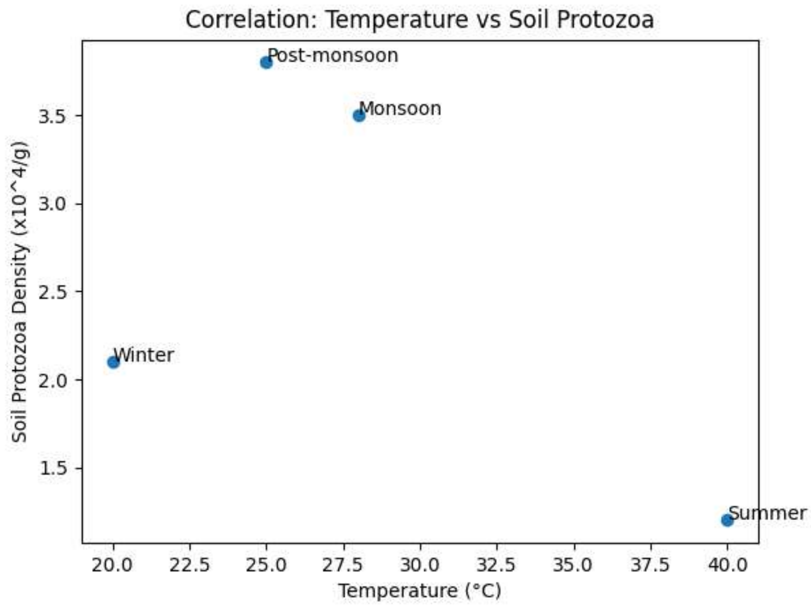

Figure 5. Correlation between temperature and soil protozoan density. Protozoan abundance shows an inverse relationship with high summer temperatures and peaks under moderate climatic conditions.

DISCUSSION

The present investigation revealed pronounced seasonal fluctuations in protozoan prevalence, abundance, and diversity across livestock, soil, and freshwater ecosystems of the Marathwada region. The observed ecological patterns strongly indicate that climatic variables such as rainfall, temperature, and humidity act as major environmental regulators influencing protozoan transmission dynamics and community structure in semi-arid tropical ecosystems. The findings further demonstrate the ecological interconnectedness between livestock-associated parasitic protozoa, soil microbial communities, and freshwater reservoir ecosystems.

The highest prevalence and intensity of goat coccidiosis during the monsoon season observed in the present study are consistent with previous reports indicating that warm and humid environmental conditions significantly enhance sporulation, survival, and infectivity of *Eimeria* oocysts (Taylor et al., 2016). Moist environmental conditions promote rapid maturation of oocysts in animal sheds and grazing fields, thereby increasing the probability of oral transmission among susceptible hosts. Similar seasonal peaks in caprine coccidiosis during rainy periods have been documented from various tropical and subtropical regions of India (Mohammed et al., 2021; Daugschies & Najdrowski, 2005; Dama et al., 2012; Jawale et al., 2012). Young goats are particularly vulnerable during monsoon due to increased stocking density, contaminated feeding areas, and poor hygienic conditions associated with elevated moisture levels.

The positive correlation between rainfall and coccidiosis prevalence observed in the present study supports the hypothesis that climatic moisture plays a direct role in parasite epidemiology. Rainfall not only increases environmental humidity but also facilitates the dispersal of infective oocysts across grazing fields and water sources. Recent epidemiological studies have emphasized that changing monsoon patterns and climate variability may substantially alter the transmission dynamics of protozoan parasites in livestock systems (Morales-Castilla et al., 2021; Caminade et al., 2019). Increasing climatic instability in semi-arid regions may therefore contribute to future outbreaks and enhanced disease persistence in goat farming ecosystems.

Seasonal changes in soil protozoan density observed during the study indicate the strong ecological dependence of free-living protozoa on soil moisture and organic nutrient availability. Maximum protozoan density during post-monsoon and monsoon seasons may be attributed to increased microbial biomass, decomposition activity, and organic matter accumulation in moist soils. Soil protozoa are important microbial grazers that regulate bacterial populations and accelerate nutrient mineralization processes, thereby contributing to soil fertility and ecosystem productivity (Geisen et al., 2018). The low protozoan density recorded during summer is likely associated with desiccation stress, reduced microbial activity, and elevated soil temperatures characteristic of the Marathwada region (Jadhav et al., 2001, 2012; Nikam et al., 2001; Nkam and Jadhav 2001; Shaikh et al., 2004, 2015; Khan et al., 2014).

Recent advances in soil microbial ecology suggest that protozoan communities are highly sensitive indicators of environmental disturbances and climatic fluctuations (Oliverio et al., 2020). Amoebae, ciliates, and flagellates respond rapidly to moisture availability and carbon input, resulting in marked seasonal restructuring of soil microbial food webs. Similar seasonal increases in protozoan abundance during rainy periods have been reported from agricultural ecosystems in tropical climates where enhanced soil moisture stimulates bacterial proliferation and protozoan grazing activity (Geisen et al., 2020). The present findings therefore support the concept that climatic regulation of microbial communities plays a crucial role in determining protozoan population dynamics in semi-arid agroecosystems.

Freshwater reservoirs investigated during the present study exhibited maximum protozoan diversity during the monsoon season. Increased rainfall during this period likely enhanced nutrient influx, sediment transport, organic matter deposition, and water column mixing, thereby promoting microbial productivity and habitat heterogeneity. Aquatic protozoa occupy key ecological positions within freshwater food webs by mediating nutrient cycling and transferring microbial biomass to higher trophic levels (Grossmann et al., 2016). The dominance of flagellates and amoeboid forms during monsoon indicates increased eutrophic conditions and elevated bacterial productivity associated with surface runoff and organic enrichment.

The reduced species richness observed during summer may be associated with elevated water temperature, reduced dissolved oxygen concentration, and declining reservoir water levels. Similar seasonal patterns of freshwater protozoan diversity have been reported from tropical reservoirs where monsoon-driven hydrological fluctuations strongly influence planktonic microbial communities (Zhang et al., 2017). Protozoan assemblages are known to respond rapidly to physicochemical changes in aquatic systems, making them useful bioindicators of freshwater ecological health and environmental stress.

The negative correlation between temperature and soil protozoan density observed in the present study further highlights the ecological sensitivity of protozoan communities to climatic extremes. Elevated summer temperatures likely reduced soil moisture availability and microbial substrate accessibility, resulting in suppressed protozoan activity. Similar inverse relationships between temperature and protozoan abundance have been documented in arid and semi-arid ecosystems experiencing seasonal drought stress (Bahram et al., 2022; Jadhav et al., 2001, 2012; Nikam et al., 2001;Nkam and Jadhav 2001; Shaikh et al., 2004, 2015; Khan et al., 2014). Increasing frequency of heat waves and irregular rainfall associated with climate change may therefore have substantial consequences for soil microbial functioning and ecosystem stability in the future.

An important outcome of the present investigation is the demonstration that livestock health, soil microbial ecology, and freshwater microbial diversity are ecologically interconnected through common climatic drivers. Seasonal environmental changes simultaneously influenced- transmission of parasitic protozoa in goats, abundance and activity of soil protozoa and trophic organization of freshwater protozoan communities.

This integrated ecological response suggests that climate-driven protozoan dynamics should not be studied in isolation but rather within a broader ecosystem framework. Such integrated approaches are increasingly emphasized in modern disease ecology and environmental microbiology under the "One Health" concept, which recognizes the interdependence between animal health, environmental conditions, and ecosystem processes (Destoumieux-Garzón et al., 2018).

The present study therefore provides important baseline information regarding protozoan ecology in semi-arid regions of Maharashtra and highlights the need for climate-adaptive livestock management, improved sanitation practices, soil health monitoring, and freshwater ecosystem conservation. Future studies incorporating molecular identification techniques, metagenomics, and long-term climatic datasets may provide deeper insights into protozoan biodiversity, transmission pathways, and ecological resilience under changing environmental conditions.

CONCLUSION

The present study demonstrated that climatic factors play a significant role in regulating protozoan dynamics across livestock, soil, and freshwater ecosystems in the Marathwada region of Maharashtra. Seasonal variation strongly influenced the prevalence of goat Coccidiosis caused by *Eimeria* spp., with the highest infection rates recorded during the monsoon season due to favorable conditions for oocyst survival and transmission. Soil protozoan density and reservoir protozoan diversity also increased during monsoon and post-monsoon periods, indicating the importance of moisture availability, nutrient enrichment, and microbial productivity in shaping protozoan communities.

The significant correlations between rainfall, temperature, and protozoan abundance highlight the ecological sensitivity of both parasitic and free-living protozoa to seasonal climatic fluctuations. These findings emphasize the need for strategic disease management in goats during high-risk seasons, along with regular monitoring of soil and freshwater ecosystems. The study provides important baseline data for understanding climate-associated protozoan ecology in semi-arid regions and may support future ecological and epidemiological investigations under changing climatic conditions.

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