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Temporal Trends and Factors Associated with Human Leptospirosis in Davao City, Philippines: An 11-Year Surveillance Analysis (2015–2025)

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Abstract

Leptospirosis remains a significant public health concern in the Philippines, particularly in urban tropical settings where environmental and climatic conditions favor disease transmission. This study examined temporal trends and factors associated with human leptospirosis in Davao City, Philippines, using surveillance data from 2015 to 2025. A retrospective observational study was conducted using 1104 surveillance records obtained from the Davao City Health Office–City Epidemiological Surveillance Unit. Annual incidence and mortality rates were calculated per 100,000 population; temporal trends were assessed using Mann–Kendall tests; and associations with demographic, seasonal, geographic, and environmental factors were evaluated using Poisson and negative binomial regression models, as appropriate, based on model diagnostics and comparative fit. Increasing incidence trends were observed across several strata, whereas increasing mortality trends were identified in selected demographic and environmental categories. In the incidence analysis, a higher disease burden was associated with age ≥ 15 years (aIRR = 14.75, 95% CI: 10.77–20.21), male sex (aIRR = 4.78, 95% CI: 3.74–6.11), high population density (aIRR = 4.19, 95% CI: 2.75–6.38), and the wet season (aIRR = 1.30, 95% CI: 1.04–1.61). Mortality was also strongly associated with age ≥ 15 years (aIRR = 36.75, 95% CI: 13.61–99.22) and male (aIRR = 8.50, 95% CI: 4.73–15.27). These findings provide a long-term surveillance-based assessment of leptospirosis in Davao City and identify demographic and environmental patterns relevant to targeted surveillance, seasonal preparedness, and locally adapted prevention strategies for leptospirosis.



Academic Editor: Georgia Vrioni

Received: 6 June 2026

Revised: 9 July 2026

Accepted: 10 July 2026

Published: 12 July 2026

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Keywords: leptospirosis; epidemiology; surveillance; incidence; mortality; risk factors

1. Introduction

Leptospirosis is a globally distributed zoonotic disease caused by pathogenic spirochetes of the genus *Leptospira*. Human infection commonly occurs through direct or indirect contact with the urine of infected animals, particularly rodents, which contaminates soil, freshwater, and floodwaters [1,2]. The disease presents with a wide clinical spectrum, ranging from mild febrile illness to severe manifestations involving multi-organ failure,

pulmonary hemorrhage, and death [3]. Leptospirosis remains a major public health concern in tropical and subtropical regions, where environmental conditions favor the survival and transmission of pathogenic *Leptospira* spp. [4].

The burden of leptospirosis is particularly pronounced in low- and middle-income countries, where rapid urbanization, inadequate sanitation, poor waste management, and recurrent flooding increase the opportunities for human exposure [5]. The World Health Organization recognizes leptospirosis as an important but often neglected infectious disease, with an estimated one million cases and approximately 60,000 deaths occurring annually worldwide [6]. In Southeast Asia, leptospirosis continues to contribute substantially to morbidity and mortality, particularly following periods of heavy rainfall, flooding, and extreme weather events [7].

In the Philippines, leptospirosis remains endemic and is regularly reported throughout the country [8]. Seasonal outbreaks are frequently associated with the rainy season and flooding events, particularly in densely populated urban areas. Previous studies have identified key demographic, environmental, and occupational risk factors for leptospirosis infection, including male sex, older age group, floodwater exposure, and urban residency [9–12]. However, the epidemiology of leptospirosis is dynamic and may change over time in response to demographic shifts, environmental conditions, urban development, and improvements in disease surveillance and diagnostic capacities.

Davao City, one of the largest and most populous cities in the Philippines, presents a unique setting for investigating the epidemiology of leptospirosis due to its diverse geographic landscape, rapid urban growth, and varying environmental conditions. A 2013 post-monsoon resurgence in Davao City demonstrated acute localized vulnerability reporting, a 9.4% case fatality rate [13]. However, while such localized outbreak reports provide invaluable cross-sectional insights, and despite the public health implications of leptospirosis, long-term epidemiological assessments examining the incidence, mortality, and associated demographic, seasonal, geographic and environmental factors in Davao City remain limited. Understanding these patterns is essential for identifying populations at increased risk and informing evidence-based prevention and control strategies.

To address this knowledge gap, this study examined the epidemiology of human leptospirosis in Davao City, Philippines, through an 11-year analysis of incidence and mortality, along with associated demographic, seasonal, geographic and environmental factors. The 11-year timeline was determined by data availability and the standardization of local surveillance tracking. The year 2015 represents the baseline for unified case logging by the CHO-CESU. This 11-year window provides a comprehensive, uninterrupted dataset available for reliable trend analysis. Temporal trends in disease incidence and mortality were assessed, and factors associated with disease occurrence and mortality burden were identified.

2. Materials and Methods

2.1. Study Design and Setting

A retrospective observational epidemiological study was conducted to examine the incidence, mortality, temporal trends, and associated demographic, seasonal, geographic, and environmental factors of leptospirosis in Davao City, Philippines, from January 2015 to December 2025. Davao City is the largest city in the Philippines by land area and is administratively divided into three congressional districts. The city encompasses diverse urban and rural communities with varying environmental and geographic characteristics, making it an appropriate setting for investigating the epidemiology of leptospirosis.

2.2. Study Population and Data Sources

A total of 1104 leptospirosis cases recorded in the surveillance databases of the Davao City Health Office–City Epidemiological Surveillance Unit (CHO–CESU) from 1 January 2015 to 31 December 2025 were eligible for inclusion. The extracted variables included age, sex, barangay of residence, date of onset, case classification, and outcome status.

Population and population density data were obtained from the Philippine Statistics Authority (PSA). Urbanization classifications were derived from the Philippine Standard Geographic Code (PSGC), and flood susceptibility classifications were obtained from the Department of Environment and Natural Resources–Mines and Geosciences Bureau Region XI (DENR–MGB XI). Seasonal classifications were based on the definitions of the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA).

Records reported outside the geographic jurisdiction of Davao City, records outside the study period, duplicate records, and records with missing information on age, sex, barangay of residence, or date of onset were excluded from the analysis.

2.3. Case Definitions and Variable Classification

Cases were classified according to the surveillance definitions used by the CHO–CESU. Non-confirmed cases included suspected and probable cases of leptospirosis. Suspected cases were defined as individuals presenting with acute febrile illness and relevant environmental exposure without laboratory confirmation of infection. Probable cases met the suspected case definition and yielded positive IgM rapid diagnostic test results. Confirmed cases were those verified through laboratory methods, including bacterial culture, Microscopic Agglutination Test (MAT), or polymerase chain reaction (PCR).

Age was categorized as <15 and ≥ 15 years. The cases were further classified according to sex, congressional district, season, population density, urbanization status, and flooding susceptibility. Seasons were categorized as dry (December–May) and wet (June–November) following the PAGASA classification. Barangays were assigned to population density, urbanization, and flood susceptibility categories based on official government datasets and standardized using PSGC codes. These classifications were assigned once, based on the respective source datasets, and treated as time-invariant throughout the 2015–2025 study period.

2.4. Statistical Analysis

Descriptive statistics were summarized using frequencies, percentages, incidence rates, and mortality rates. Annual leptospirosis incidence was calculated as the number of reported leptospirosis cases divided by the corresponding annual population and expressed per 100,000 population. The annual mortality rate was calculated as the number of reported leptospirosis-related deaths divided by the corresponding annual population and expressed per 100,000 population.

Temporal trends in annual incidence and mortality rates from 2015 to 2025 were assessed using the Mann–Kendall trend test. Separate trend analyses were conducted across demographic, seasonal, geographic and environmental strata. Kendall's τ was reported to indicate the direction and magnitude of monotonic trends. Given the limited number of annual observations and multiple parallel trend tests performed, the stratified Mann–Kendall analyses were considered exploratory, and individual p -values were interpreted cautiously in conjunction with the magnitude and direction of Kendall's τ and the consistency of trends across related strata. Trend figures additionally included locally weighted scatterplot smoothing (LOESS) curves and linear regression lines with 95% confidence intervals for visualization purposes only.

Associations between demographic, seasonal, geographic, and environmental factors, and annual counts of leptospirosis case and deaths were evaluated using count regression models. The unit of analysis was the stratum-year aggregate. Confirmed, probable, and suspected cases were combined for the primary analyses of incidence and mortality association. Separate factor-specific regression models, rather than a single model that simultaneously includes all demographic and environmental factors, were fitted for age group, sex, season, urbanization, flood susceptibility, and population density. Each factor-specific model included calendar year and congressional district as adjustment covariates to account for secular temporal trends and geographic differences. Congressional district was additionally evaluated as an exposure in the mortality analysis; this model was adjusted for calendar year only. For both the incidence and mortality models, the natural logarithm of the corresponding annual city population was included as an offset to account for changes in the population at risk during the study period.

Poisson regression models were initially fitted, and overdispersion was assessed using Pearson and deviance dispersion statistics. For the incidence analyses, evidence of overdispersion was observed across all models. Negative binomial regression models were therefore fitted and compared with the corresponding Poisson models using the Akaike Information Criterion (AIC). Because the negative binomial models consistently yielded lower AIC values, they were selected for the final incidence association analyses. For the mortality analyses, model selection was performed separately for each factor-specific model based on dispersion diagnostics and comparative model fit. Negative binomial regression was selected for the sex and population-density models, whereas Poisson regression was retained for the age, season, flood-susceptibility, urbanization, and congressional-district models. The residual temporal autocorrelation in the final incidence and mortality models was assessed using the Ljung–Box test applied to the annual mean Pearson residuals. Because residual temporal autocorrelation was detected in the population density mortality model, a sensitivity analysis was performed using negative binomial regression with a first-order autoregressive [AR(1)] temporal correlation structure. Results are reported as adjusted incidence rate ratios (aIRRs) with corresponding 95% confidence intervals (CIs) and *p*-values.

To examine potential overlap among area-level environmental predictors, pairwise associations among urbanization, population density, and flood susceptibility were assessed at the barangay-classification level using chi-square tests and Cramér's *V*. Each barangay contributed a unique set of environmental classifications to the analysis. Cramér's *V* was used to quantify the strength of association between pairs of categorical environmental predictors.

Records with incomplete key demographic or geographic variables were excluded from the analysis. Statistical significance was set at $p < 0.05$. All analyses were performed using R version 4.4.1 (R Foundation for Statistical Computing, Vienna, Austria) and Stata version 14 (StataCorp LLC, College Station, TX, USA).

3. Results

3.1. Epidemiological Characteristics of Leptospirosis Cases

Table 1 presents the cumulative counts and rates of confirmed and non-confirmed leptospirosis cases and deaths according to demographic, seasonal, geographic, and environmental characteristics in Davao City, Philippines, between 2015 and 2025. A total of 1108 human leptospirosis surveillance records were initially retrieved for this study. Of these, four records were excluded because of missing core demographic or geographic data, leaving a final analytical sample of 1104 cases. A total of 151 deaths were recorded.

Table 1. Cumulative counts and rates of confirmed and non-confirmed leptospirosis according to demographic, seasonal, geographic, and environmental characteristics in Davao City, Philippines, 2015–2025.

Category	Non-Confirmed Cases, <i>n</i> (Rate)	Confirmed Cases, <i>n</i> (Rate)	Non-Confirmed Deaths, <i>n</i> (Rate)	Confirmed Deaths, <i>n</i> (Rate)
Age				
≥15 years old	850 (43.65)	38 (1.95)	145 (7.45)	2 (0.10)
<15 years old	64 (3.29)	0 (0.00)	4 (0.21)	0 (0.00)
Sex				
Female	160 (8.22)	6 (0.31)	16 (0.82)	1 (0.05)
Male	754 (38.72)	33 (1.69)	141 (7.24)	1 (0.05)
Congressional District				
District I	380 (19.51)	14 (0.72)	62 (3.18)	0 (0.00)
District II	349 (17.92)	17 (0.87)	55 (2.82)	2 (0.10)
District III	185 (9.50)	7 (0.36)	32 (1.64)	0 (0.00)
Seasonal Pattern				
Dry season	399 (20.49)	12 (0.62)	72 (3.70)	1 (0.05)
Wet season	515 (26.45)	27 (1.39)	77 (3.95)	1 (0.05)
Population Density				
High	607 (31.17)	29 (1.49)	100 (5.14)	2 (0.10)
Moderate	174 (8.94)	2 (0.10)	21 (1.08)	0 (0.00)
Low	133 (6.83)	8 (0.41)	28 (1.44)	0 (0.00)
Urbanization				
Rural	45 (2.31)	4 (0.21)	6 (0.31)	0 (0.00)
Urban	869 (44.63)	35 (1.80)	143 (7.34)	2 (0.10)
Flooding Susceptibility				
High susceptibility	186 (9.55)	8 (0.41)	35 (1.80)	0 (0.00)
Moderate susceptibility	170 (8.73)	6 (0.31)	30 (1.54)	1 (0.05)
Low susceptibility	558 (28.66)	25 (1.28)	84 (4.31)	1 (0.05)

Note: Values are presented as *n* (cumulative rate per 100,000 population). Non-confirmed cases include suspected and probable cases.

Among non-confirmed cases, the highest number and rate were observed among individuals aged ≥15 years, with 850 cases (43.65 per 100,000 population), compared with 64 cases (3.29 per 100,000 population) among those aged <15 years. Similarly, all 38 confirmed cases with available age group classification occurred among individuals aged ≥15 years, corresponding to a rate of 1.95 per 100,000. Males accounted for a higher number and rate of cases than females in both the nonconfirmed and confirmed groups. Among non-confirmed cases, 754 (38.72 per 100,000) occurred in males compared with 160 (8.22 per 100,000) in females. Among the confirmed cases, 33 (1.69 per 100,000) occurred in males and six (0.31 per 100,000) in females.

District I recorded the highest number and rate of non-confirmed cases, with 380 cases (19.51 per 100,000), followed by District II with 349 cases (17.92 per 100,000), and District III with 185 cases (9.50 per 100,000). Among the confirmed cases, District II recorded the highest number and rate, with 17 cases (0.87 per 100,000), followed by District I with 14 cases (0.72 per 100,000) and District III with seven cases (0.36 per 100,000). The wet season accounted for a higher number and rate of cases than the dry season in both classification groups. Among non-confirmed cases, 515 (26.45 per 100,000) occurred during the wet season compared with 399 (20.49 per 100,000) during the dry season. Among the confirmed cases, the corresponding values were 27 (1.39 per 100,000) and 12 (0.62 per 100,000) cases, respectively.

The highest numbers and rates of both non-confirmed and confirmed cases were observed in high-population-density areas, with 607 non-confirmed cases (31.17 per 100,000 population) and 29 confirmed cases (1.49 per 100,000 population). Similarly, urban areas accounted for 869 non-confirmed cases (44.63 per 100,000) and 35 confirmed cases (1.80 per 100,000), compared with 45 non-confirmed cases (2.31 per 100,000) and four confirmed cases (0.21 per 100,000) in rural areas. With respect to flood susceptibility, areas with low susceptibility recorded the highest number and rate of cases in both groups, with 558 non-confirmed cases (28.66 per 100,000) and 25 confirmed cases (1.28 per 100,000).

Deaths predominantly occurred among non-confirmed cases. Among this group, the highest number and rate of deaths were observed among individuals aged ≥ 15 years (145 deaths, 7.45 per 100,000), males (141 deaths, 7.24 per 100,000), cases occurring during the wet season (77 deaths, 3.95 per 100,000), cases from high-population-density areas (100 deaths, 5.14 per 100,000), and cases from urban areas (143 deaths, 7.34 per 100,000). Only two deaths occurred among confirmed cases, corresponding to cumulative rates not exceeding 0.10 per 100,000 in any demographic, seasonal, geographic, or environmental category.

3.2. Temporal Trends in Leptospirosis Incidence

Figure 1 illustrates the temporal trends in leptospirosis incidence across demographic, seasonal, geographic, and environmental factors between 2015 and 2025. Significantly increasing incidence trends were observed among both males ($\tau = 0.818$, $p < 0.001$) and females ($\tau = 0.527$, $p = 0.029$), with incidence remaining consistently higher among males throughout the study period (Figure 1A). By age group, significantly increasing trends were observed among individuals aged < 15 years ($\tau = 0.500$, $p = 0.042$) and those aged ≥ 15 years ($\tau = 0.782$, $p = 0.001$), with the incidence remaining substantially higher among individuals aged ≥ 15 years throughout the study period (Figure 1B).

Across congressional districts, significantly increasing incidence trends were observed in the First ($\tau = 0.782$, $p = 0.001$), Second ($\tau = 0.636$, $p = 0.008$), and Third Districts ($\tau = 0.709$, $p = 0.003$) (Figure 1C). Significant increasing trends were also observed in areas with high ($\tau = 0.745$, $p = 0.002$), moderate ($\tau = 0.782$, $p = 0.001$), and low population densities ($\tau = 0.782$, $p = 0.001$), with the incidence remaining highest in high-density areas throughout the study period (Figure 1D).

Significantly increasing incidence trends were observed in high- ($\tau = 0.782$, $p = 0.001$), moderate- ($\tau = 0.855$, $p < 0.001$), and low-susceptibility areas ($\tau = 0.709$, $p = 0.003$). Despite increasing trends across all categories, the absolute incidence was generally highest in areas classified as having low flood susceptibility, particularly the recent years (Figure 1E). The incidence also increased significantly in both rural ($\tau = 0.600$, $p = 0.013$) and urban areas ($\tau = 0.745$, $p = 0.002$), with the incidence remaining substantially higher in urban settings (Figure 1F). Seasonal analyses showed significant upward trends in the incidence trends during both the dry ($\tau = 0.636$, $p = 0.008$) and wet seasons ($\tau = 0.782$, $p = 0.001$), with the incidence generally remaining higher during the wet season (Figure 1G).

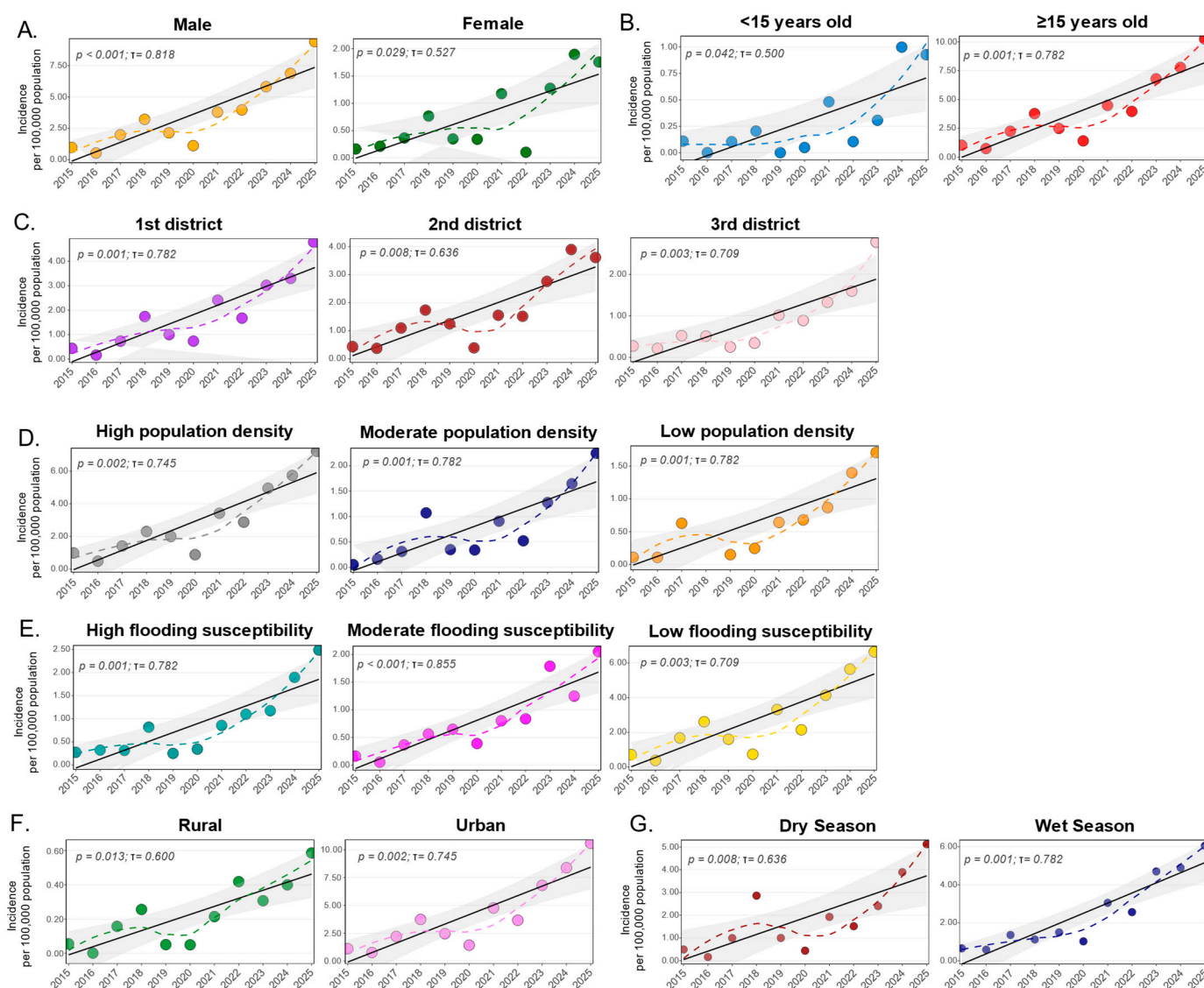


Figure 1. Annual leptospirosis incidence rates per 100,000 population across demographic and geographic subgroups in Davao City, Philippines, from 2015 to 2025. (A) Sex, (B) age group, (C) congressional district, (D) population density, (E) flooding susceptibility, (F) urbanization and (G) seasonality. Points represent observed annual incidence rates. Solid black lines indicate linear regression trends with 95% confidence intervals (shaded areas), while dashed colored lines represent locally weighted smoothing (LOESS) curves. Reported p -values correspond to the Mann–Kendall trend test.

3.3. Factors Associated with Leptospirosis Incidence

Table 2 presents the associations between demographic, seasonal, geographic and environmental factors and annual leptospirosis incidence based on the combined counts of confirmed, probable, and suspected cases. Model diagnostics indicated overdispersion across all incidence models, and negative binomial regression models consistently showed better fit than the corresponding Poisson models based on the Akaike Information Criterion (AIC). Therefore, negative binomial regression was used for the final incidence association analyses. Residual diagnostic assessment showed no evidence of significant temporal autocorrelation across the final factor-specific models (Ljung–Box $p = 0.722$ – 0.976). The corresponding model diagnostics, model comparisons, and residual autocorrelation assessments are presented in Supplementary Table S1.

Table 2. Associations between demographic, seasonal, geographic and environmental factors and leptospirosis incidence in Davao City, Philippines, 2015–2025.

Variable	Comparison	Reference	Adjusted IRR	95% CI	p-Value
Age	≥15 years old	<15 years old	14.75	10.77–20.21	<0.001
Sex	Male	Female	4.78	3.74–6.11	<0.001
Season	Wet season	Dry season	1.30	1.04–1.61	0.021
Urbanization	Rural	Urban	0.06	0.04–0.08	<0.001
Flood susceptibility	High	Low	0.33	0.25–0.43	<0.001
Flood susceptibility	Moderate	Low	0.30	0.23–0.40	<0.001
Population density	High	Low	4.19	2.75–6.38	<0.001
Population density	Moderate	Low	1.10	0.70–1.72	0.681

Note. aIRR, adjusted incidence rate ratio; CI, confidence interval. Adjusted IRRs were estimated from separate factor-specific negative binomial regression models adjusted for calendar year and congressional district. An IRR > 1 indicates a higher incidence relative to the reference category, whereas an IRR < 1 indicates a lower incidence.

Individuals aged ≥15 years had a significantly higher incidence than those aged <15 years (aIRR = 14.75, 95% CI: 10.77–20.21, $p < 0.001$). Similarly, incidence was significantly higher in males than in females (aIRR = 4.78, 95% CI: 3.74–6.11, $p < 0.001$). The incidence was significantly higher during the wet season than during the dry season (aIRR = 1.30, 95% CI: 1.04–1.61, $p = 0.021$).

Among the geographic and environmental factors, high-population-density areas had a significantly higher incidence than low-density areas (aIRR = 4.19, 95% CI: 2.75–6.38, $p < 0.001$), whereas the difference between moderate- and low-density areas was not statistically significant (aIRR = 1.10, 95% CI: 0.70–1.72, $p = 0.681$). The incidence was significantly lower in rural than in urban areas (aIRR = 0.06, 95% CI: 0.04–0.08, $p < 0.001$). Compared with areas with low flood susceptibility, both high-susceptibility (aIRR = 0.33, 95% CI: 0.25–0.43, $p < 0.001$) and moderate-susceptibility areas (aIRR = 0.30, 95% CI: 0.23–0.40, $p < 0.001$) had significantly lower incidence.

To examine the potential overlap among the area-level environmental predictors, pairwise associations between urbanization, population density, and flood susceptibility were assessed using Cramér's V. A strong association was observed between urbanization and population density (Cramér's V = 0.552, $p < 0.001$), whereas a moderate association was observed between urbanization and flood susceptibility (Cramér's V = 0.301, $p = 0.003$). The association between population density and flood susceptibility was weak (Cramér's V = 0.265; $p = 0.002$). The complete pairwise association results are presented in Supplementary Table S2.

3.4. Temporal Trends in Leptospirosis Mortality Rate

Figure 2 illustrates the temporal trends in leptospirosis mortality rates across demographic, seasonal, geographic, and environmental factors between 2015 and 2025. By sex, a significantly increasing trend was observed among females ($\tau = 0.529$, $p = 0.039$), whereas the increasing trend among males was not statistically significant ($\tau = 0.440$, $p = 0.072$) (Figure 2A). By age group, mortality rates increased significantly among individuals aged ≥15 years ($\tau = 0.673$, $p = 0.006$), whereas no significant trend was detected among those aged <15 years ($\tau = 0.317$, $p = 0.268$) (Figure 2B).

Across congressional districts, significantly increasing mortality trends were observed in the First ($\tau = 0.636$, $p = 0.010$), Second ($\tau = 0.725$, $p = 0.003$), and Third Districts ($\tau = 0.496$, $p = 0.048$) (Figure 2C). Significant increases were also observed in areas with high ($\tau = 0.636$, $p = 0.009$) and moderate ($\tau = 0.517$, $p = 0.043$) population densities, whereas the trend in low-density areas was not significant ($\tau = 0.477$, $p = 0.063$) (Figure 2D).

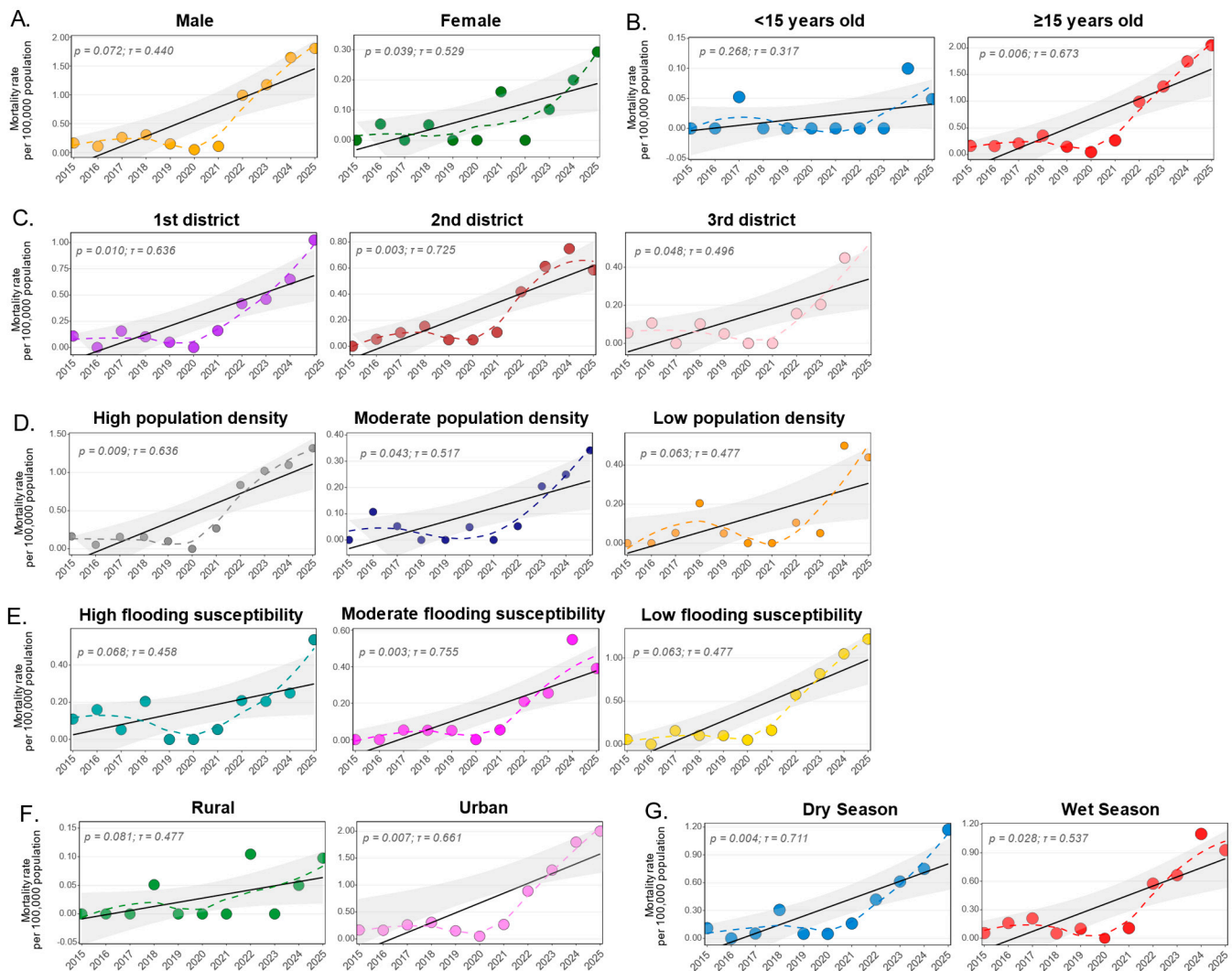


Figure 2. Temporal trends in leptospirosis mortality rate across (A) sex, (B) age group, (C) congressional district, (D) population density, and (E) flooding susceptibility, (F) urbanization, and (G) seasonality. Points represent observed annual mortality rates. Solid black lines indicate linear regression trends with 95% confidence intervals (shaded areas), while dashed colored lines represent locally weighted smoothing (LOESS) curves. Reported p -values correspond to the Mann–Kendall trend test.

Regarding flooding susceptibility, significantly increasing mortality trends were observed in areas with moderate susceptibility ($\tau = 0.755$, $p = 0.003$), whereas the trend in highly susceptible areas was not statistically significant ($\tau = 0.458$, $p = 0.068$) (Figure 2E). The mortality rate increased significantly in urban areas ($\tau = 0.661$, $p = 0.007$), but no significant trend was observed in rural areas ($\tau = 0.477$, $p = 0.081$) (Figure 2F). Seasonal analyses showed significantly increasing mortality trends during the dry ($\tau = 0.711$, $p = 0.004$) and wet seasons ($\tau = 0.537$, $p = 0.028$) (Figure 2G).

3.5. Factors Associated with Leptospirosis Mortality

Table 3 presents the associations between demographic, seasonal, geographic and environmental factors and leptospirosis mortality. Model selection was based on overdispersion diagnostics and comparative model fitting. Poisson regression models were retained for age, season, urbanization, flood susceptibility, and congressional district, whereas negative binomial regression models were selected for sex and population density. The residual diagnostic assessment showed no evidence of significant temporal autocorrelation in six

of the seven selected models. Residual temporal autocorrelation was detected in the population density model ($p = 0.044$); therefore, a sensitivity analysis was conducted using a negative binomial model with an AR(1) temporal correlation structure.

Table 3. Associations between demographic, seasonal, geographic and environmental factors and leptospirosis mortality rate in Davao City, Philippines, 2015–2025.

Variable	Comparison	Reference	Adjusted IRR	95% CI	<i>p</i> -Value
Age ^a	≥15 years old	<15 years old	36.75	13.61–99.22	<0.001
Sex ^b	Male	Female	8.50	4.73–15.27	<0.001
District ^a	Second District	First District	0.92	0.64–1.32	0.647
District ^a	Third District	First District	0.52	0.34–0.79	0.002
Season ^a	Wet season	Dry season	1.07	0.78–1.47	0.684
Urbanization ^a	Rural	Urban	0.04	0.02–0.09	<0.001
Flood susceptibility ^a	High	Low	0.41	0.28–0.61	<0.001
Flood susceptibility ^a	Moderate	Low	0.37	0.24–0.55	<0.001
Population density ^b	High	Low	3.37	1.94–5.87	<0.001
Population density ^b	Moderate	Low	0.71	0.36–1.41	0.330

Note. aIRR, adjusted incidence rate ratio; CI, confidence interval. ^a Estimates were obtained using Poisson regression models. ^b Estimates were obtained from the negative binomial regression models. Adjusted IRRs were estimated from separate factor-specific models adjusted for calendar year and congressional district, except for the congressional district model, which was adjusted only for the calendar year.

Individuals aged ≥15 years had significantly higher mortality than those aged <15 years (aIRR = 36.75, 95% CI: 13.61–99.22, $p < 0.001$). Similarly, males had significantly higher mortality than females (aIRR = 8.50, 95% CI: 4.73–15.27, $p < 0.001$).

Compared with the First District, mortality did not differ significantly in the Second District (aIRR = 0.92, 95% CI: 0.64–1.32, $p = 0.647$), whereas the Third District had significantly lower mortality (aIRR = 0.52, 95% CI: 0.34–0.79, $p = 0.002$). Mortality did not differ significantly between the wet and dry seasons (aIRR = 1.07, 95% CI: 0.78–1.47, $p = 0.684$).

Among the geographic and environmental factors, mortality was significantly higher in areas with high population density than in low-density areas (aIRR = 3.37, 95% CI: 1.94–5.87, $p < 0.001$), whereas no significant difference was observed between moderate- and low-density areas (aIRR = 0.71, 95% CI: 0.36–1.41, $p = 0.330$). The sensitivity analysis accounting for AR(1) temporal correlation supported the primary finding, with high-population-density areas retaining significantly higher mortality than low-density areas (aIRR = 3.52, 95% CI: 1.28–9.69, $p = 0.015$). Rural areas had significantly lower mortality than urban areas (aIRR = 0.04, 95% CI: 0.02–0.09, $p < 0.001$). Compared with areas with low flood susceptibility, both high-susceptibility (aIRR = 0.41, 95% CI: 0.28–0.61, $p < 0.001$) and moderate-susceptibility areas (aIRR = 0.37, 95% CI: 0.24–0.55, $p < 0.001$) had significantly lower mortality.

4. Discussion

This study provides an 11-year surveillance-based assessment of the temporal trends and factors associated with human leptospirosis in Davao City, Philippines. The findings indicate an increasing reported burden across several demographic, seasonal, geographic and environmental strata, with important patterns related to age, sex, urbanization, population density, and seasonality. However, these findings should be interpreted within the context of passive surveillance, in which the observed temporal patterns may reflect both changes in disease occurrence and changes in surveillance, diagnosis, and reporting over time.

The increasing temporal patterns observed in this study are broadly consistent with reports from other tropical settings, where urbanization, environmental change, and repeated

human contact with contaminated environments contribute to sustained leptospirosis transmission [14–16]. Nevertheless, the apparent increase, particularly in recent years, should not be attributed solely to increasing transmission. Improvements or changes in surveillance capacity, disease recognition, reporting completeness, diagnostic awareness, healthcare-seeking behavior, and case ascertainment may have also contributed to the observed patterns [17]. This possibility is particularly important because the temporal analyses were based on only 11 annual observations, limiting the statistical power, especially for stratified analyses. Trends with borderline statistical significance should therefore be interpreted cautiously, and continued surveillance using consistent case definitions and diagnostic practices will be important for determining whether the observed increases represent sustained epidemiological changes in the future.

The greater overall burden among males and individuals aged ≥ 15 years is consistent with previous epidemiological studies [18,19]. This pattern may partly reflect occupational and behavioral differences in exposure, as working-age adults, particularly males, may be more frequently engaged in activities involving contact with contaminated water, soil, drainage systems, and flood-affected areas. The concentration of disease burden among economically productive age groups may also have broader socioeconomic consequences through lost productivity, healthcare costs, and disruption of household income.

However, the age distribution of leptospirosis cases requires cautious interpretation. The greater burden among individuals aged ≥ 15 years was observed in both non-confirmed and confirmed case classifications, with all confirmed cases with available age-group classification occurring among individuals aged ≥ 15 years. This pattern may partly reflect greater occupational, behavioral, and environmental exposure among adolescents and adults, while differences in clinical presentation, healthcare-seeking behavior, referral pathways, and access to confirmatory testing may also influence the observed age distribution [20]. As information on occupation, specific exposure history, testing indications, clinician testing thresholds, and age-specific testing practices was unavailable, the mechanisms underlying this pattern could not be directly evaluated. Therefore, the findings should be interpreted as patterns in reported surveillance cases rather than direct evidence of age-related differences in the underlying infection risk.

The concentration of disease burden in urban and densely populated settings is biologically and environmentally plausible. Rapid urban growth can create conditions favorable for leptospirosis transmission through inadequate drainage, poor waste management, rodent proliferation, and frequent human contact with contaminated environments [21,22]. The relationship between urbanization and population density observed in this study further suggests that these characteristics represent interconnected components of the urban environment rather than completely independent exposure. Consequently, their associations with leptospirosis should be interpreted within a broader urban ecological context, involving infrastructure, sanitation, population concentration, and opportunities for environmental exposure.

The seasonal pattern observed in this study is consistent with the established relationship between rainfall and leptospirosis transmissions. Heavy rainfall facilitates the environmental dispersal of pathogenic *Leptospira* and increases the opportunities for human contact with contaminated water. Similar patterns have been reported in the Philippines, where heavy rainfall and post-typhoon flooding are associated with increased leptospirosis transmission and urban outbreaks [23]. Nevertheless, seasonal increases in disease occurrence may not necessarily correspond to similar changes in mortality, as fatal outcomes may also depend on disease severity, healthcare access, timeliness of diagnosis and treatment, and underlying health conditions.

The inverse association between flood susceptibility and leptospirosis incidence requires cautious interpretation. Cramér's V analysis supports the geographic interrelationships among urbanization, population density, and flood susceptibility, suggesting that the observed pattern may partly reflect the spatial distribution of densely populated urban areas rather than an independent protective effect of greater flood susceptibility. Broad area-level classifications may fail to capture localized exposure conditions. Areas classified as having relatively low overall flood susceptibility may still experience localized waterlogging caused by impermeable surfaces, inadequate or overloaded drainage systems, blocked waterways, and poor waste management practices. Other unmeasured factors, including stagnant water, sanitation conditions, occupational activities, and individual contact behaviors, may further influence exposure [24]. Therefore, the flood susceptibility findings should be interpreted as ecological associations that may be affected by geographic overlap, residual confounding, and unmeasured local exposure conditions.

The factors identified in this study should also be interpreted considering the analytical structure. Separate factor-specific regression models were used, with adjustments for temporal and geographic variations, rather than a single model simultaneously included all demographic and environmental predictors. Therefore, residual confounding among correlated characteristics cannot be ruled out, particularly for interconnected environmental factors such as urbanization, population density, and flooding susceptibility. Consequently, the observed associations should be regarded as adjusted factor-specific relationships rather than independent causal effects. Future studies using individual-level or barangay-year data would permit more comprehensive multivariable modeling and assessment of the interactions among demographic, environmental, and climatic determinants.

This study had several limitations. First, reliance on passive surveillance data may have resulted in underreporting and may have been influenced by reporting delays, healthcare-seeking behavior, and changes in diagnostic and reporting practices over time. Second, information on occupation, socioeconomic status, comorbidities, individual environmental exposures, detailed clinical characteristics, and diagnostic testing practices were unavailable. Third, the limited number of annual observations reduced the statistical power of the temporal trend analyses, particularly in the subgroup analyses. Fourth, area-level classifications of urbanization, population density, and flood susceptibility may not adequately capture localized or individual exposure conditions. Finally, because the analytical data were aggregated separately by factor and year, simultaneous adjustment for all demographic and environmental predictors was not possible, and residual confounding may have remained.

Despite these limitations, this study provides a long-term perspective on leptospirosis patterns in Davao City and identifies population groups and environmental settings that may warrant greater public health attention. Prevention strategies should combine consistent surveillance and diagnostic practices with seasonal preparedness, early case detection, occupational risk reduction, education for at-risk workers, community risk communication, environmental sanitation, improved drainage and waste management, and targeted urban rodent control. Future prospective studies incorporating occupational and socioeconomic information, diagnostic testing data, climate indicators, and finer-scale spatial and environmental measurements are needed to better distinguish changes in disease transmission from changes in surveillance and case ascertainment.

5. Conclusions

This 11-year surveillance study provides a long-term assessment of human leptospirosis in Davao City, Philippines, and identifies important temporal, demographic, and environmental patterns relevant to local public health planning. To maximize the practical

utility of these findings, targeted public health actions should be translated into coordinated institutional and policy-based strategies, supported by sustained surveillance, timely case detection, seasonal preparedness, and locally adapted prevention measures. Future prospective studies incorporating detailed occupational and socioeconomic exposures, diagnostic practices, climate indicators, and finer-scale spatial data are needed to clarify individual-level risks and evaluate the effectiveness of targeted interventions.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/amh71030023/s1>. Supplementary Table S1. Model diagnostics and residual temporal autocorrelation assessment for factor-specific incidence models. Supplementary Table S2. Pairwise associations among area-level environmental predictors. Supplementary Table S3. Model diagnostics and residual temporal autocorrelation assessment for factor-specific mortality models.

Author Contributions: Conceptualization, R.L.D. and A.H.H.J.; methodology, R.L.D. and A.H.H.J.; software, A.H.H.J.; validation, R.L.D., R.J.T.S., A.F.F.-B., G.C.L.B., M.A.B.M. and A.H.H.J.; formal analysis, R.L.D. and A.H.H.J.; investigation, R.L.D. and A.H.H.J.; resources, R.L.D., R.J.T.S., A.F.F.-B., G.C.L.B. and M.A.B.M.; data curation, R.L.D. and A.H.H.J.; writing—original draft preparation, R.L.D. and A.H.H.J.; writing—review and editing, R.L.D. and A.H.H.J.; visualization, A.H.H.J.; supervision, A.H.H.J.; project administration, A.H.H.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the University of the Immaculate Conception Research Ethics Committee (Protocol Code: GS-EX-03-26-0108; Date of Approval: [23 March 2026]). Formal authorization and administrative clearance for data access, retrospective analysis were officially granted by the Davao City Health Office—City Epidemiological Surveillance Unit (CHO-CESU).

Informed Consent Statement: Patient consent was waived due to the retrospective nature of the study and the use of anonymized surveillance data.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. Restrictions apply to the availability of these data because they contain information obtained from the Davao City Health Office—City Epidemiological Surveillance Unit and are not publicly available.

Acknowledgments: The authors gratefully acknowledge the Davao City Health Office—City Epidemiological Surveillance Unit (CHO-CESU) for providing access to the leptospirosis surveillance data used in this study. The authors also thank the personnel involved in disease surveillance, reporting, and data management for their contributions to public health monitoring and infectious disease control in Davao City, Philippines.

Conflicts of Interest: The authors declare no conflicts of interest.

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