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ORIGINAL PAPER

Influence of weather patterns and air quality on ecological population dynamics of ectoparasites in goats

Y. Ajith[1,2,3] · U. Dimri[1] · E. Madhesh[1] · A. Gopalakrishnan[1] · Med Ram Verma[4] · H. A. Samad[5] · K. K. Reena[6] · A. K. Chaudhary[1] · G. Devi[1] · J. Bosco[5]

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Abstract

Ectoparasitism has a damaging impact on the economy of goat production in India, but the factors influencing its distribution and dynamics are less explored. The present study was designed to investigate the influence of environmental factors like weather and air quality parameters on the occurrence of different types of ectoparasites in goats of two agro-climatic regions of India, viz. the Upper Gangetic Plain (UGP) and the Western Himalayas (WH). The prevalence survey for ectoparasitism among goats was conducted during the four distinct climatic seasons (winter, summer, monsoon, autumn) in both regions. The season-wise data of weather parameters (maximum and minimum temperature, relative humidity in morning and evening, sunrise and sunset time, mean daily temperature and relative humidity, daily variation in temperature and relative humidity, and day length) and air quality parameters (air quality index (AQI), particulate matter 2.5 μm ($PM_{2.5}$), particulate matter 10 μm (PM_{10})) of both regions were analyzed in relation with the ectoparasitic prevalence pattern of corresponding regions. The results depict a noticeable correlation between the studied parameters and seasonal variation in the occurrence of each type of ectoparasites. This outcome on the interaction of studied parameters and ectoparasitism is intriguing and it opens a huge scope for future studies on the biometeorological aspects of host-parasite ecological interplay and evolutionary biology. The better understanding of climatological aspects of ectoparasite occurrences helps goat farmers in formulating appropriate timely intervention strategies for the economic control of ectoparasites, which in turn tackles ectoparasiticidal drug resistance and reduces threat of vector-borne diseases.

Keywords Animals · Climate change · Ecology · Ectoparasitism · Epidemiology · Pollution · Season-wise

Highlights

i. Climatic and air quality parameters can affect the population dynamics of ectoparasites in goats.
ii. The low prevalence of highly host-specific chewing lice in the UGP region may be resulted from ecological destruction due to severely uncomfortable climate and hazardous air.
iii. The prevalence of each type of ectoparasitism is dependent on the biometeorological features of the region.

✉ Y. Ajith
ajithy123456789@gmail.com; ajithy@bhu.ac.in

1 Division of Medicine, ICAR-Indian Veterinary Research Institute, Izatnagar, UP 243122, India

2 Department of Veterinary Medicine, Faculty of Veterinary and Animal Sciences, Banaras Hindu University, Rajiv Gandhi South Campus, Mirzapur, UP 231001, India

3 Banaras Hindu University, Varanasi, India

4 Division of Livestock Economics, Statistics and Information Technology, ICAR-Indian Veterinary Research Institute, Izatnagar, UP 243122, India

5 Division of Physiology & Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, UP 243122, India

6 Division of Parasitology, ICAR-Indian Veterinary Research Institute, Izatnagar, UP 243122, India

Introduction

India is an amalgam of characteristically diverse geographical, cultural, social, and climatic features. Its geographical extremities extend from the Indira Col (35.4° N 76.5° E; altitude 5764 m) in Siachen Glacier in the eastern Karakoram range of the Himalayas in the north to the Indira point (6.78° N, 93.83°E; altitude 47 m) of Great Nicobar Island in the south and from the Kibithu (28.17° N, 97.37° E; altitude 1240 m) in Anjaw district of Arunachal Pradesh in the east to Ghuar Moti (23.62° N, 68.53° E; altitude 2 m) in Kutch district of Gujarat in the west. This vivid land area ranging between the altitude from the lowest point Kuttanad (− 2.2 m; below sea level) in Kerala to the highest point Mount Kanchenjunga in Sikkim (elevation of 8586 m) offers diverse weather features even at a single point of time. Hence, 15 broad agro-climatic zones have been proposed by the Planning Commission of India considering this variable nature of weather parameters as well as agricultural practices (Alagh et al. 1989; Khanna 1989; Venkateswarlu et al. 1996).

Ectoparasitism plays a crucial role in the economics of goat rearing by deteriorating animal health, reducing growth rate, and lowering production performance (Ghosh et al. 2007). Such ecological interactions between the vertebrate hosts and the "invertebrate" arthropods/parasites display astonishing complexity fuelling a highly dynamic research program. Skin and associated structures serve as the ecological habitat for the ectoparasites by providing optimum microclimate for the successful completion of its life stages. Some facultative parasites that have only intermittent contact with their hosts are less host-specific and are usually free-living for the major part of their life cycle. The obligatory parasites are totally dependent on the host to complete their life cycle and are highly host-specific (Taylor et al. 2016). Developing better scientific perceptions on the host specificity, dependency, and feeding habits of these arthropod organisms and explorations into its evolutionary basis always attracted researchers' interest. The biometeorological aspects of vertebrate host-ectoparasite ecological interactions are less described in veterinary science literature. But, the role of climate in determining vector activity and fecundity which in turn results in the altered risk for vector-borne infectious disease occurrence is a critically explored field in biomedical research (Zamora-Vilchis et al. 2012; Altizer et al. 2013). Some recent studies reported the critical role of climatic factors in determining the successful establishment of ectoparasite infestation and their distribution across the landscape (Pilosof et al. 2012; Cantarero et al. 2013; Møller et al. 2013; Dube et al. 2018). But, most of these studies were concentrated on the influence of climate on some specific ectoparasites (especially flies and fleas) in avian species and bats. Some researchers suggested the possible effect of climate change on occurrences and distribution of tick species in Africa using multiple regression model studies on different simulated climate change scenarios (Estrada-Peña 2003; Cumming and Van Vuuren 2006; Olwoch et al. 2009). Lamarre et al. (2018) investigated the effects of extreme climatic conditions in the reproductive success of ectoparasites and thereby determining the distribution of ectoparasites on host populations. A few studies addressed the issue of ectoparasitism in higher order mammals like goats in relation to agro-climatic factors, but unfortunately, critical analysis on meteorological parameters and its effect in determining the prevalence and type of ectoparasite was found lacking (Costa-Junior et al. 2012; Beyecha et al. 2014; Paz et al. 2015; Adang et al. 2015).

The previous work conducted during winter season among goats in the present study regions reported considerably significant difference in the type and the prevalence of ectoparasites (Ajith et al. 2017), whereas the effect of biometeorological factors on the ecological aspect of animal-arthropod relations is not widely studied. Studies on the ecology, epidemiology, pathobiology, and formulation of economic therapeutic strategies with practical utility and field application to curb ectoparasitism in animals based on these factors are the need of the hour. Hence, this study was designed to investigate the influence of environmental variables like weather and air quality parameters on the distribution of ectoparasites in goats.

Materials and methods

Prevalence survey for ectoparasites

The study was conducted in two agro-climatic regions of India sharing humid subtropical climate, viz. the fertile UGP region (Bareilly (28.37° N, 79.43° E) and Moradabad (28.84° N, 78.77° E) districts of Uttar Pradesh—elevation ranging from 198 to 268 m) and the WH region (Dehradun (30.32° N, 78.03° E) and Tehri Garhwal (30.30° N, 78.57° E) districts in Uttarakhand located in the lower Shivalik ranges—elevation ranging from 600 to 1550 m). The Northern hemisphere experiences four distinct climatic seasons (winter—21 December 2017 to 20 March 2018; summer—21 March 2018 to 20 June 2018; monsoon—21 June 2018 to 23 September 2018; post-monsoon/autumn season—23 September 2018 to 22 December 2018). The prevalence survey was conducted on selected 14 days from the middle of each distinct season with ideal climatic features of that season. A total of 960 goats (120 animals per season per agro-climatic region) were selected by stratified random sampling from the villages of the two agro-climatic regions of India, viz. the UGP region and the WH region, and were screened for ectoparasitic infestation during the four distinct climatic seasons of the years 2017–2018. Special attention was made not to include any animal from well-maintained organized farms and those that had a history of recent ectoparasiticidal therapy for this study. Each animal was examined thoroughly by a systematic search for ectoparasites on the body regions, viz., around the eyes, pinna of the ears, neck, shoulder, withers, flank, rump, inguinal region, and perineal region which were described as the common predilection sites of ectoparasitic infestation in previous studies (Ajith et al. 2017; Gopalakrishnan et al. 2017). Lice and ticks were visualized by the hair parting method and fleas were searched out by the flea comb method. The presence of lice in goats was easily presumed by observing the presence of lice eggs or nits on the outer hair coat of animals.

Parasitological evaluation

The collected parasites were immediately transferred into clean vials containing 70% ethanol and were identified microscopically based on the morphological characteristics (Soulsby 1982). The sucking lice and chewing lice identified from the study area were *Linognathus africanus* and *Bovicola caprae*, respectively (Figs. 1 and 2). For better viewability of morphological features, fleas and ticks were processed using 10% sodium hydroxide for 24 h after making a small hole in the abdomen using a 24-G needle and evenly cleared the liquefied tissue by applying gentle pressure followed by keeping in serial solutions of ethanol (70%, 80%, 95%, and 100%) for 30 min each. The fleas obtained from the study area were identified as *Ctenocephalides felis orientis* based on the morphological features suggested by Ashwini et al. (2017) (Fig. 3). We also observed variations in chaetotaxy of the hind tibia of *C. orientis* (Fig. 4), which was earlier reported in *Ctenocephalides felis felis* by Linardi and Santos (2012).

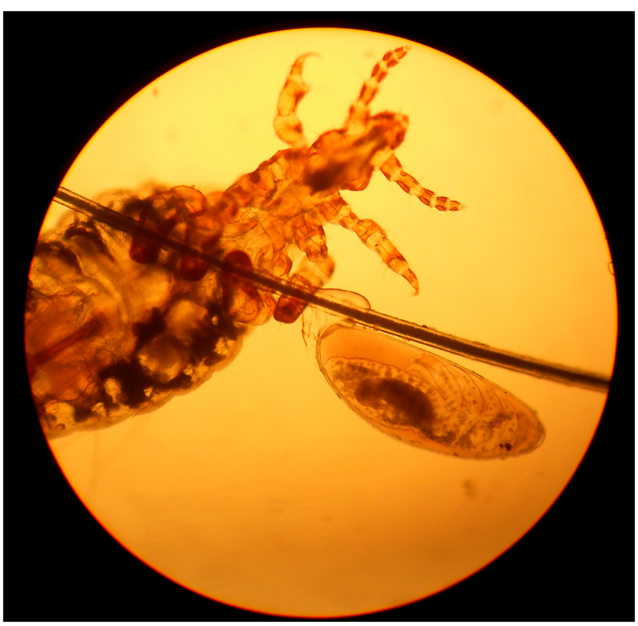

Fig. 1 Magnified view (× 40) of the sucking louse (*Linognathus africanus*) with a lice egg having ready-to-hatch larvae inside. Characteristic bulging of postero-lateral aspect of the head, used to differentiate *L. africanus* from *L. stenopsis*

Fig. 2 Magnified view (× 40) of the head and thorax of adult chewing louse (*Bovicola caprae*). Blunt mouth parts adapted for chewing only, rather than blood sucking

The ticks identified from the study area were *Haemaphysalis* spp. and *Rhipicephalus* (*Boophilus*) *microplus* (Figs. 5 and 6).

Fig. 3 Microscopic view of the flea (*C. orientis*)

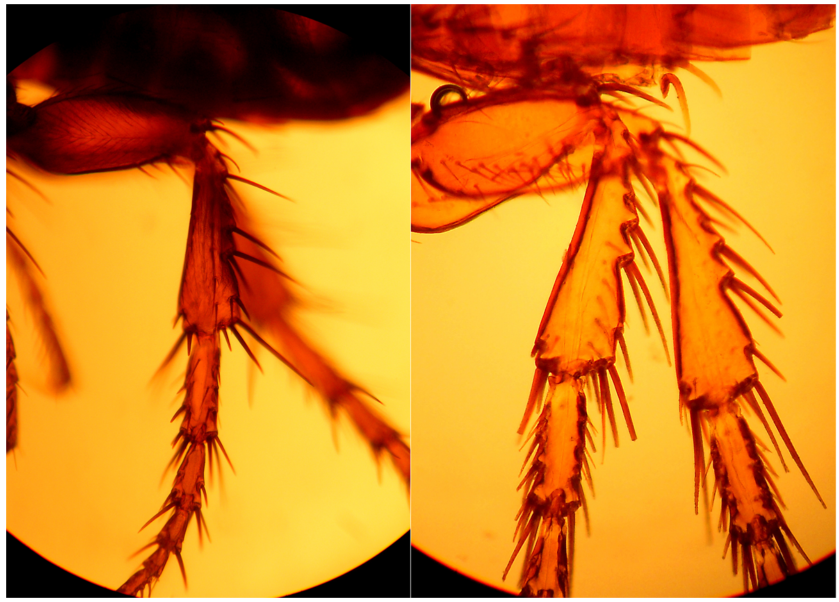

Fig. 4 Variation in chaetotaxy of the hind tibia of fleas (*C. orientis*)

Biometeorological study

The prevalence patterns on the type of ectoparasites were studied in relation to the biometeorological factors of the study area. The weather parameters (maximum temperature, minimum temperature, relative humidity at morning (08:30 h), relative humidity at evening (17:30 h), sunrise time, and sunset time) of both agro-climatic regions (Bareilly in UGP region and Dehradun in WH region) during the prevalence survey period (14 days per season) were recorded from the website of India Meteorological Department, Government of India, New Delhi (http://www.imd.gov.in/pages/city_weather_main.php). The parameters like mean daily temperature, daily variation in temperature, mean daily relative humidity, daily variation in relative humidity, and day length were calculated from the above parameters by using standard arithmetic formulas. The temperature-humidity index is calculated by using the formula, $THI = T - [0.55 \times (1 - RH)\ (T - 58)]$, where "$T$" denotes temperature in degree Fahrenheit and "RH" denotes relative humidity in percentage (Schlatter 1987). The air quality parameters (air quality index (AQI), particulate matter 2.5 μm ($PM_{2.5}$), particulate matter 10 μm (PM_{10})) of both the agro-climatic regions (Moradabad in UGP region and Dehradun in WH region) were recorded daily at two points of time (morning (11:00 am) and evening (11:

Fig. 5 Microscopic view (× 4) of the tick (*Haemaphysalis* sps.)

Fig. 6 Microscopic view (× 4) of the tick (*Rhipicephalus* (*Boophilus*) *microplus*)

Table 1 Prevalence of different ectoparasites in both agro-climatic regions during different climatic seasons

Agro-climatic region	Type of ectoparasite infested	Winter season		Summer season		Monsoon season		Autumn season		Cumulative/yearly		Chi-square (between seasons)
		Number of goats	Prevalence (%)	Number of goats	Prevalence (%)	Number of goats	Prevalence (%)	Number of goats	Prevalence (%)	Number of goats	Prevalence (%)	
Upper Gangetic Plains region (UGP region)	Sucking lice	34	28.33	21	17.50	9	7.50	23	19.17	87	18.13	
	Chewing lice	1	0.83	0	0.00	0	0.00	0	0.00	1	0.21	
	Ticks	2	1.67	13	10.83	28	23.33	16	13.33	59	12.29	
	Fleas	8	6.67	26	21.66	46	38.33	39	32.50	119	24.79	
	Concurrent infestation: ticks and fleas	0	0.00	1	0.83	15	12.50	12	10.00	28	5.83	
	Total ectoparasite-infested goats	*45*	*37.50*	*59*	*49.17*	*68*	*56.67*	*66*	*55.00*	*238*	*49.58*	*10.834**
	No ectoparasite (healthy goats)	*75*	*62.50*	*61*	*50.83*	*52*	*43.33*	*54*	*45.00*	*242*	*50.42*	
	Total goats screened	*120*	*100.00*	*120*	*100.00*	*120*	*100.00*	*120*	*100.00*	*480*	*100.00*	
	Chi-square (within season)	*7.50***		*0.03*		*2.13*		*1.20*		*0.033*		
Western Himalayas region (WH region)	Sucking lice	14	11.67	32	26.67	13	10.83	28	23.33	87	18.13	
	Chewing lice	80	66.67	32	26.67	12	10.00	38	31.66	162	33.75	
	Ticks	0	0.00	2	1.67	41	34.17	6	5.00	49	10.21	
	Fleas	13	10.83	36	30.00	78	65.00	35	29.16	162	33.75	
	Concurrent infestation: ticks and fleas	0	0.00	0	0.00	32	26.67	3	2.50	35	7.29	
	Concurrent infestation: fleas and chewing lice	3	2.50	11	9.17	7	5.83	10	8.33	31	6.46	
	Total ectoparasite-infested goats	*104*	*86.67*	*91*	*75.83*	*105*	*87.50*	*94*	*78.33*	*394*	*82.08*	*8.44**
	No ectoparasite (healthy goats)	*16*	*13.33*	*29*	*24.17*	*15*	*12.50*	*26*	*21.67*	*86*	*17.92*	
	Total goats screened	*120*	*100.00*	*120*	*100.00*	*120*	*100.00*	*120*	*100.00*	*480*	*100.00*	
	Chi-square (within season)	*64.53****		*32.03****		*67.50****		*38.53****		*197.63****		

The italicized values are subtotal for each climatic region and respective statistical analysis value

$^{*}P < 0.05$, $^{**}P < 0.01$, and $^{***}P < 0.001$

Table 2 Climatic season-wise data of weather parameters in the study area (mean ± SD)

Climatic season	Winter season (n = 14)		Summer season (n = 14)		Monsoon season (n = 14)		Autumn season (n = 14)		Yearly average (n = 56)	
Agro-climatic region	UGP region	WH region	UGP region	WH region	UGP region	WH region	UGP region	WH region	UGP region	WH region
Maximum temperature (°C)	19.66 ± 1.77Db	21.07 ± 1.77Da	39.88 ± 1.81A	38.59 ± 1.46A	31.94 ± 2.90B	31.22 ± 2.51B	29.33 ± 1.28C	28.38 ± 1.90C	30.20 ± 1.94	29.82 ± 1.91
Minimum temperature (°C)	5.05 ± 1.42C	5.31 ± 1.65D	24.66 ± 1.39Aa	21.96 ± 0.98Bb	24.67 ± 1.09A	23.87 ± 0.71A	13.31 ± 1.41B	12.49 ± 1.13C	16.92 ± 1.33	15.91 ± 1.12
Relative humidity at 08:30 h (%)	97.00 ± 2.63Aa	93.86 ± 4.02Ab	62.36 ± 5.94Da	45.21 ± 9.02Db	89.57 ± 9.15Bb	92.71 ± 5.90Ba	80.00 ± 10.89Ca	78.21 ± 8.29Cb	82.23 ± 7.15a	77.50 ± 6.81b
Relative humidity at 17:30 h (%)	69.93 ± 7.89Ba	64.57 ± 5.52Cb	33.14 ± 10.54Da	25.79 ± 9.42Db	80.50 ± 10.73Ab	85.71 ± 10.51Aa	66.57 ± 4.85Cb	69.50 ± 7.73Ba	62.54 ± 8.50	61.39 ± 8.30
Sunset time (HH/MM)	17:26 ± 00:03	17:27 ± 00:04	19:00 ± 00:03	19:10 ± 00:03	18:50 ± 00:06	18:59 ± 00:07	17:30 ± 00:04	17:32 ± 00:04	18:12 ± 00:04	18:17 ± 00:04
Sunrise time (HH/MM)	07:04 ± 00:02	07:14 ± 00:02	05:18 ± 00:02	05:20 ± 00:02	05:42 ± 00:09	05:45 ± 00:09	06:23 ± 00:04	06:31 ± 00:04	06:07 ± 00:04	06:10 ± 00:04
Mean daily temperature (°C)	12.35 ± 1.07D	13.19 ± 0.98D	32.27 ± 1.04Aa	30.28 ± 0.65Ab	28.31 ± 1.77B	27.55 ± 1.48B	21.32 ± 1.12C	20.44 ± 1.05C	23.56 ± 1.25	22.86 ± 1.04
Daily variation in temperature (°C)	14.61 ± 2.38C	15.76 ± 2.81C	15.22 ± 2.47B	16.63 ± 2.12A	7.27 ± 2.57D	7.35 ± 2.21D	16.02 ± 1.52A	15.89 ± 2.31B	13.28 ± 2.23	13.91 ± 2.36
Mean daily relative humidity (%)	83.46 ± 4.49Ba	79.21 ± 3.06Bb	47.75 ± 7.46Da	35.50 ± 7.83Db	85.04 ± 9.25Ab	89.21 ± 6.49Aa	73.29 ± 5.76C	73.86 ± 7.24C	72.38 ± 6.74a	69.45 ± 6.15b
Daily variation in relative humidity (%)	27.07 ± 7.59Bb	29.29 ± 7.46Aa	29.21 ± 8.38Aa	19.43 ± 9.76Bb	9.07 ± 7.41Da	7.00 ± 11.05Db	13.43 ± 12.31Ca	8.71 ± 6.90Cb	19.70 ± 8.92a	16.11 ± 8.79b
Temperature-humidity index (THI)	54.57 ± 1.81Db	55.99 ± 1.58Da	80.84 ± 1.66Aa	76.36 ± 0.97Bb	80.77 ± 1.95B	80.14 ± 2.22A	68.54 ± 1.67Ca	67.21 ± 1.58Cb	71.18 ± 1.77a	69.92 ± 1.59b
Day length (HH/MM)	10:22 ± 00:02	10:13 ± 00:02	13:42 ± 00:04	13:50 ± 00:05	13:08 ± 00:05	13:14 ± 00:07	11:07 ± 00:08	11:01 ± 00:08	12:05 ± 00:05	12:05 ± 00:05

Values with lowercase letters a and b differ significantly ($p < 0.05$) between agro-climatic region; values with uppercase letters A, B, C, and D differ significantly ($p < 0.05$) between seasons

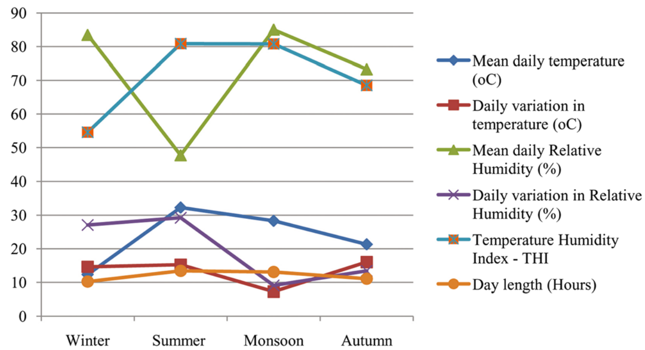

Fig. 7 Season-wise analysis of climatic parameters of the UGP region

00 pm)) on 28 randomly selected days of the entire study period from the website (https://www.aqi.in/) maintained by Purelogic Labs India Pvt. Ltd., New Delhi.

Statistical analysis

The data was organized and analyzed using spreadsheet software, Microsoft Excel 2007 and statistical software package. Prevalence data were expressed in percentage and the Chi-square test was used to find the association between seasons and ectoparasite prevalence. The logistic regression analysis was conducted for studying the effect of selected weather and air quality parameters on the prevalence of each species of ectoparasite by coding incidence of ectoparasitism (presence (1) and absence (0)). The biometeorological parameters were expressed as mean ± SD and the differences within the two regions for each season were studied using the repeated measures ANOVA.

Results

In this study, varying degrees of ectoparasitic infestations, viz. sucking and chewing lice, fleas and ticks, were observed in goats (Table 1). Interestingly, nits of sucking lice attached evenly on the hair of all the body regions of the animal, especially the body trunk region, whereas nits of chewing lice were distributed as aggregates on the hair of the neck and shoulder region in goats. This may be attributed to the mobile nature of chewing lice and particularly to the ecological adaptation of lice to protect their eggs by keeping on a comparatively inaccessible area for the animal for self-grooming. The overall cumulative/yearly prevalence of ectoparasitism was higher in the WH region and lower in the UGP region. In the WH region, both fleas and chewing lice were the most frequently found ectoparasites, but variable with respect to the season. Fleas were also found as combined infestations with chewing lice and ticks in some uncomfortable seasons. In the UGP region, the most prevalent ectoparasite was flea, followed by ticks and sucking lice (in winter). Concurrent infestations

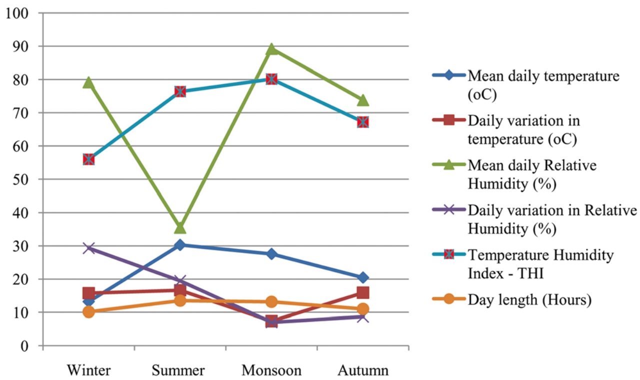

Fig. 8 Season-wise analysis of climatic parameters of the WH region

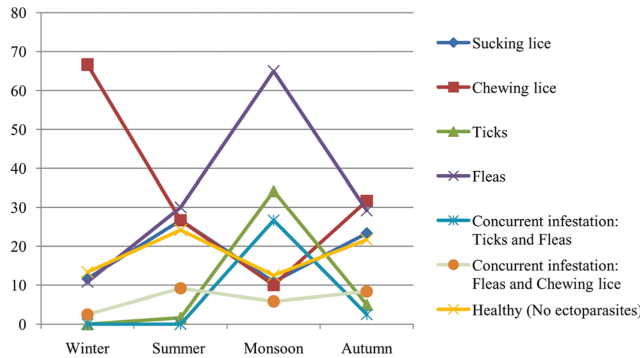

Fig. 10 Season-wise analysis of ectoparasitic prevalence in the WH region

were less prevalent in the UGP region. The higher prevalence of hematophagous ectoparasites undergoing facultative ectoparasitism and low host specificity is observed in the UGP region. In the case of the UGP region, there was a significant difference ($P < 0.01$) between the animals infested with ectoparasites and healthy animals in winter season and non-significant ($P > 0.05$) in summer, monsoon, and autumn seasons. In the WH region, there was a significant difference ($P < 0.001$) between animals infested with ectoparasites and healthy animals during all the four seasons. However, there was a significant association between seasons and ectoparasites' prevalence ($P < 0.05$) in both regions.

On analyzing season-wise climatic parameters of UGP and WH regions (Table 2), it is evident that both regions were showing a similar trend in variations in most of the climatic parameters in each season (Figs. 7 and 8). But, THI and daily variation in RH remained significantly high in major part of the year in the UGP region. Winter season was characterized by high mean daily RH, whereas lower mean daily temperature and THI. Highly host-specific insects, sucking and chewing lice, were the most prevalent during this season in UGP and WH regions, respectively (Figs. 9 and 10). As mean daily temperature increased and mean daily RH reduced in summer, the prevalence of ectoparasitism (especially chewing lice) reduced significantly whereas blood-sucking (hematophagous) insects like sucking lice, fleas, and ticks gradually increased. The monsoon season was warmer but humid with a high THI value representing severe uncomfortable climatic conditions in both regions and a pattern of increased prevalence of the least host-specific ectoparasite (flea) to decreased prevalence of the highly host-specific ectoparasite (chewing lice) was observed. The autumn season trends in weather parameters were moving again to comfortable climatic conditions with an increase in the prevalence of highly host-specific non-blood-feeding ectoparasite, the chewing lice. On analyzing the overall prevalence trends in both the agro-climatic regions, an interesting fact is that the highly host-specific chewing lice are least prevalent in the UGP region and the total number of animals infested with ectoparasites is very high in the WH region (Fig. 11). Among the weather parameters, daily variation in RH and THI was significantly high in most part of the year in the UGP region. The air in the WH region is satisfactory to moderately polluted, whereas the UGP region has recorded very poor to hazardous levels of pollution (Table 3; Fig. 12). The influence of temperature, relative humidity, and THI on the incidence of all the

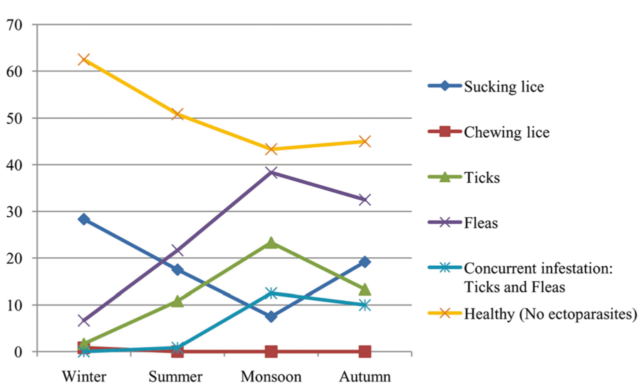

Fig. 9 Season-wise analysis of ectoparasitic prevalence in the UGP region

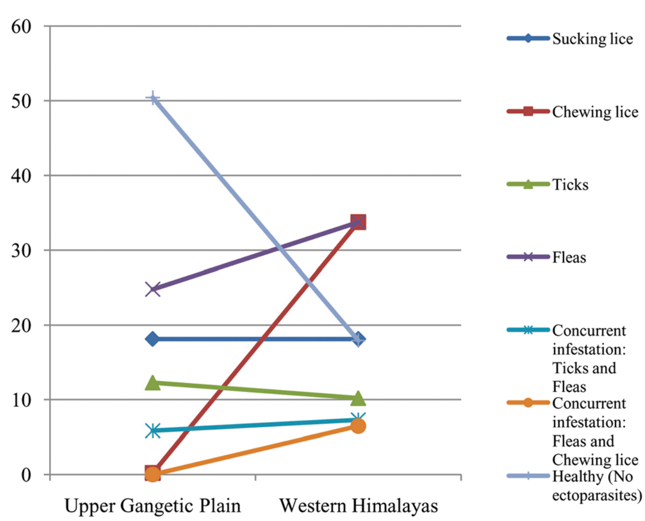

Fig. 11 Agro-climatic region-wise analysis of yearly ectoparasitic prevalence

Table 3 Comparative data of air quality parameters in both agro-climatic regions (mean ± SD)

Agro-climatic region	Upper Gangetic Plains region ($n = 28$)		Western Himalayas region ($n = 28$)		Reference grading index
Air quality parameter	Mean value	Grade	Mean value	Grade	
Air quality index (AQI)					
Morning	486.61 ± 84.37a	Hazardous	120.29 ± 40.60b	Poor	Good (0–50); moderate (51–100); poor (101–200); unhealthy (201–300); severe (301–400); hazardous (401–500)
Evening	434.04 ± 126.20a	Hazardous	155.86 ± 63.12b	Poor	
Average	460.32 ± 93.68a	Hazardous	138.07 ± 46.18b	Poor	
Particulate matter 2.5 μm ($PM_{2.5}$) (mcg/m^3)					
Morning	351.04 ± 90.06a	Severe	60.86 ± 17.28b	Moderately polluted	Good (0–30); satisfactory (31–60); moderately polluted (61–90); poor (91–120); very poor (121–250); severe (250+)
Evening	293.11 ± 115.05a	Severe	77.32 ± 27.93b	Moderately polluted	
Average	322.07 ± 89.33a	Severe	69.09 ± 19.61b	Moderately polluted	
Particulate matter 10 μm (PM_{10}) (mcg/m^3)					
Morning	401.89 ± 109.13a	Very poor	92.93 ± 20.86b	Satisfactory	Good (0–50); satisfactory (51–100); moderately polluted (101–250); poor (251–350); very poor (351–430); severe (430+)
Evening	336.36 ± 137.20a	Poor	99.89 ± 30.45**b**	Satisfactory	
Average	369.13 ± 106.85a	Very poor	96.41 ± 22.86b	Satisfactory	

Values with lowercase letters a and b differ significantly ($p < 0.05$) between agro-climatic region

ectoparasites and the effect of AQI on chewing lice and fleas were evident (Tables 4 and 5).

Discussion

Among the ectoparasites found in goats in the study area, *C. orientis* (cat flea) displays low host specificity and is reported to infect a wide range of phylogenetically unrelated host species like cats, dogs, wild animals, and cattle. The obligate arachnid parasite *Rhipicephalus* (*Boophilus*) *microplus* (tick) is more host-specific than fleas but is less specific than both lice, since it is known to infest most of the ruminant species like cattle, buffalo, and sheep. Lice are most host-specific and are known to infect closely related species only. However,

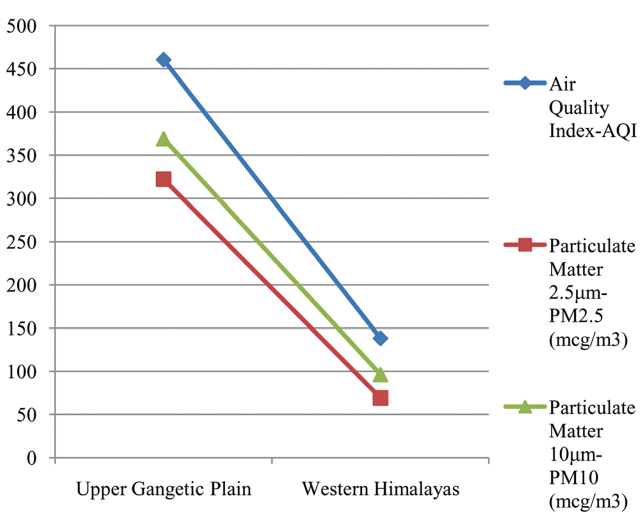

Fig. 12 Agro-climatic region-wise analysis of air quality parameters

there have been reports of *Damalinia* (*Bovicola*) *caprae* infestation in sheep, but sucking lice (*L. africanus*) infestation least or mistakenly reported and uncommon (Hallam 1985; Mulugeta et al. 2010). This host specificity (flea < ticks < chewing lice < sucking lice) may be related to the obligatory or facultative existence of parasite on the host skin; the less host-specific, the more facultative in nature and the more host-specific, the more obligatory in nature (Taylor et al. 2016). The host specificity was found to be directly proportional to the prevalence of the ectoparasite arthropod in the comfortable winter season in this study. Inverse pattern (with respect to host specificity) of the prevalence of these ectoparasites was observed during the monsoon season representing severe uncomfortable climatic conditions. The results of the study indicated that the overall discomforting conditions (both air and climatic) that prevail in UGP may be acting as the ecological stimuli for the reduction in ecologically fragile highly host-specific chewing lice in the region.

Climate change, environmental pollution, and global warming are key challenges to the ecological stability of living beings including arthropods in the twenty-first century (Scherm et al. 2000; Gomiero et al. 2018). The detrimental effects of air pollutants in determining insect populations and host-ectoparasite ecology have been warned by ecologists before a few decades itself (Alstad et al. 1982; Whittaker 1994). Recent observations on the chronic effects of pollutants in ecology and its significance on the evolutionary cascade are also worthy of interest, but alarming (Zvereva and Kozlov 2010; Kotze et al. 2011; Lister and Garcia 2018). Khaliq et al. (2014) reviewed the effects of environmental variations in disturbing arthropod ecology and determining the population dynamics of insects. Extreme climatic conditions/

Table 4 Logistic regression analysis of weather factors affecting the prevalence of ectoparasites

Ectoparasite	Factor	Level	*B*	SE	Wald	DF	Sig.	Odds ratio
Sucking lice	Constant		− 1.551	.240	41.655	1	< .001	0.212
	Temperature (°C)				20.471	2	< .001	
		10–20	0.623	.314	3.925	1	.048	1.864
		20–30	− 0.743	.328	5.121	1	.024	0.476
		30–40	Reference					
	Relative humidity (%)				12.757	2	.002	
		30–40	0.539	.317	2.896	1	.089	1.714
		40–50	− 1.096	.349	9.861	1	.002	0.334
		70–80	Reference					
	THI				21.977	1	< .001	
		60–70	2.080	.444	21.977	1	< .001	8.004
		80–90	Reference					
Chewing lice	Constant		− 21.203	3669.081	.000	1	.995	0.000
	Temperature (°C)				3.071	2	.215	
		10–20	16.424	3669.082	.000	1	.996	1.3587
		20–30	18.258	3669.081	.000	1	.996	8.5027
		30–40	Reference					
	Relative humidity (%)				28.631	2	< .001	
		30–40	20.191	3669.081	.000	1	.996	5.8748
		40–50	5.472	1.023	28.631	1	< .001	238.000
		70–80	Reference					
	THI				15.132	1	< .001	
		60–70	− 4.199	1.079	15.132	1	< .001	0.015
		80–90	Reference					
Ticks	Constant		− 2.108	.294	51.504	1	< .001	0.121
	Temperature (°C)				29.991	2	< .001	
		10–20	− 1.970	.771	6.523	1	.011	0.140
		20–30	1.200	.327	13.514	1	< .001	3.321
		30–40	Reference					
	Relative humidity (%)				6.523	2	.038	
		30–40	− 1.970	.771	6.523	1	.011	0.140
		40–50	− 17.125	3669.101	.000	1	.996	.000
		70–80	Reference					
	THI				.000	1	.997	
		60–70	15.739	3669.101	.000	1	.997	6,847,960.332
		80–90	Reference					
Fleas	Constant		− 1.285	.222	33.640	1	< .001	0.277
	Temperature (°C)				65.922	2	< .001	
		10–20	− 1.354	.428	10.014	1	.002	0.258
		20–30	1.352	.256	27.781	1	< .001	3.865
		30–40	Reference					
	Relative humidity (%)				3.441	2	.179	
		30–40	.438	.298	2.160	1	.142	1.549
		40–50	.531	.469	1.281	1	.258	1.701
		70–80	Reference					
	THI				7.707	1	.006	
		60–70	− 1.406	.506	7.707	1	.006	0.245
		80–90	Reference					

Table 5 Logistic regression analysis of air quality parameters affecting the prevalence of ectoparasites

Parasite	Factor	Level	*B*	SE	Wald	DF	Sig.	Odds ratio
Sucking lice	Constant		− 1.508	.118	161.963	1	< .001	0.221
	AQI	101–200	.000	.168	.000	1	1.000	1.000
		401–500	Reference					
Chewing lice	Constant		− 6.172	1.001	38.011	1	< .001	0.002
	AQI	101–200	5.497	1.006	29.879	1	< .001	244.019
		401–500	Reference					
Ticks	Constant		− 1.965	.139	199.830	1	< .001	0.140
	AQI	101–200	− .209	.205	1.041	1	.308	0.811
		401–500	Reference					
Fleas	Constant		− 1.110	.106	110.222	1	< .001	0.330
	AQI	101–200	.435	.143	9.247	1	.002	1.545
		401–500	Reference					

accumulation of heavy metals or pollutants may affect the growth rate and larval survivability, which in turn results in the destruction of those insect species which were least resistant to harsh environmental conditions (Catalán et al. 2012), whereas, in the case of some other insects, elevated temperatures resulted in better reproduction and immune function and rapid adaptability (Adamo and Lovett 2011). Merino and Møller (2010) suggested several possibilities for how climate change may affect host-parasite interactions. The condition of extremely low ambient temperature leading to the destruction of larva in the environment described by Lamarre et al. (2018) is interesting but not much significant to the tropical/subtropical climatic condition of India.

Highly host-specific arthropods like lice can complete their entire life cycle on the host skin itself. The microenvironment produced by the hair coat is a key contributor to the maintenance and development of distinct life stages of such highly host-specific arthropods. But, the other least host-specific arthropods like fleas and ticks have critical life stages, which are able to normally survive in the harsh atmospheric conditions and even able to develop better in higher environmental temperature and elevated humidity levels (Krasnov et al. 2001; Ogden et al. 2004). In an experimental study, *C. felis* reared at RH 92% produced larger adults than those reared at RH 50% (Silverman et al. 1981). Ticks preferred high-humid high-temperature conditions for better development (Heath 1981). These differences in tolerance of distinct life stages of arthropods to extreme climatic conditions and environmental hazards determine the ecological and evolutionary responses of such organisms (Kingsolver et al. 2011). Interestingly, increased skin blood flow in warm/high THI environment may also contribute to the ecological evolution of these blood-sucking arthropods in summer and monsoon (Thoresen and Walløe 1980). These least host-specific blood-feeding arthropods have highly resistant environmental forms of larvae which can survive toxic attack from the altered environmental conditions (Hitchcock 1955). This, in turn, leads to the survivability of certain resistant species of arthropods and the destruction of ecologically fragile species. These constant ecological stimuli of altered temperature-humidity combinations and air pollution may result in altered arthropod ecological distribution through constant evolution and survival of the fittest. Although variations in rainfall, public awareness on cleanliness and hygiene, the presence of certain vegetations and landscapes, altitude, and proximity to the forest also may be the decisive factors in the prevalence of ectoparasitic arthropods in a certain region, these factors also are indirectly contributing to the climate and environmental quality.

Conclusions

The prevalence of each type of ectoparasites was dependent on weather parameters and air quality parameters. The better understanding of climatological aspects of ectoparasite occurrences helps farmers in formulating appropriate timely intervention strategies for the economic control of ectoparasites, which in turn tackles ectoparasiticidal drug resistance. Increase in the environmental temperature-humidity index and poor air quality may be acting as ecological stimuli for the destruction of highly host-specific ecologically fragile arthropod species and an increase in the least host-specific hematophagous ectoparasites. This influence of climatic alterations and air pollutants in determining the prevalence of ectoparasitism is intriguing and it opens a huge scope for future studies on biometeorological aspects of host-parasite ecological interactions.

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Compliance with ethical standards

This work was undertaken in compliance with the universal ethical standards and approved for PhD research work under SEED/SARTHI/HP/19/2012.

Conflict of interest The authors declare that they have no conflict of interest.

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