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Spatial Epidemiology and Risk Assessment of Gastrointestinal Parasitism in Small Ruminants Across Agroclimatic Zones of Punjab, India

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ABSTRACT

Background: This cross-sectional study examined 1,838 small ruminants (661 sheep and 1,227 goats) to investigate the spatial epidemiology and associated risk factors of gastrointestinal parasites (GIPs) through coprological analysis across all twenty-two districts within five agroclimatic zones of Punjab, India.

Methods: Classical parasitological coprological techniques were employed to confirm the endemic nature of gastrointestinal parasitism, assess infection intensity (EPG) and determine risk factors across all agroclimatic zones of Punjab, India.

Result: An alarming overall copro-prevalence of 83.46% was recorded (85.60% in sheep; 82.40% in goats). Dual infections (38.47%) were significantly higher (χ^2: 270.044, P<0.01) than single (21.87%) and multiple infections (22.23%), highlighting polyparasitism as a critical health challenge. Quantitative assessment indicated 36.72% mild (EPG 100-1000), 23.47% light (EPG 1000-3000), 3.16% moderate (EPG 3000-4000) and 6.75% heavy infections (mean EPG >4000). Females and adult ruminants (>6 months) were at significantly higher risk (χ^2: 8.653, P<0.01). Highest prevalence was in the central plain zone (86.30%) and lowest in the western plain zone (73.43%). Binary logistic regression indicated significant association (P<0.01) in Barnala, Ludhiana, Moga, SAS Nagar, Mohali and Sangrur districts. The findings underscore the urgent need for targeted control programs, particularly in the southern regions of Punjab. Detailed spatial distribution maps of these cases to serve as a vital resource for veterinary practitioners and policymakers are presented.

Key words: Agroclimatic zones, Gastrointestinal parasites, Risk factors, Small ruminants, Spatial distribution.

INTRODUCTION

Small ruminants represent a vital source of income for small and landless livestock communities, contributing significantly to socioeconomic development. According to the 20th National Livestock Census, India possesses one of the largest sheep populations in Asia (74.26 million) and the world's largest domestic goat population (148.88 million). These small ruminants are vital to the rural economy and contribute significantly to the livestock sector, which accounts for roughly 25.6%-30.47% of the agricultural GDP (DAH and F, 2019).

However, the practice of grazing sheep and goats on roadsides and uncultivated public and private lands exposes them to malnutrition and infectious diseases (Singla, 1995). Moreover, poorly drained and unhygienic environments heighten their vulnerability to parasitic infections (Singh *et al*., 2017). Acute gastrointestinal parasitic infections (GIPs) can lead to rapid mortality, while more common chronic or subclinical infections result in reduced weight gain, decreased wool and milk production and compromised reproductive performance (Sutherland and Scott, 2010). Consequently, both clinical and subclinical gastrointestinal parasitism impact host metabolism and present serious threats, significantly hindering small ruminant production and leading to substantial economic losses worldwide, including in India (Singla *et al*., 2024).

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Parasitic diseases profoundly impact small ruminant production, posing severe health risks due to associated morbidity and mortality, which ultimately translate to considerable economic losses (Abede and Esayas, 2001; Cernanska *et al*., 2005; Kaur *et al*., 2019). Such losses can be insidious, affecting diverse agroclimatic zones (Waller, 1997; Taylor, 2009). The impact of gastrointestinal helminth infections varies depending on the parasite species, infection severity and risk factors such as host species, age, season and worm burden intensity (ILCA, 1990). In tropical regions, *Haemonchus* and *Trichostrongylus* species are among the most prevalent helminth parasites affecting small ruminants (Gathuma *et al*., 2007; Goel *et al*., 2020; Mbuh *et al*., 2008; Opara *et al*., 2005; Singh *et al*., 2019; Dova *et al*., 2024).

While there is existing literature on gastrointestinal parasites of sheep and goats across various regions in India, most studies are limited to specific geographic areas, including individual flocks, villages, cities, districts, or single zones (Dhara *et al*., 2015; Jithendran *et al*., 2001; Khajuria and Kapoor, 2003; Lathamani *et al*., 2016; Pathak and Pal, 2008; Sharma *et al*., 2007; Varadharajan and Vijayalakshmi, 2015; Yadav *et al*., 2006). Punjab has reported only a few studies on gastrointestinal parasites of small ruminants, primarily focusing on specific regions (Goel *et al*., 2023; Singh, 2015; Singh *et al*., 2017; Singla, 1995; Singla *et al*., 2018). There remains a critical gap in understanding the epidemiological status of parasitic infections in Punjab due to the lack of a comprehensive surveillance system.

To address this gap, a comprehensive study covering a broader geographic area is essential to generate accurate data on the prevalence of gastrointestinal parasitism and its associated risk factors. Such information is crucial for formulating effective disease control and prevention strategies. Therefore, the present study aims to determine the comparative copro-prevalence of GIT parasites in small ruminants across all districts within the various agroclimatic zones of Punjab state.

MATERIALS AND METHODS

Geographical study area

Punjab state, located in the northwestern region of India, spans latitudes 29°30′N to 32°32′N and longitudes 73°55′E to 76°50′E, covering a geographical area of 50,362 km^2. The average annual rainfall in Punjab is 565.9 mm, varying significantly from approximately 915 mm in the northern districts to just 102 mm in the south (http://punjabonline.in/Profile/Geography/climate.asp). Gurdaspur, in the north, experiences the highest rainfall, while Ferozepur in the southwest records the lowest. As part of a tropical country, Punjab experiences three distinct seasons: summer (April to June: average rainfall = 51.6 mm; average temperature = 34°C), monsoon (July to September: Average temperature = 20°C; average rainfall = 395.2 mm) and winter (October to March: average rainfall = 119.1 mm; average temperature = 13°C). Additionally, Punjab is stratified into five major agroclimatic zones based on climatic, edaphic and agricultural patterns. Small ruminants were sampled from all twenty-two districts of the state across these five agroclimatic zones and the research work was conducted at Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India.

Sample collection

To accurately assess the comparative epidemiological status of gastrointestinal parasites (GIPs) in sheep and goats across Punjab's five zones, a rigorous fecal sampling process was conducted. A total of 1,838 samples were collected (611 from sheep and 1,227 from goats) directly from the rectum of animals, ensuring contamination-free collection in small polythene bags (6×4 inches). A comprehensive questionnaire was designed to gather information regarding breed, age, sex, management practices, clinical symptoms and any treatments administered to the animals. The data were categorized by season: Monsoon (July to October), winter (November to February) and summer (March to June). Random fecal sampling included both sexes and all age groups reared under intensive and extensive management systems. Of the sampled animals, over 77% were female, consistent with the typical sex composition of small ruminant flocks managed in the study area. The fecal samples were subsequently processed and qualitatively screened using sedimentation and flotation methods, while quantitative assessments were conducted using the McMaster technique (Gupta and Singla, 2012) to evaluate the incidence and magnitude of infections.

Ethical approval

This study received ethical approval from the Animal Experiment Ethics Committee (IAEC/2016/410-435) at Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India. Fecal samples were collected humanely with the prior consent of small ruminant farmers, ensuring that no accidental harm occurred during the collection process.

Spatial analysis

The total number of animals sampled from each village was integrated with digital village boundaries in a Geographic Information System (GIS), generating the centroid for each village in ArcGIS 10.2. Spatial maps of GIPs were created using Inverse Distance Weighting (IDW), an interpolation technique that estimates values at unmeasured locations based on the weighted average of neighboring known points. This method assumes that the influence of a known point diminishes with distance, providing accurate predictions for intermediate locations. IDW is particularly suitable for spatial analysis of disease prevalence data where continuous surfaces need to be estimated from discrete sampling points.

Statistical analysis

Descriptive statistics were employed to summarize the data, calculating prevalence rates across different categories. Chi-square (χ^2) tests were performed to assess the association between categorical variables (species, sex, age group, season, management system, agroclimatic zone and district) and parasitic infection status. Binary logistic regression analysis was conducted to identify risk factors associated with GIT parasitism, with district-wise prevalence as the dependent variable. All statistical analyses were performed using SAS software version 9.4 (SAS Institute Inc., 2013), with statistical significance set at $P<0.05$.

RESULTS AND DISCUSSION

A total of 1,838 faecal samples were collected from twenty-two districts representing five agro-climatic zones of Punjab. Of these, 1,534 samples were positive for gastrointestinal (GIT) parasitic infections, yielding an overall copro-prevalence of 83.46% in small ruminants.

Among the agro-climatic zones, the central plain zone (CPZ) recorded the highest prevalence (86.30%), whereas the western plain zone (WPZ) showed the lowest (73.43%). In sheep, the highest prevalence was observed in the Western Zone (WZ) (90.87%), while the lowest occurred in the WPZ (62.34%). In contrast, goats exhibited the highest prevalence in the WPZ (86.36%) and the lowest in the sub-mountain undulating zone (SMU) (71.79%) (Fig 1, Table 1). Prevalence varied significantly among districts within agro-climatic zones ($p<0.05$), ranging from 100% in Amritsar to 66.67% in Shri Muktsar Sahib (Table 1).

Overall, sheep (85.60%) were slightly more affected than goats (82.40%) (Table 1-3). Dual infections (38.47%) were significantly more frequent ($P<0.01$) than single (21.87%) or multiple infections (23.23%). Among single infections, strongyle eggs (27.72%) and coccidian oocysts (8.80%) were more prevalent in sheep, whereas goats showed lower rates (14.74% for strongyles and 0.30% for coccidia) (Table 2).

The mean eggs per gram (EPG) count was significantly higher in goats (1,520.61±2,239.33; range: 100-10,000) than in sheep (1,323.81±2,135.97; range: 100-6,700). The wide SE values for EPG reflect the characteristically over-dispersed, right-skewed distribution of gastrointestinal helminth egg counts in field surveys, wherein most animals harbour low burdens, while a minority carry disproportionately high parasite loads. Multiple infections were significantly more common in goats (33.14%) than in sheep (20.46%) ($\chi^2 = 15.441$).

Sex-wise analysis revealed a higher prevalence in females (85.43%) than males (72.16%). This pattern was consistent in both sheep (86.46% in females vs. 79.14% in males) and goats (84.89% vs. 69.65%) (Table 3). Notably, over 77% of the studied animals were female, which could skew the overall prevalence.

Age-wise comparison showed that adults (>6 months) had a significantly higher prevalence (88.00%, $P<0.01$) than young animals (<6 months; 68.53%). Although age-related differences were not significant in sheep, adult goats had significantly higher infection rates than younger goats ($P<0.05$) (Table 3).

Animals maintained under intensive systems showed higher prevalence (88.36%) than those under extensive systems (81.93%). Seasonally, the highest prevalence was recorded during the monsoon (92.50%), followed by winter (79.09%) and summer (78.55%) (Table 3).

The mean quantitative parasitic load (EPG± SE) was also highest during the monsoon (4,541.5±6,027.28), followed by winter (2,017.09±4,109.74) and summer (1,974.66±2,899.90). Among positive samples, 36.72% were lightly infected (100-1,000 EPG), whereas 6.75% were heavily infected (>4,000 EPG). Additionally, 16.56% had 1,000-2,000 EPG, 6.91% had 2,000-3,000 EPG and 3.16% had 3,000-4,000 EPG (Table 3).

Spatial distribution

Spatial mapping revealed that GIP prevalence ranged from 45-100% in sheep and 65-100% in goats, with overall prevalence between 65-100%. The highest predicted prevalence (95-100%) was observed in Amritsar and Ludhiana, particularly within the CPZ (Fig 2c). Moga and adjoining western districts showed predicted prevalence of 80-95%, while the lowest prevalence in the WPZ was recorded in Faridkot and Muktsar.

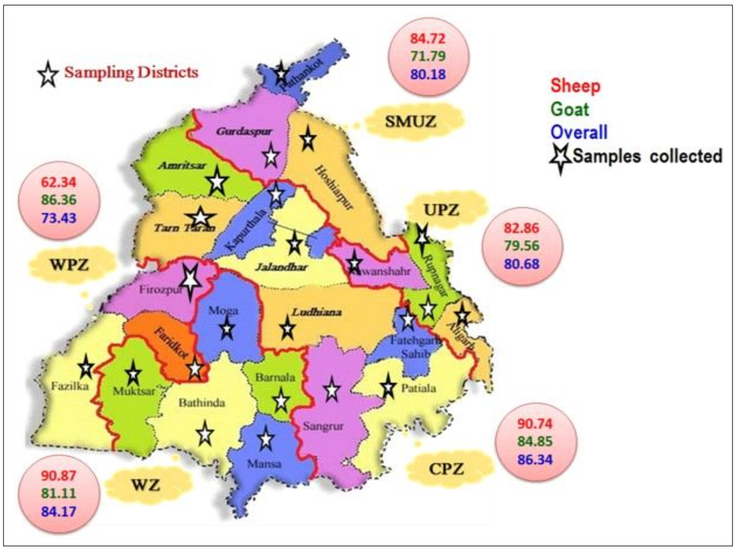

Fig 1: Comparative Zone wise *i.e.* Sub mount undulating plain zone (SMU), Undulating plain zone (UPZ), Central plain zone (CPZ), Western plain zone (WPZ) and Western zone (WZ) and animal species wise copro-prevalence GIT parasites of small ruminants.

Table 1: Comparative agro-climatic zone, district and species wise copro-prevalence gastrointestinal parasites of small ruminants in Punjab.

Zone	District	Sheep		Goat		Overall	
		Samples examined	Positive (%)	Samples examined	Positive (%)	Samples examined	Positive (%)
Zone I (SMU)	Gurdaspur	31	26 (83.87)	16	13 (81.25)	47	39 (82.98)
	Hoshiarpur	7	6 (85.71)	13	8 (61.54)	20	14 (70.00)
	Pathankot	34	29 (85.29)	10	7 (70.00)	44	36 (81.82)
Total		72	61 (84.72)	39	28 (71.79)	111	89 (80.18)
Zone II (UPZ)	SAS Nagar, Mohali	13	10 (76.92)	56	44 (78.57)	69	54 (78.26)
	SBS Nagar, Nawanshahr	40	31 (77.50)	66	55 (83.33)	106	86 (81.13)
	Rupnagar	17	17 (100.00)	15	10 (66.67)	32	27 (84.38)
Total		70	58 (82.86)	137	109 (79.56)	207	167 (80.68)
Zone III (CPZ)	Amritsar	30	30 (100.00)	27	27 (100.00)	57	57 (100.00)
	Fatehgarh Sahib	22	21 (95.45)	50	37 (74.00)	72	58 (80.56)
	Jalandhar	9	7 (77.78)	73	48 (65.75)	82	55 (67.07)
	Kapurthala	6	5 (83.33)	20	17 (85.00)	26	22 (84.62)
	Ludhiana	40	40 (100.00)	197	191 (96.95)	237	231 (97.47)
	Patiala	40	34 (85.00)	100	77 (77.00)	140	111 (79.29)
	Tarn Taran	15	10 (66.67)	15	12 (80.00)	30	22 (73.33)
Total		162	147 (90.74)	482	409 (84.85)	644	556 (86.34)
Zone IV (WPZ)	Faridkot	50	24 (48.00)	38	36 (94.74)	88	60 (68.18)
	Firozpur	27	24 (88.89)	28	21 (75.00)	55	45 (81.82)
Total		77	48 (62.34)	66	57 (86.36)	143	105 (73.43)
Zone V (WZ)	Barnala	26	22 (84.62)	91	79 (86.81)	117	101 (86.32)
	Bathinda	24	23 (95.83)	52	43 (82.69)	76	66 (86.84)
	Mansa	10	10 (100.00)	64	46 (71.88)	74	56 (75.68)
	Moga	69	67 (97.10)	108	101 (93.52)	177	168 (94.92)
	Shri Muktsar Sahib	15	12 (80.00)	60	38 (63.33)	75	50 (66.67)
	Sangrur	66	56 (84.85)	78	64 (82.05)	144	120 (83.33)
	Fazilka	20	19 (95.00)	50	37 (74.00)	70	56 (80.00)
Total		230	209 (90.87)	503	408 (81.11)	733	617 (84.17)
	Overall total	611	523 (85.60)	1227	1011 (82.40)	1838	1534 (83.46)
	χ^2	8.391^{NS}		9.674^{NS}		11.083^{NS}	

Zone: SMU: Submountain undulating plain zone, UPZ: Undulating plain zone, CPZ: Central plain zone, WPZ: Western plain zone, WZ: Western zone, NS: Non significant.

Table 2: Comparative species wise copro-prevalence and quantitative load of gastrointestinal parasites of small ruminants in Punjab.

Species	Total examined	Positive (%)	Single parasitic infection		Dual parasitic infection					Multiple infection (%)	Mean egg Per gram ± Standard Error (range)
			Str. (%)	Coc. (%)	Str. + Coc.(%)	Str. + Mon. (%)	Str. + Strg. (%)	Str. + Tri. (%)	Str. + Amp. (%)		
Sheep	611	523 (85.60)	145 (27.72)	46 (8.80)	162 (30.98)	15 (2.87)	33 (6.31)	14 (2.68)	3 (0.57)	107 (20.46)	1323.81 ± 2135.97 (100-6700)
Goat	1227	1011 (82.40)	149 (14.74)	3 (0.30)	428 (42.32)	43 (4.25)	22 (2.18)	20 (1.98)	11 (1.09)	335 (33.14)	1520.61 ± 2239.33 (100-10000)
χ^2		0.271^{NS}			33.792**		28.233**			15.441**	

Superscript *indicates values varying significantly at P<0.05, **indicates values varying significantly at P<0.01. NS: Non significant.
Str = Strongyle, Coc = Coccidia, Tri = *Trichuris*, Amp.= Amphistomes, Mon.= *Moniezia*, Strg = *Strongyloides*
Note: The wide SE values for EPG reflect the characteristically over-dispersed, right-skewed distribution of gastrointestinal helminth egg counts in field surveys, wherein most animals harbour low burdens while a minority carry disproportionately high parasite loads.

In sheep, predicted prevalence in Faridkot ranged from 45-55% (Fig 2a). Higher rates were observed in Tarn Taran (CPZ), Mansa (WZ), Ludhiana, Amritsar (CPZ) and Rupnagar (Undulating Plain Zone). Overall, southeastern and northern districts exhibited higher predicted prevalence compared to western districts.

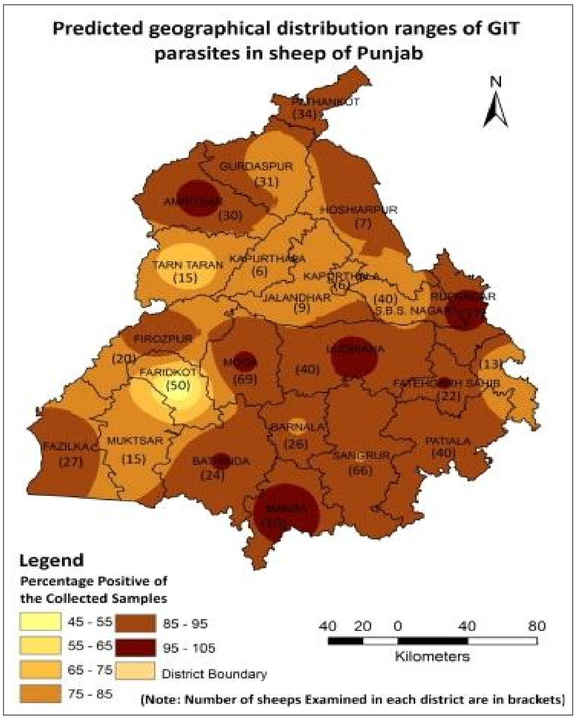

Fig 2a: Predicted geographical distribution of gastrointestinal parasitism in sheep.

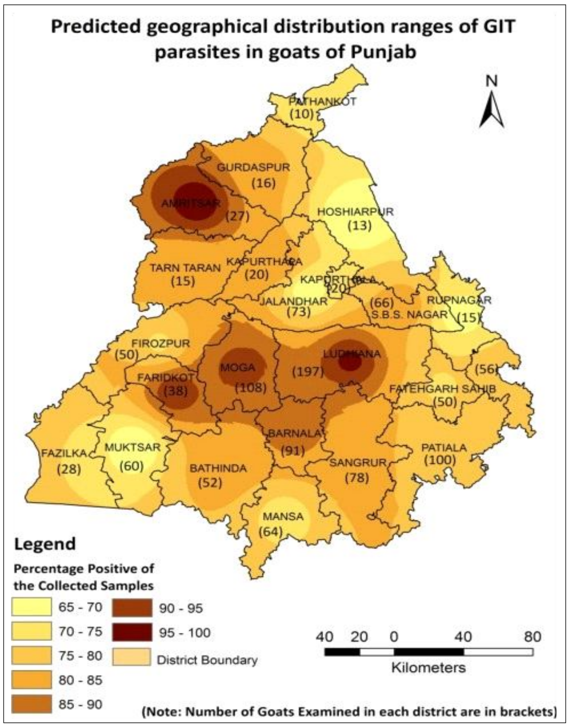

Fig 2b: Predicted geographical distribution of gastrointestinal parasitism in goats.

For goats, central districts including Ludhiana, Moga and Faridkot showed predicted prevalence of 85-95% (Fig 2b), with Amritsar also demonstrating high rates. Other districts displayed low to moderate prevalence.

Binary logistic regression identified geographical location as a significant risk factor (P<0.01), particularly in Barnala (OR 22.03; CI 5.66-87.19), Ludhiana (OR 33.25; CI 8.38-136.29) and Moga (OR 27.79; CI 7.17-89.98). Age emerged as the most significant risk factor (P<0.01). Seasonal effects (summer and monsoon) were significantly associated with infection compared to winter. Other factors, including agro-climatic zone, species, sex and management system, were not statistically significant (Table 3).

Punjab's economy heavily relies on agriculture and livestock production, particularly small ruminants. Therefore, systematic disease surveillance and robust epidemiological reporting of economically important parasitic infections are essential. Comparative coprological surveys are especially valuable for identifying high-risk regions.

The present study revealed a high overall prevalence of GIT parasitism, with sheep (85.60%) slightly more affected than goats (82.40%). These findings are consistent with earlier reports from Punjab and other regions (Vardharajan and Vijayalakshmi, 2015; Velusamy *et al*., 2015; Singh, 2015; Singh *et al*., 2013, 2017), possibly reflecting species-specific grazing and browsing behaviors (Berry, 2011; Lathamani *et al*., 2016).

However, some studies have reported higher prevalence in goats (Saha *et al*., 1996; Singla, 1995; Pandey *et al*., 1994), highlighting the complexity of host-parasite dynamics. The extremely high prevalence observed in Amritsar may be attributed to confinement practices without adequate deworming, leading to environmental contamination and increased transmission risk (Morgan *et al*., 2006).

Conversely, the lower prevalence noted in districts like Faridkot, Jalandhar, Hoshiarpur and Muktsar may be linked to the nomadic practices of local farmers, who frequently shift pastures. These farmers tend to adhere more rigorously to deworming schedules, as indicated by our questionnaire data collected during sampling (Cai and Bai, 2009).

The stark differences in GIP prevalence between agro-climatic zones, highest in the central plain zone (CPZ) at 86.30% and lowest in the western plain zone (WPZ) at 73.43% (Table 1 and 3), can be attributed to variations in agro-climatic conditions, availability of grazing resources and the presence of susceptible hosts (Singh *et al*., 2013). Moreover, the finding that females (85.43%) are more susceptible to infections than males (72.16%) across both species reinforces existing literature indicating a higher prevalence of GIT parasites in females compared to males (Buragohain *et al*., 2013; Sharma *et al*., 2009; Singh *et al*., 2017). This susceptibility may result from hormonal influences, genetic predispositions and physiological stresses, particularly in lactating females who may experience malnutrition and weakened immune responses (Golo Dabasa *et al*., 2017).

The higher infection rates in adults compared to younger animals can be explained by several factors, including prolonged exposure to drug-resistant parasites, chronic infections, climatic conditions and extensive grazing across contaminated pastures (Radostits *et al*., 1994). Young animals typically experience lower prevalence due to less exposure, as they primarily depend on milk feeding. These observations are consistent with findings

Table 3: Risk factors associated parasitic infections in sheep and goats in Punjab (Regression analysis).

	Parameter	Examined	Positive (%)	Estimate	Standard Error	Wald Chi-square	Pr > Chi Sq	Odds ratio	CL of odds ratio. (LL-UL)
Intercept	Districts			1.1295	0.1886	35.8842	<.0001		
1	Amritsar	57	57 (100.00)	-0.7998	0.35	5.2232*	0.0223	3.41	1-12.06
2	Barnala	117	101 (86.32)	1.0658	0.3256	10.7174**	0.0011	22.031	5.66-87.19
3	Bathinda	76	66 (86.84)	0.2914	0.3307	0.7765	0.3782	10.155	2.63-39.88
4	Faridkot	88	60 (68.18)	0.3179	0.3185	0.9961	0.3183	10.428	2.78-39.72
5	Fatehgarh Sahib	72	58 (80.56)	0.7088	0.3399	4.3483*	0.037	15.417	3.91-61.99
6	Firozpur	55	45 (81.82)	-0.1961	0.3474	0.3187	0.5724	6.237	1.61-24.5
7	Fazilka	70	56 (80.00)	0.271	0.336	0.6504	0.42	9.95	2.52-39.75
8	Gurdaspur	47	39 (82.98)	0.779	0.4386	3.1544	0.0757	16.538	3.82-74.42
9	Hoshiarpur	20	14 (70.00)	0.3078	0.5307	0.3365	0.5619	10.324	2.1-53.47
10	Jalandhar	82	55 (67.07)	-0.7536	0.2955	6.5026*	0.0108	3.572	0.97-13.3
11	Kapurthala	26	22 (84.62)	1.1757	0.5702	4.2519*	0.0392	24.588	4.83-140.61
12	Ludhiana	237	231 (97.47)	1.4737	0.4864	9.1779**	0.0024	33.125	8.38-136.29
13	Mansa	74	56 (75.68)	0.2179	0.3135	0.483	0.487	9.436	2.46-36.73
14	Moga	177	168 (94.92)	1.1836	0.3397	12.1423**	0.0005	24.786	7.17-89.98
15	Shri Mukstar Sahib	75	50 (66.67)	-0.4695	0.281	2.7915	0.0948	4.745	1.29-17.61
16	SBSN Nawanshahr	106	86 (81.13)	0.2175	0.2849	0.5832	0.4451	9.432	2.56-35.09
17	Pathankot	44	36 (81.82)	-0.0918	0.4855	0.0358	0.85	6.923	1.56-31.8
18	Patiala	140	111 (79.29)	0.314	0.3086	1.0348	0.309	10.387	2.77-39.45
19	Rupnagar	32	27 (84.38)	-0.7832	0.5931	1.7437	0.1867	3.468	0.98-13.3
20	SASN Mohali	69	54 (78.26)	-1.853	0.4458	17.2801**	<.0001	1.19	0.43-3.15
21	Sangrur	144	120 (83.33)	-1.3505	0.4115	10.7699**	0.001	1.966	0.75-4.83
22	Tarn Taran	30	22 (73.33)	Reference					
Zone I	SMU	111	89 (80.18)	-0.0757	0.2086	0.1317	0.7166	0.752	0.45-1.29
Zone II	UPZ	207	167 (80.68)	-0.1736	0.1642	1.1172	0.2905	0.682	0.46-1.03
Zone III	CPZ	644	556 (86.34)	-0.0908	0.1269	0.5111	0.4747	0.741	0.53-1.04
Zone IV	WPZ	143	105 (73.43)	0.1314	0.1914	0.4712	0.4924	0.926	0.57-1.53
Zone V	WP	733	617 (84.17)	Reference					
Species	Goat	1227	1011 (82.40)	0.1094	0.0763	2.053	0.1519	1.245	0.92-1.68
(Goat × Sheep)	Sheep	611	523 (85.60)	Reference					
Age	Adult	1409	1240 (88.00)	0.5672	0.0748	57.5539**	<.0001	3.11	2.32-4.17
(Adult × Kid)	Kid	429	294 (68.53)	Reference					
Sex	Male	273	197 (72.16)	-0.151	0.0844	3.2015	0.0736	0.739	0.53-1.03
(Male × Female)	Female	1565	1337 (85.43)	Reference					
Management (Intensive ×	Intensive	438	387 (88.36)	-0.0937	0.1967	0.227	0.6338	0.829	0.38-1.78
Extensive)	Extensive	1400	1147 (81.93)	Reference					
Season	Summer	661	519 (78.52)	-0.7589	0.2139	12.5898**	0.0004	0.694	0.41-1.17
	Monsoon	627	580 (92.50)	1.1522	0.2976	14.9898**	0.0001	4.69	2.02-11.97
	Winter	550	435 (79.09)	Reference					

Zone: SMU: Sub mount undulating plain zone, UPZ: Undulating plain zone, CPZ: Central plain zone, WPZ: Western plain zone, WZ: Western zone.

Superscript * indicates values varying significantly at P<0.05, **indicates values varying significantly at P<0.01.

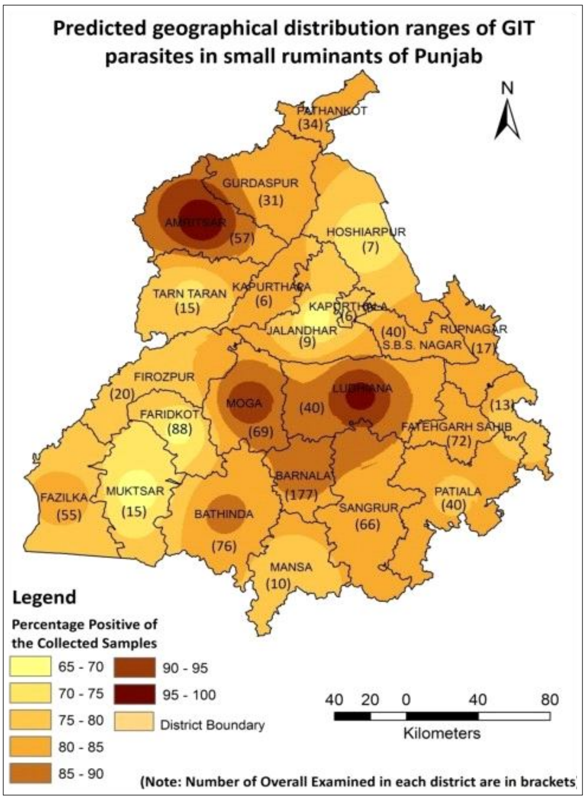

Fig 2c: Predicted geographical distribution of gastrointestinal parasitism in Small ruminants.

from India and other regions (Emiru *et al*., 2013; Singh *et al*., 2017; Yadav *et al*., 2006).

Additionally, the prevalence of GIT parasites was significantly higher in intensive management systems (88.36%) compared to extensive systems (81.93%). This discrepancy can be attributed to factors such as overcrowding, poor hygiene and the contamination of feed and water, which collectively promote the rapid transmission and environmental buildup of GIT parasites (Soulsby, 1982).

Seasonal variations in copro-prevalence of GIT parasitic infections revealed a peak during the monsoon (92.50%), followed by winter (79.09%) and summer (78.55%) for both species. These findings align with previous research (Dhara *et al*., 2015; Gaherwal *et al*., 2016; Vardharajan and Vijayalakshmi, 2015; Singh *et al*., 2017). The heightened prevalence during the monsoon can be attributed to favorable climatic conditions-namely, increased humidity and temperature-that enhance parasitic growth and the availability of infective larvae on pastures.

The substantial quantitative parasitic load (eggs per gram of faeces, mean±SE) during the monsoon (4,541.5 ±6,027.28) underscores the fecundity of nematode parasites in conditions of reduced immunity, particularly in pregnant animals, or among young animals with underdeveloped immune systems (Hawlader *et al*., 2002; Singh *et al*., 2017). While the pathogenic thresholds for EPG counts vary widely among researchers (Smeal *et al*., 1980), it is crucial to recognize that elevated EPG counts are often positively correlated with worm burden (Hawlader *et al*., 2002).

The variability in prevalence rates across the five zones may be influenced by a complex interplay of biotic and abiotic factors, including geographical distribution and management practices. The notably higher predicted prevalence in the centro-southern region for sheep and in the central region for goats (Fig 2 a, b, c) likely reflects intensive animal management practices, higher stocking densities and the warm, humid monsoon conditions prevalent in these zones, all of which are known to favour the development and survival of infective nematode larvae. In conclusion, the urgent need for effective disease management strategies cannot be overstated. Enhanced awareness and improved management practices among farmers are critical to mitigating the impact of GIT parasitic infections in small ruminants across Punjab.

CONCLUSION

This comprehensive cross-sectional study demonstrates the high burden of gastrointestinal parasitism in small ruminants across Punjab, with significant spatial variation among agroclimatic zones and districts. The identification of specific risk factors and high-prevalence areas provides crucial baseline data for implementing targeted control programs. The spatial mapping approach employed in this study offers a valuable tool for veterinary health planning and resource allocation. Future research should focus on species-specific parasite identification, anthelmintic resistance monitoring and evaluation of integrated control strategies tailored to different agroclimatic zones.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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