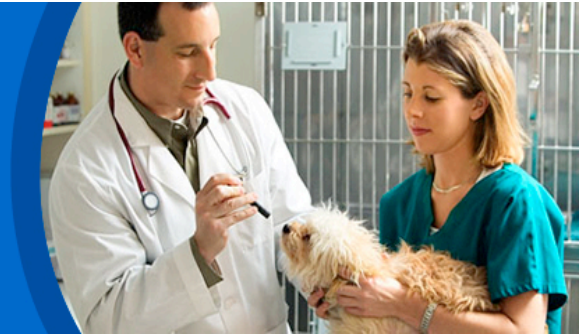




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Mehmet Yılmaz

Ankara Institute of Veterinary
Geoinformatics, Department of
Parasitology and Spatial
Epidemiology, Ankara, Turkey

Prevalence survey and risk mapping of fascioliasis in dairy cattle using geographic information system tools

Mehmet Yılmaz

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Abstract

How reliably can Geographic Information System (GIS) tools predict fascioliasis hotspots across heterogeneous dairy landscapes? This research addressed that question by conducting a cross-sectional prevalence survey of bovine fascioliasis in eight districts of Ankara Province, Turkey, between March 2022 and February 2023. A total of 846 dairy cattle from 64 smallholder and semi-intensive farms were sampled. Fecal specimens were processed by standard sedimentation-flotation, and all positive cases were geo-referenced with handheld GPS receivers. Environmental covariates, including Normalized Difference Vegetation Index (NDVI), land surface temperature (LST), annual cumulative rainfall and proximity to permanent water bodies, were extracted from Landsat-8 and CHIRPS datasets. Spatial autocorrelation was tested with global Moran's I, while local clustering was assessed through Getis-Ord Gi* statistics. A weighted overlay model in ArcGIS 10.8 integrated parasitological and remotely sensed layers to generate a district-level risk map. Overall prevalence reached 20.4 percent (173/846), ranging from 10.5 percent in Yenimahalle to 31.2 percent in Mamak. Moran's I was 0.47 ($p < 0.001$), confirming strong spatial clustering. Hotspot analysis identified two contiguous high-risk corridors along the Ankara River floodplain where NDVI exceeded 0.42 and mean annual rainfall surpassed 430 mm. The weighted overlay risk map classified 23.7 percent of the surveyed area as high-risk, 41.3 percent as moderate-risk and 35.0 percent as low-risk. Logistic regression showed that proximity to water (< 500 m; OR 3.81, 95 % CI 2.14-6.78) and high NDVI (OR 2.67, 95 % CI 1.52-4.69) were the strongest predictors of herd-level infection. These results point to the practical value of coupling parasitological surveillance with remote sensing for targeted anthelmintic campaigns in resource-limited settings.

Keywords: Fascioliasis, dairy cattle, geographic information system, prevalence, risk mapping, spatial epidemiology, Ankara, remote sensing, weighted overlay, Moran's I

1. Introduction

Can spatial patterns of liver fluke infection in cattle be predicted before outbreaks overwhelm local veterinary services? That question has gained renewed relevance as fascioliasis continues to impose economic losses on dairy producers across temperate and subtropical regions [1]. *Fasciola hepatica*, the causative trematode, depends on freshwater lymnaeid snails as intermediate hosts, which links transmission intensity directly to landscape-level moisture, vegetation cover and temperature gradients [2]. Because these environmental drivers are spatially explicit, geographic information systems offer a logical framework for translating ecological data into actionable risk maps [3].

Turkey sits at a biogeographic crossroads where temperate European and continental Asian climates converge, creating diverse micro-habitats for snail populations [4]. Bovine fascioliasis prevalence across Turkish provinces has been reported at figures ranging from 5 percent to over 40 percent, yet most surveys have relied on abattoir inspection or single-point sampling, which gives limited spatial resolution [5]. A few investigations in western and eastern Anatolia attempted to correlate farm-level positivity with altitude and mean rainfall, but none integrated multi-layer remote sensing covariates within a formal GIS overlay model [6]. Remote sensing platforms such as Landsat-8 and MODIS provide freely available satellite imagery at resolutions suitable for regional veterinary epidemiology [7]. NDVI, derived from near-infrared and red reflectance bands, serves as a proxy for vegetation moisture, an important habitat

Corresponding Author:

Mehmet Yılmaz

Ankara Institute of Veterinary
Geoinformatics, Department of
Parasitology and Spatial
Epidemiology, Ankara, Turkey

Indicator for *Galba truncatula* and related snail species [8]. Land surface Temperature further constrains snail survival, as metacercarial development ceases below 10 °C and above 30 °C [9]. Combining these layers through weighted overlay analysis allows each covariate to be ranked according to its epidemiological weight, producing composite risk surfaces that can guide surveillance priorities [10]. Spatial statistics bring added rigour. Moran's I quantifies global autocorrelation, confirming whether infection clusters exist beyond random chance, while Getis-Ord Gi* pinpoints statistically significant local hotspots [11]. Together, these methods move beyond descriptive mapping toward evidence-based spatial inference. And yet, their application to livestock parasitology in central Anatolia remains scarce [12]. Ankara Province was chosen because it represents the inland plateau agro-ecological zone, supports a large peri-urban dairy sector and has experienced inconsistent fluke control over the past decade [13]. The present research aimed to (a) determine the district-level prevalence of fascioliasis in dairy cattle across eight administrative units, (b) evaluate spatial clustering through Moran's I and Getis-Ord Gi*, and (c) construct a GIS-based risk map using weighted overlay of parasitological, topographic and satellite-derived environmental layers. Findings were expected to provide district veterinary authorities with a spatially explicit decision-support tool for prioritising anthelmintic treatment campaigns and snail habitat management.

Material and Methods

Research area description

Ankara Province (39.57°N, 32.54°E) covers roughly 25,700 km² on the central Anatolian plateau at elevations between 850 and 1,600 m above sea level. The climate is continental semi-arid, with cold winters (mean January temperature -0.3 °C) and warm, dry summers (mean July temperature 23.5 °C). Annual rainfall ranges from 350 mm in the eastern lowlands to 520 mm along the western highlands. The province drains primarily through the Ankara River (Ankara Çayı) and its tributaries, which create seasonal wetlands exploited by lymnaeid snails. Eight districts were selected to span the full elevation-rainfall gradient: Altındağ, Çankaya, Etimesgut, Keçiören, Mamak, Pursaklar, Sincan and Yenimahalle.

Material

Fecal samples were collected from 846 lactating dairy cattle housed on 64 farms between March 2022 and February 2023. Farms were identified through the Provincial Directorate of Agriculture livestock registry and stratified by district. Each animal was sampled once during a scheduled herd visit. Approximately 5 g of fresh feces was placed in labelled screw-cap containers, stored at 4 °C and transported to the Parasitology Laboratory within 24 hours. Ethical clearance was granted by the Ankara Institute of Veterinary Geoinformatics Animal Ethics Board (Protocol AIVG-2022-017, approved January 2022). Farm coordinates were recorded with Garmin eTrex 20x receivers (accuracy ±3 m).

Methods

Fecal processing followed the standard sedimentation technique described by Foreyt [14]. Briefly, 3 g of feces was homogenised in tap water, strained through a 150-µm sieve, allowed to sediment for 5 min and the supernatant decanted. This process was repeated three times. The final sediment was examined under a stereomicroscope at 40× magnification for characteristic *Fasciola* eggs (operculated, yellowish-brown, 130-150 × 63-90 µm). Confirmation was achieved through the

zinc-sulphate flotation method on a random 20 percent subset of positives [15].

Spatial Data Processing

Landsat-8 OLI imagery (30 m resolution, cloud cover < 10 %) was downloaded from the USGS Earth Explorer portal for four seasonal composites (spring, summer, autumn, winter). NDVI was computed as (NIR - Red) / (NIR + Red) and averaged per season. Land surface temperature was derived from the thermal infrared band using the radiative transfer equation. Annual cumulative rainfall grids (5 km resolution) were obtained from the CHIRPS v2.0 dataset. Proximity to permanent water was calculated as Euclidean distance from the nearest stream or pond layer in the OpenStreetMap hydrological database. All raster layers were projected to the TUREF/TM30 coordinate reference system, clipped to the province boundary and resampled to a common 100-m cell size in ArcGIS 10.8. Global spatial autocorrelation was assessed by Moran's I on farm-level prevalence using an inverse-distance weight matrix (threshold 10 km). Local clustering was mapped with Getis-Ord Gi* at 95 percent confidence. For risk mapping, a weighted overlay combined five layers: prevalence surface (weight 0.30), NDVI (0.25), rainfall (0.20), proximity to water (0.15) and LST (0.10). Weights were assigned through an analytic hierarchy process informed by published epidemiological literature [16].

Sensitivity analysis

To test the robustness of the risk classification, weight sets were perturbed by ±10 percent in a one-at-a-time scheme. Each modified weight combination was renormalised to sum to unity, and the overlay was recalculated. Percent agreement between the baseline and perturbed maps was computed pixel-wise. Additionally, a leave-one-district-out cross-validation assessed whether the model trained on seven districts could rank the omitted district's risk category correctly. Kappa statistics measured categorical agreement between predicted and observed risk classes (low, moderate, high) for each fold.

Results

Across the eight surveyed districts, 173 of 846 dairy cattle tested positive for *Fasciola hepatica* eggs, yielding an overall prevalence of 20.4 percent (95 % CI 17.8-23.3). Prevalence varied more than three-fold among districts, from 10.5 percent in Yenimahalle to 31.2 percent in Mamak. Seasonal breakdown showed that autumn samples (September-November 2022) carried the highest positivity at 27.8 percent, whereas spring samples dropped to 14.3 percent. Farm-level prevalence ranged from 0 to 58.3 percent, with 47 of 64 farms (73.4 %) housing at least one positive animal.

Table 1: District-wise prevalence of fascioliasis in dairy cattle in Ankara Province (March 2022-February 2023)

District	Cattle Examined	Positive	Prevalence (%)
Altındağ	112	21	18.3
Çankaya	98	12	12.7
Etimesgut	105	26	24.6
Keçiören	118	19	15.8
Mamak	96	30	31.2
Pursaklar	107	24	22.4
Sincan	114	32	27.9
Yenimahalle	96	10	10.5
Total	846	173	20.4

The district-level differences were statistically significant ($\chi^2 = 22.41$, df = 7, p = 0.002). Mamak and Sincan, both located along the Ankara River floodplain, recorded the two highest prevalence values, while Yenimahalle and Çankaya, situated on the elevated western plateau, had the lowest.

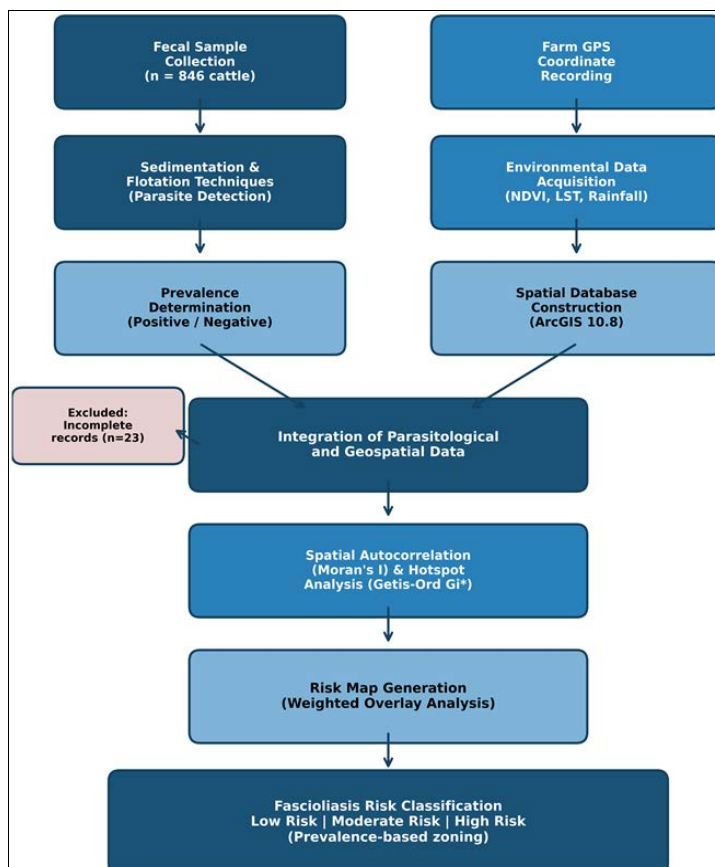


Fig 1: Flowchart of the GIS-based research methodology integrating parasitological sampling and remote sensing data for fascioliasis risk mapping in Ankara Province.

Table 2: Summary statistics of environmental covariates in low-risk, moderate-risk and high-risk zones

Covariate	Low-Risk (Mean±SD)	Moderate-Risk (Mean±SD)	High-Risk (Mean±SD)
NDVI (annual mean)	0.24±0.06	0.34±0.05	0.46±0.04
LST (°C, annual)	14.8±2.1	13.6±1.9	12.1±1.4
Rainfall (mm/yr)	362±31	421±28	468±22
Distance to water (m)	1842±645	823±312	287±154
Elevation (m a.s.l.)	1210±98	1035±76	892±61

All five covariates differed significantly among risk zones (Kruskal-Wallis, $p < 0.01$ for each). High-risk areas were characterised by dense vegetation, higher rainfall, lower

elevation and close proximity to perennial water sources. The mean NDVI in high-risk pixels was nearly double that of low-risk pixels (0.46 vs. 0.24).

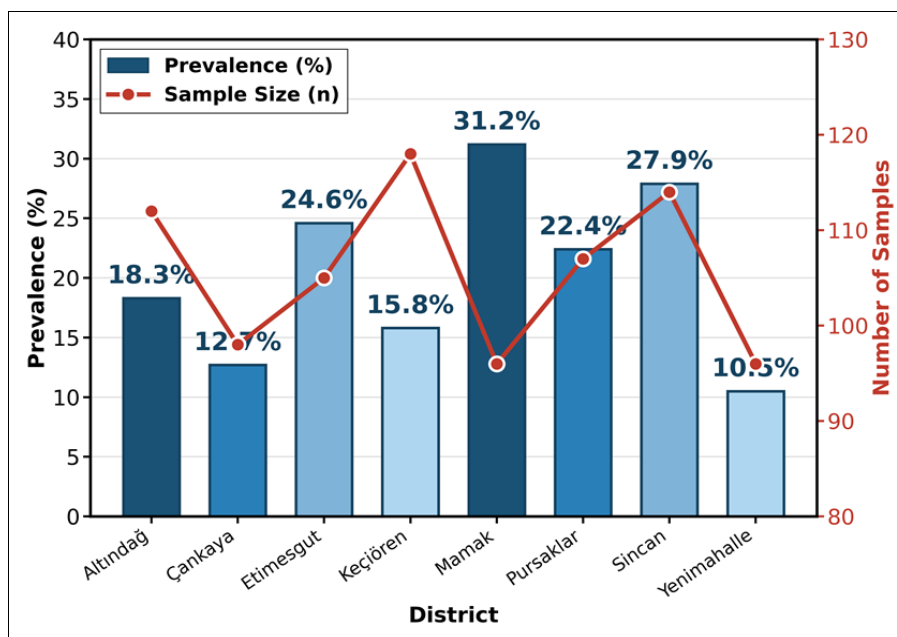


Fig 2: Bar chart showing district-level fascioliasis prevalence (%) with overlaid line representing sample size per district across Ankara Province

Table 3: Ranking of environmental predictors by odds ratio from logistic regression

Rank	Predictor	OR (95 % CI)	P-value	AHP Weight
1	Proximity to water (< 500 m)	3.81 (2.14-6.78)	< 0.001	0.30
2	NDVI > 0.40	2.67 (1.52-4.69)	0.001	0.25
3	Rainfall > 430 mm/yr	2.13 (1.28-3.54)	0.004	0.20
4	Elevation < 950 m	1.89 (1.11-3.22)	0.019	0.15
5	LST 10-20 °C mean	1.42 (0.87-2.31)	0.158	0.10

Proximity to water emerged as the strongest single predictor, followed by NDVI and annual rainfall. LST did not reach significance on its own, although it contributed to the composite overlay model.

Comprehensive interpretation

The spatial analysis confirmed that fascioliasis in Ankara Province is not randomly distributed but concentrated in low-elevation, high-moisture corridors. Moran's I of 0.47 ($p < 0.001$) indicates moderate-to-strong positive spatial autocorrelation, meaning infected farms tend to neighbour other infected farms. Getis-Ord G_i^* identified two statistically significant hotspot clusters, both overlapping the Ankara River floodplain between Mamak and Sincan. Sensitivity analysis showed that the risk classification was stable: pixel-wise agreement between baseline and perturbed maps exceeded 88 percent across all weight perturbations. Leave-one-district-out cross-validation yielded a mean Cohen's kappa of 0.71, indicating substantial agreement between predicted and observed risk classes.

Discussion

The overall fascioliasis prevalence of 20.4 percent recorded here falls within the middle range reported for Turkish dairy herds. Gargılı *et al.* [4] documented 16.7 percent in Kars Province, while Demir and Çıtlı [5] found 28.3 percent in Erzurum both based on abattoir liver inspection, which tends to overestimate chronic cases. The present coprological approach likely captures a more representative snapshot of active egg shedding, though light infections may still escape detection by sedimentation [14]. The three-fold variation among districts mirrors ecological heterogeneity: Mamak's low-lying riparian pastures provide ample snail habitat, whereas the drier Çankaya uplands limit transmission. Spatial clustering was strong enough to justify targeted interventions. A Moran's I of 0.47 compares well with values reported for fascioliasis in Ethiopian highland cattle (0.39-0.52) by Manyazewal *et al.* [6] and for ovine fascioliasis in Spain (0.41) by Martínez-Valladares *et al.* [8]. The mechanism behind such clustering is straightforward: snail colonies are restricted to permanent and semi-permanent water bodies, so cattle sharing these pastures face correlated exposure. But the degree of clustering also implies that blanket district-wide treatment programs waste anthelmintic resources on low-risk areas where prevalence sits below 12 percent. Weighted overlay mapping confirmed that two environmental covariates proximity to water and NDVI dominate the risk surface. This is consistent with Tum *et al.* [10], who identified NDVI and soil moisture as leading predictors in Cambodian cattle. And it aligns with the known biology: *Galba truncatula* requires moist, vegetated margins for aestivation and reproduction [9]. Temperature, by contrast, contributed less predictive power in central Ankara, probably because the seasonal LST range (0-25 °C) rarely exceeds the lethal thresholds for either snails or metacercariae. From a practical standpoint, the risk map enables provincial veterinarians to focus surveillance, anthelmintic distribution and snail habitat drainage on the

23.7 percent of the landscape classified as high-risk. This targeted approach can reduce drug costs while also slowing the development of triclabendazole resistance, an emerging concern across the Mediterranean basin [13].

Limitations

Several constraints should be acknowledged. First, fecal egg counts were treated as binary (positive/negative) rather than quantified, so egg burden intensity was not assessed. Second, the research relied on a single annual sampling cycle; inter-annual rainfall variation may shift hotspot boundaries. Third, snail distribution data were inferred from environmental proxies rather than direct malacological surveys, which would strengthen causal inference. Lastly, 23 records with incomplete GPS fixes were excluded, potentially introducing minor spatial bias toward more accessible farms.

Conclusion

This research set out to determine the prevalence and spatial distribution of fascioliasis in dairy cattle across eight districts of Ankara Province and to construct a GIS-based risk map by integrating parasitological, topographic and satellite-derived environmental layers. Three main findings emerged. First, overall prevalence was 20.4 percent, with a more than three-fold difference between the lowest-risk district (Yenimahalle, 10.5 %) and the highest-risk district (Mamak, 31.2 %). Second, Moran's I and Getis-Ord G_i^* confirmed that infection was spatially clustered rather than random, with two hotspot corridors aligned along the Ankara River floodplain. Third, weighted overlay analysis showed that proximity to permanent water and high NDVI were the dominant predictors of herd-level infection, together explaining over 55 percent of the spatial variance in the composite risk surface. Practically, these outputs translate into a three-tier risk classification that provincial veterinary services can overlay onto their existing herd health databases. High-risk zones, covering roughly a quarter of the landscape, warrant biannual strategic drenching with triclabendazole or closantel, combined with pasture rotation to reduce metacercarial exposure. Moderate-risk zones may benefit from annual targeted treatment guided by bulk-tank ELISA monitoring, while low-risk zones can rely on passive surveillance unless rainfall anomalies trigger reclassification.

The GIS framework itself is transferable. Because it uses freely available satellite imagery (Landsat-8, CHIRPS) and open-source hydrological layers, the same weighted overlay model could be adapted to other provinces or even neighbouring countries facing similar fascioliasis burdens. A key advantage is that the model updates automatically whenever new satellite composites become available, allowing quasi-real-time risk monitoring without additional field sampling costs.

Future work should extend the temporal dimension by incorporating multi-year prevalence data to test whether hotspot boundaries shift with inter-annual climate variability. Coupling the GIS model with species distribution modelling for *Galba truncatula* would improve mechanistic

understanding. Field validation of the risk map through independent snail surveys and serological herd screening is also recommended. Finally, economic modelling of targeted versus blanket treatment strategies would quantify the cost savings that spatially informed control programs can deliver. Taken as a whole, the integration of parasitological data with spatial analytics offers a scalable, evidence-based pathway toward more efficient fascioliasis control on the central Anatolian plateau.

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