Individual and Environmental Determinants of Leptospirosis in Bantul, Indonesia: A Case-Control Study

Abstract

Background: Leptospirosis constitutes a significant zoonotic disease with substantial global distribution, particularly affecting tropical and subtropical regions. Despite extensive documentation of its burden, significant knowledge deficits persist regarding localized transmission determinants, particularly concerning the relative contributions of individual versus environmental risk factors.

Aims: This study aimed to examine the relationship between individual factors (gender, occupation, education) and biotic environmental parameters (flood history, drainage conditions, waste disposal conditions) with leptospirosis incidence in the working area of Kasihan II Bantul Public Health Center during 2022-2023.

Instruments & Methods: An observational analytical study with a retrospective case-control design was implemented. Total sampling yielded 34 participants, comprising 17 laboratory-confirmed leptospirosis cases and 17 community-matched controls from the same catchment area. Data collection employed structured questionnaires assessing sociodemographic parameters, occupational exposures, and environmental conditions. The analysis employed chi-square tests to evaluate associations between independent variables and leptospirosis status, with odds ratios and corresponding 95% confidence intervals calculated to quantify risk magnitude.

Findings: Significant associations were identified between leptospirosis and male gender (OR=5.760, 95%CI: 1.317-25.187) and high-risk occupations (OR=6.667, 95%CI: 1.377-32.278). Educational attainment and environmental parameters including flood history, drainage conditions, and waste disposal infrastructure demonstrated non-significant associations despite elevated risk estimates. Demographic analysis revealed a predominance of middle-aged and older adults (64.8% aged 46-65 years), with a balanced gender distribution and a high prevalence of lower educational attainment (91.2%).

Conclusion: The predominance of individual rather than environmental risk factors suggests that personal protection and behavioral modification approaches may constitute high-priority intervention targets, particularly among male workers in the agricultural, construction, and fishing sectors. Future research incorporating larger sample populations, prospective designs, and integrated environmental sampling would enhance understanding of transmission dynamics in this endemic region.

Introduction

Leptospirosis is a significant zoonotic disease with a global distribution, particularly affecting tropical, subtropical, and temperate regions. The disease is prevalent in areas such as the Caribbean, Latin America, the Indian subcontinent, Southeast Asia, Oceania, and parts of Eastern Europe [1]. Globalization and international travel have also increased exposure to leptospirosis in developed countries, expanding its epidemiological footprint beyond traditional endemic zones [1]. The Asia-Pacific region is notably affected, with outbreaks often linked to poor sanitation, overcrowding, and climatic conditions that favor bacterial persistence and transmission [2]. These demographic and environmental determinants create complex transmission dynamics that challenge public health control efforts across diverse geographical settings.

Leptospirosis is often underdiagnosed, leading to an underestimation of its global burden. The World Health Organization (WHO) has established the Leptospirosis Burden Epidemiology Reference Group (LERG) to estimate the global burden using disability-adjusted life years (DALYs) as a standardized metric [3]. Current epidemiological data indicate an estimated annual incidence of approximately half a million severe human cases globally, though this figure likely represents substantial underreporting due to diagnostic limitations and surveillance inadequacies [4]. Mortality rates demonstrate significant variation, with higher rates documented in older patients and those presenting with severe clinical manifestations such as jaundice and renal failure [5]. The burden of disease extends beyond acute mortality, with persistent post-infection sequelae including fatigue and myalgia contributing to long-term morbidity and reduced quality of life [6].

Leptospirosis is caused by spirochetes of the genus Leptospira, with pathophysiological mechanisms that produce a remarkably diverse clinical spectrum. Disease presentations range from mild febrile illness to severe complications including hepatorenal dysfunction, myocarditis, pulmonary hemorrhage, and meningitis [7]. The pathophysiology involves bacterial entry through mucous membranes or skin abrasions, often from exposure to contaminated water sources, followed by hematogenous dissemination affecting multiple organ systems [7]. This complex pathophysiological profile creates diagnostic challenges and contributes to the underestimation of disease burden, particularly in regions with limited laboratory capacity. The interplay between bacterial virulence factors, host immune responses, and environmental exposures creates a multifaceted disease entity requiring integrated surveillance and management approaches across the healthcare continuum.

Previous systematic reviews indicate that leptospirosis carries substantial morbidity and mortality metrics, yet remains underrepresented in global health prioritization frameworks, resulting in fragmented surveillance systems and limited intervention development [8, 9]. The disease exhibits pronounced socioeconomic stratification patterns, with highest incidence documented among marginalized communities where inadequate sanitation infrastructure, occupational exposures, and limited healthcare access create synergistic risk profiles [10-12]. Epidemiological analyses demonstrate that agricultural workers, fishermen, sewage workers, and inhabitants of informal settlements face exponentially higher exposure probability, reflecting the intersection between environmental determinants and structural inequalities in disease distribution [10, 12].

The persistent neglect and substantial underreporting of leptospirosis present formidable challenges to accurate burden quantification, with current surveillance systems capturing only an estimated 5-15% of actual cases across endemic regions [8, 13, 14]. This surveillance inadequacy stems from multiple intersecting factors, including the non-specific clinical presentation that frequently mimics other febrile illnesses, leading to misdiagnosis and classification errors within healthcare systems [15, 16]. Diagnostic complexity represents a fundamental barrier to effective surveillance, as the disease manifests along a broad clinical spectrum ranging from mild influenza-like illness to severe manifestations encompassing Weil's disease with its characteristic triad of jaundice, renal failure, and hemorrhagic phenomena [9, 11, 12, 16].

Leptospirosis determinants comprise interrelated environmental and socioeconomic factors that create complex risk landscapes with significant geographical and temporal heterogeneity. Environmental parameters, including temperature, precipitation, flooding events, and humidity levels demonstrate consistent associations with disease incidence, with multivariate analyses identifying annual mean temperature and rainfall metrics as significant predictors of transmission intensity [17-19]. Hydrological factors, particularly flood exposure, function as critical risk amplifiers (incidence rate ratios: 2.3-8.7) [20, 21], while geographical characteristics including land cover typologies, altitudinal gradients, and proximity to water bodies further modulate spatial distribution patterns [18, 22]. These environmental determinants interact synergistically with socioeconomic

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factors, with quantitative evidence establishing significant associations between leptospirosis burden and urbanization patterns, especially in informal settlements characterized by high population density and inadequate sanitation infrastructure [20, 23].

Housing quality metrics demonstrate strong correlations with infection risk (odds ratios: 2.21-5.15 for substandard dwellings) [23], while economic vulnerability indicators, including poverty rates and educational attainment consistently predict disease distribution through pathways involving reduced protective infrastructure access, occupational exposures, and limited healthcare utilization [23-25]. Advanced geospatial modeling approaches incorporating these determinants enable high-resolution risk mapping and targeted intervention deployment, with vulnerability indices constructed from composite socioeconomic indicators providing evidence-based frameworks for public health resource allocation in endemic regions [18, 19, 22, 23].

Leptospirosis cases in Indonesia have shown an increasing trend annually. In 2020, there were 1,170 cases with 106 deaths (Case Fatality Rate/CFR of 9.06%, significantly higher than COVID-19 mortality), while in 2021, there were 736 cases with 84 deaths (CFR 11.41%). In 2022, based on reports from 11 provinces, there were 1,408 leptospirosis cases with 139 deaths (CFR 9.87%) [26]. Leptospirosis is believed to have the most widespread distribution globally and is known in some countries as "Rat Urine Fever". High-risk populations include those whose occupations, living environments, or lifestyles expose them to the pathogen. High transmission risk occurs among farmers, plantation workers, pet shop employees, livestock handlers, sewer workers, slaughterhouse workers, meat processors, and military personnel [27].

According to the Yogyakarta Special Region Health Office, hundreds of leptospirosis cases are distributed across all districts/cities in the region. The highest number of cases was reported in Bantul Regency, reaching 110 cases. Yogyakarta City recorded 19 cases, Kulonprogo Regency 36 cases, Gunungkidul Regency 56 cases, and Sleman 42 cases [27]. Based on data from the Bantul District Health Office, leptospirosis cases in 2022 totaled 141 across 17 sub-districts, with the highest distribution in Kasihan Sub-district (15 cases) and Bantul Sub-district (13 cases), followed by Srandakan and Jetis Sub-districts (12 cases each), Imogiri, Pundong, and Sewon Sub-districts (11 cases each), Pandak Sub-district (10 cases), Bambanglipuro Sub-district (9 cases), Pleret Sub-district (7 cases), Piyungan and Sedayu Sub-districts (6 cases each), Banguntapan Sub-district (5 cases), Kretek, Pajangan, and Sanden Sub-districts (4 cases each), and Dlingo Sub-district (2 cases) [27].

According to data from the Bantul District Health Office, leptospirosis cases in 2023 totaled 155 across 17 sub-districts, with the highest distribution in Bantul Sub-district (24 cases), followed by Sewon Sub-district (18 cases), Kasihan Sub-district (17 cases), Pundong Sub-district (16 cases), Bambanglipuro Sub-district (12 cases), Pandak Sub-district (12 cases), Sedayu Sub-district (9 cases), Imogiri, Jetis, and Sanden Sub-districts (7 cases each), Banguntapan and Kretek Sub-districts (5 cases each), and Pleret and Srandakan Sub-districts (2 cases each) [27].

Despite extensive epidemiological documentation of the leptospirosis burden globally, significant knowledge deficits persist regarding localized transmission determinants in endemic Indonesian regions, particularly concerning the Yogyakarta Special Region where case fatality rates consistently exceed 9% markedly higher than COVID-19 mortality metrics. While surveillance data demonstrate distinct spatial clustering with Kasihan sub-district maintaining high incidence, analytical investigations quantifying the relative contribution of individual versus environmental risk factors within this high-transmission zone remain conspicuously absent from the current evidence base.

This study therefore aimed to examine the relationship between individual factors (gender, occupation, education) and biotic environmental parameters (flood history, drainage conditions, waste disposal systems) with leptospirosis incidence in the Kasihan II Bantul Public Health Center catchment area during 2022-2023, employing a case-control analytical framework to identify high-priority modifiable determinants for targeted public health interventions aligned with local epidemiological patterns and resource constraints.

Instruments and Methods
Study design
This study employed an observational analytical design with a retrospective case-control approach to investigate the relationship between individual and environmental factors with leptospirosis incidence. This methodological framework was selected to enable quantitative assessment of risk factor associations by comparing exposure histories between individuals with confirmed leptospirosis diagnoses and matched controls without the disease. The retrospective orientation

facilitated the examination of temporal relationships between potential risk factors and disease occurrence while maximizing efficiency within the constraints of available resources and epidemiological context.

The case-control methodology was selected after systematic consideration of alternative designs, including prospective cohort approaches. The retrospective design offered practical advantages in the study context, including 1) feasibility for investigating relatively uncommon outcomes within resource and temporal constraints; 2) capacity for simultaneous evaluation of multiple exposure variables; And 3) established precedent in leptospirosis epidemiological literature, facilitating cross-study comparison. However, this approach introduced methodological limitations including potential recall bias in exposure assessment and inability to establish precise temporal sequences between environmental exposures and disease occurrence. These limitations are explicitly addressed in the discussion section with appropriate interpretive caution regarding causal inference.

Population and sampling

The target population comprised all leptospirosis patients residing within the catchment area of Kasihan II Bantul Public Health Center. A total sampling technique was implemented to recruit all eligible cases diagnosed during the 2022-2023 study period, yielding 17 confirmed leptospirosis patients. Controls were selected using a 1:1 matching ratio, with 17 individuals without leptospirosis recruited from the same geographic area, resulting in a total sample of 34 participants.

Sample size considerations included a retrospective power analysis demonstrating adequate statistical capacity ($1-\beta=0.80$, $\alpha=0.05$) to detect large effect sizes (OR≥5.0) but limited power for moderate (OR=2.0-3.0) or small effect associations. This statistical parameter was deemed acceptable for primary risk factors with established high-magnitude associations based on previous epidemiological investigations, though potentially insufficient for detecting environmental determinants with more modest effect sizes. The sampling approach was designed to maximize analytical validity within the constraints of case availability in this endemic region, with case identification protocols including a comprehensive surveillance system review to ensure the inclusion of all laboratory-confirmed infections during the study period.

Inclusion criteria for cases encompassed laboratory-confirmed leptospirosis diagnosis through microscopic agglutination testing or PCR methodologies and current residence within the study area, while controls were selected from the same communities to ensure comparable exposure opportunities to environmental risk factors. Control recruitment employed frequency matching to maintain demographic comparability in age distribution while allowing analytical assessment of other hypothesized risk factors including gender and occupational exposure.

Variables and measurements

The independent variables examined comprised two categories: Individual factors (gender, occupation, education) and biotic environmental factors (flood history, drainage conditions, waste disposal conditions). The dependent variable was leptospirosis status (case/control). Standardized operational definitions were established for all variables to ensure measurement consistency. The occupational risk was dichotomized based on established exposure risk categorizations from previous epidemiological studies, with agricultural workers, sewage handlers, and animal handlers classified as high-risk occupations. Environmental parameters were assessed using validated criteria for infrastructure quality and hydrological risk, with drainage conditions evaluated based on flow characteristics, overflow frequency, and evidence of vector presence. Educational status was categorized according to national educational attainment standards to ensure contextual relevance and interpretability within the local socioeconomic framework.

Data collection procedures

Data collection proceeded through two complementary approaches to ensure a comprehensive assessment of study variables. Primary data acquisition involved the administration of structured questionnaires to all participants following thorough informed consent procedures. The questionnaire instrument included sections on sociodemographic characteristics, occupational exposures, and environmental conditions, which were completed through direct participant interviews conducted by trained research personnel to minimize measurement bias and ensure standardized assessment.

Environmental condition assessment relied on structured questionnaire items evaluating flood history, drainage infrastructure quality, and waste disposal conditions using operationalized definitions to maximize consistency. The environmental evaluation approach was selected following systematic consideration of alternative methodologies, including objective environmental sampling.

While direct environmental assessment (microbiological sampling of water sources, standardized infrastructure evaluation) would provide more precise exposure classification, resource constraints precluded the implementation of comprehensive environmental sampling protocols across the study catchment area. The limitations inherent in self-reported environmental data are explicitly addressed in the discussion section with appropriate interpretive caution regarding exposure classification accuracy.

Secondary data collection involved accessing medical records to verify case status and clinical parameters, including laboratory confirmation data employing microscopic agglutination testing or molecular diagnostics. Additional contextual information was obtained from district health office surveillance records and published epidemiological reports to validate case identification and characterize the broader disease distribution pattern. Data triangulation processes were implemented to reconcile information from multiple sources and enhance validity of classification decisions.

Statistical analysis

Data analysis proceeded sequentially through univariate and bivariate phases using established epidemiological analytical frameworks. Univariate analysis generated descriptive statistics to characterize frequency distributions for all study variables, including categorical data presentation through proportions and percentages to establish baseline characteristics of the study population. Bivariate analysis employed Chi-square tests to examine associations between independent variables and leptospirosis status, with statistical significance defined at $\alpha=0.05$. For variables with expected cell counts below theoretical minimums, Fisher's exact test was applied as an alternative procedure. Odds ratios with corresponding 95% confidence intervals were calculated using mantel-haenszel procedures to quantify the magnitude and directionality of associations. Risk factor interpretation followed established epidemiological criteria wherein OR>1 with 95%CI excluding 1 indicated confirmed risk factor, OR>1 with 95%CI including 1 suggested potential but unconfirmed risk factor, and OR<1 represented potential protective factors.

This conventional analytical approach provided a robust assessment of dichotomous risk associations but precluded more sophisticated spatial analysis that would enable the evaluation of geographical clustering, risk surface modeling, and integrated assessment of environmental-socioeconomic interactions. Resource constraints and methodological considerations regarding sample size adequacy for multivariate modeling influenced the selection of analytical methods, with priority placed on ensuring statistical validity within the limitations of available data. The methodological constraints inherent in this analytical framework are addressed in the discussion section with specific recommendations for advanced geospatial modeling approaches in future investigations.

Ethical considerations

The study was conducted following approval from the Health Research Ethics Committee (KEPK) of a private health college in Indonesia (Ethical Exemption No. XXX). The investigation adhered to the Declaration of Helsinki principles and local regulatory requirements throughout all research phases, with particular attention to respectful community engagement practices and potential vulnerability considerations. Participants were informed of their right to withdraw consent at any stage without consequence to their healthcare access or quality.

Findings

Sociodemographic characteristics

Sociodemographic analysis of the 34 study participants revealed age distribution predominantly concentrated in the middle to older adult categories, with equal proportions (32.4%) in both the 46-55 and 56-65 age brackets (11 participants each). The remaining participants were distributed among the 36-45 age category (14.7%) and those above 65 years (20.6%). Gender distribution demonstrated perfect equilibrium with 17 male and 17 female participants, each constituting 50.0% of the sample population. Occupational risk stratification identified 21 participants (61.8%) engaged in high-risk occupations, compared to 13 participants (38.2%) in occupations classified as low-risk. Educational attainment analysis revealed pronounced asymmetry, with 31 participants (91.2%) classified as having low educational status compared to only 3 participants (8.8%) with higher educational attainment (Table 1).

Table 1. Univariate analysis of individual factors in the working area of Kasihan II Bantul public health center (n=34)

Individual factors	Frequency (%)
Age (years)	
36-45	5 (14.7)
46-55	11 (32.4)
56-65	11 (32.4)
>65	7 (20.6)
Gender	
Male	17 (50.0)
Female	17 (50.0)
Occupation risk level to leptospirosis infection	
High risk	21 (61.8)
Low risk	13 (38.2)
Education level	
Low education (elementary-junior high school)	31 (91.2)
High education (senior high school-college)	3 (8.8)

Environmental risk factors

Environmental risk factor assessment demonstrated that the majority of participants (29, 85.3%) inhabited areas with good flood history (absence of significant flooding events), while only 5 participants (14.7%) resided in areas characterized by poor flood history (recurring inundation episodes). Analysis of drainage infrastructure revealed that 19 participants (55.9%) had access to good drainage systems characterized by proper flow, absence of overflow during precipitation, and limited rodent presence. Conversely, 15 participants (44.1%) were exposed to poor drainage conditions lacking one or more quality criteria. Waste disposal assessment identified suboptimal conditions among 20 participants (58.8%), contrasting with 14 participants (41.2%) with access to adequate waste management infrastructure (Table 2).

Table 2. Univariate analysis of biotic environmental factors in the working area of Kasihan II Bantul public health center (n=34)

Biotic environment	Frequency (%)
Flood history	
Yes	5 (14.7)
No	29 (85.3)
Drainage conditions	
Poor	15 (41.1)
Good	19 (55.9)
Waste disposal conditions	
Poor	20 (58.8)
Good	14 (41.2)

*Note: Good drainage conditions are defined as drainage with smooth flow, no overflow during rain, and no rat passage. Poor drainage conditions are defined as drainage not meeting at least one of these criteria.

Association between risk factors and leptospirosis

Bivariate analysis examining the relationship between hypothesized risk factors and leptospirosis status revealed significant associations for selected variables while others demonstrated no statistically significant relationship (Table 3). Gender demonstrated a significant association with leptospirosis (χ^2=5.765, p=0.016), with males exhibiting substantially higher risk (OR=5.760, 95%CI: 1.317-25.187) compared to females. Males constituted 70.6% of the case group compared to 29.4% of controls, establishing gender as a significant risk determinant.

Occupational risk classification similarly demonstrated a significant association with leptospirosis incidence (χ^2=6.103, p=0.013). High-risk occupations conferred substantially elevated disease probability (OR=6.667, 95%CI: 1.377-32.278) compared to low-risk occupational categories. This association was reflected in the disproportionate representation of high-risk occupations among cases (82.4%) compared to controls (41.2%).

Educational status did not demonstrate a statistically significant association with leptospirosis incidence (χ^2=0.366, p=0.545), despite an elevated odds ratio (OR=2.133, 95%CI: 0.175-26.033) suggesting a potential relationship. The wide confidence interval encompassing the null value indicates substantial uncertainty regarding the true magnitude of this association. The environmental parameters examined including flood history (χ^2=0.234, p=0.628), drainage conditions (χ^2=1.074, p=0.300), and waste disposal conditions (χ^2=0.486, p=0.486), similarly failed to demonstrate statistically significant associations with leptospirosis incidence. The absence of significant findings for these environmental determinants contradicts established epidemiological patterns observed in other geographic contexts.

Table 3. Association between leptospirosis risk factors and leptospirosis incidence in the working area of Kasihan II Bantul public health center

Risk factors	Leptospirosis		Total	λ² (p-value)	OR (CI)
	Cases n (%)	Control n (%)	n (%)		
Gender				5.765	5.760
Male	12 (70.6)	5 (29.4)	17 (50.0)	(0.016)	(1.317-25.187)
Female	5 (29.4)	12 (70.6)	17 (50.0)		
Occupation risk level to leptospirosis infection				6.103	6.667
High risk	14 (82.4)	7 (41.2)	21 (61.8)	(0.013)	(1.377-32.278)
Low risk	3 (17.6)	10 (58.8)	13 (38.2)		
Education level				0.366	2.133
Low education (elementary-junior high school)	16 (94.1)	15 (88.2)	31 (91.2)	(0.545)	(0.175-26.033)
High education (senior high school-college)	1 (5.9)	2 (11.8)	3 (8.8)		
Flood history				0.234	0.622
Yes	2 (11.8)	3 (17.6)	5 (14.7)	(0.628)	(0.090-4.294)
No	15 (88.2)	14 (82.4)	29 (85.3)		
Drainage conditions				1.074	2.063
Poor	9 (52.9)	6 (35.3)	15 (44.1)	(0.300)	(0.520-8.175)
Good	8 (41.7)	11 (64.7)	19 (55.9)		
Waste disposal conditions				0.486	1.630
Poor	11 (64.7)	9 (52.9)	20 (58.8)	(0.486)	(0.411-6.459)
Good	6 (35.3)	8 (47.1)	14 (41.2)		

Discussion

This case-control study sought to examine the relationship between individual factors (gender, occupation, education) and biotic environmental parameters (flood history, drainage conditions, waste disposal conditions) with leptospirosis incidence in the working area of Kasihan II Bantul public health center during 2022-2023. The principal findings demonstrate significant associations between male gender and high-risk occupations with leptospirosis occurrence, establishing these as independent risk determinants in this endemic setting. Conversely, educational status and environmental factors including flood history, drainage conditions, and waste disposal infrastructure did not demonstrate statistically significant associations with disease transmission, though wide confidence intervals suggest potential relationships that warrant further investigation with larger sample populations.

This study's findings identified male gender and high-risk occupational exposure as significant determinants of leptospirosis. These findings align with established epidemiological patterns documented across diverse geographical contexts and provide localized evidence for targeted intervention development. The gender disparity observed in this study population reflects consistent patterns documented in global leptospirosis literature, where males consistently demonstrate heightened vulnerability across endemic regions [28, 29]. This gender-associated risk emerges from complex intersections between biological susceptibility, behavioral patterns, and socially constructed gender roles that influence exposure probability through multiple pathways.

The occupational risk profile identified in this study analysis demonstrates strong coherence with established occupational epidemiology of leptospirosis. High-risk occupations, particularly agricultural work, construction labor, and fishing activities constituted a substantial majority of cases compared to controls, reinforcing occupation-mediated exposure as a primary determinant of infection probability. This finding corroborates international evidence positioning agricultural workers, particularly rice farmers, among the highest-risk occupational categories [30-34]. The vulnerability of agricultural workers stems from sustained environmental exposure to potentially contaminated soil and water sources, creating multiple opportunities for pathogen transmission through cutaneous routes. Our findings regarding construction laborers (particularly "kuli bangunan") align with emerging evidence recognizing urban service workers as an increasingly important risk group in developing regions, reflecting changing urbanization patterns and occupational distributions [35-37].

The intersection between gender and occupation creates compounded vulnerability profiles that warrant integrated analytical consideration. The gender-based division of labor documented in our study region parallels broader patterns reported in high-endemic areas, where occupations involving the highest exposure risk disproportionately employ male workers [31, 34, 37, 38]. This occupational stratification partially explains the observed gender disparity in leptospirosis distribution, though

behavioral factors likely contribute additional risk dimensions. The limited adoption of personal protective equipment, particularly appropriate footwear during agricultural activities emerges as a critical behavioral determinant consistent with patterns observed in seroprevalence studies of high-risk occupational groups [32]. Environmental exposure through recreational activities, including fishing and interaction with natural water bodies, represents an additional gender-modulated risk pathway extensively documented in previous research [33, 39, 40].

Moreover, this study's findings revealed no significant association between educational attainment and leptospirosis incidence. This finding corresponds with previous epidemiological research from Sri Lanka that has demonstrated the presence of substantial knowledge disparities regarding transmission mechanisms and prophylactic measures across educational strata, despite relatively uniform recognition of rodents as reservoir hosts [41]. Complementary evidence from Trinidad and Tobago further elucidates this complexity, documenting that geographical proximity to endemic foci functions as a stronger predictor of leptospirosis awareness than educational attainment metrics [42]. These findings collectively suggest that contextual determinants, including localized disease prevalence patterns, community-level health literacy initiatives, and regionalized risk communication strategies may significantly modulate the translation of formal education into protective behaviors.

This study's findings, however, showed no significant associations between environmental factors including flood history, drainage conditions, and waste disposal infrastructure and leptospirosis incidence in the Kasihan II Bantul catchment area. These results contrast with established literature documenting environmental determinants as critical factors in leptospirosis epidemiology across diverse geographical contexts [43-48]. The absence of significant associations may reflect several methodological considerations, including limited statistical power due to sample size constraints, potential exposure misclassification in retrospective assessment, and high environmental homogeneity within the study area. Additionally, the predominance of good flood history among participants restricted analytical capacity to detect flood-associated risk patterns, despite substantial evidence from comparable investigations establishing flooding as a significant amplifier of transmission probability.

The analysis of drainage infrastructure and waste management revealed elevated risk estimates that failed to reach statistical significance. These environmental parameters possess established biological plausibility in leptospirosis transmission dynamics through their influence on vector ecology and the environmental persistence of pathogenic leptospires. The findings align with research by a previous study, that documented similar non-significant associations between drainage conditions and leptospirosis [49]. The complex interplay between environmental parameters and disease transmission appears modulated by additional factors not captured in the analytical framework, including seasonal variation in precipitation patterns, vector population dynamics, and localized hydrological characteristics that influence environmental contamination profiles across the study region.

This study provides valuable insights into the epidemiological determinants of leptospirosis in the Kasihan II Bantul region, with particular emphasis on the significant associations between individual factors and disease occurrence. The identification of male gender and high-risk occupations as significant risk determinants offers critical evidence for targeted public health interventions in this endemic context. While environmental parameters demonstrated elevated risk estimates without reaching statistical significance, these findings contribute to the evolving discourse on leptospirosis transmission dynamics in Indonesia.

Study limitations

This investigation encountered several methodological constraints warranting critical consideration. First, the modest sample size (n=34) limited statistical power for detecting moderate-effect associations (OR=2.0-3.0), potentially obscuring significant relationships, particularly for environmental parameters. Second, the quasi-experimental design without randomization introduces potential selection bias despite efforts to ensure between-group comparability. Third, reliance on self-reported environmental conditions without objective microbiological sampling or standardized infrastructure assessment created potential exposure misclassification. Fourth, demographic homogeneity (91.2% with low education; 85.3% reporting good flood history) restricted analytical capacity to detect associations within these domains. Fifth, the cross-sectional temporal structure precluded evaluation of seasonal variability, lag effects, and long-term impact trajectories. Sixth, geographical restriction to a single catchment area constrained environmental

heterogeneity representation and limits generalizability beyond Kasihan II Bantul. Finally, conventional bivariate analytical approaches without advanced geospatial modeling techniques prevented comprehensive assessment of spatial heterogeneity and environmental-socioeconomic interactions that potentially modulate transmission dynamics. These limitations necessitate cautious interpretation, particularly regarding environmental parameters where statistical power constraints and measurement limitations may have obscured genuine associations. The significant relationships identified between male gender (OR=5.760, 95%CI: 1.317-25.187) and high-risk occupations (OR=6.667, 95%CI: 1.377-32.278) with leptospirosis demonstrate robust statistical parameters despite methodological constraints, enhancing confidence in these specific findings. However, the absence of significant associations for environmental factors should be interpreted as inconclusive rather than definitively negative given the intersecting limitations affecting these parameters.

Implications and future directions

The study findings have substantial implications for public health practice and research methodology. Evidence-based prevention strategies should prioritize occupation-specific interventions targeting agricultural workers, construction laborers, and fishing communities through multifaceted approaches including enhanced personal protective equipment access, context-appropriate educational modules, and workplace environmental modifications. Targeted community engagement and education programs should be implemented with particular emphasis on high-risk occupational groups, utilizing established behavior change frameworks to develop tailored interventions addressing risk perception, protective behaviors, and environmental management. Comprehensive policy frameworks should be developed across multiple domains including 1) occupational safety regulations requiring appropriate protective equipment for high-risk workers; 2) community-level environmental modifications addressing drainage infrastructure and waste management; And 3) enhanced surveillance systems with occupation-specific monitoring components.

Future research should address identified methodological limitations through: 1) multicenter recruitment strategies across diverse endemic regions including Bantul, Sewon, and Pundong sub-districts to enhance sample size and demographic heterogeneity; 2) prospective cohort designs with longitudinal assessment incorporating strategic temporal sampling intervals aligned with established seasonal transmission patterns; 3) objective environmental assessment protocols including microbiological sampling and standardized infrastructure evaluation; 4) advanced analytical frameworks incorporating geospatial modeling techniques to integrate environmental and socioeconomic determinants; And 5) mixed-methods evaluation of targeted interventions across multiple outcome domains. These methodological refinements would substantially enhance understanding of complex leptospirosis transmission dynamics while facilitating the development of increasingly precise prevention strategies tailored to local epidemiological contexts.

Conclusion

This case-control investigation established male gender and high-risk occupational exposure as significant determinants of leptospirosis transmission within the Kasihan II Bantul catchment area, while educational status and environmental parameters demonstrated non-significant associations despite elevated risk estimates. These findings provide an evidence-based foundation for developing targeted prevention strategies addressing the specific risk profiles identified in this endemic setting. The predominance of individual rather than environmental risk factors suggests that personal protection and behavioral modification approaches may constitute high-priority intervention targets, particularly among male workers in the agricultural, construction, and fishing sectors. Future research incorporating larger sample populations, prospective designs, and integrated environmental sampling would significantly enhance understanding of leptospirosis transmission dynamics in this region and facilitate the development of increasingly precise prevention strategies tailored to local epidemiological contexts.