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Prevalence of Leptospira antibodies in cattle, sheep, and goats in Kilwa District, Tanzania: a risk to public health

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Abstract

Background: Leptospirosis is a global zoonotic infection affecting both humans and animals in tropical and subtropical countries, including Tanzania. The objective of this study was to determine the prevalence of leptospirosis in livestock in Kilwa Southern Tanzania.

Methods: A cross-sectional investigation was undertaken from January to March 2023 to establish the prevalence of leptospirosis in livestock in Kilwa district, southern Tanzania. A total of 100 blood samples from cattle, 120 blood samples from goats, and 20 blood samples from sheep were sampled from different selected sites for serum harvesting. Through a microscopic agglutination test, the collected serum samples were tested against five live leptospiral antigens to detect leptospiral antibodies. Common five reported serovars in Tanzania were used in this study such as leptospiral serovars Sokoine, Pomona, Grippotyphosa, Hebdomadis, and Lora.

Results: The overall prevalence of leptospirosis in cattle was 26.0%=95%CI=0.1774-0.3573, in goats was 27.5%=95%CI=0.1975-0.3640, and in sheep was 30.0%=95%CI=0.1189-0.5428. Both livestock hosts demonstrated high prevalence with serovar Sokoine being the most prevalent serovar over others. Most of the antibody titers obtained suggested prolonged exposures of this livestock to leptospirosis infection and only a few antibody titers especially from goats suggest recent infection of leptospirosis Logistic regression analysis was performed to determine the association between different characteristics and disease. A significant (P=0.0086) association was obtained between disease prevalence and different characteristics such as location, sex, host, and serovars.

Conclusion: Increased human-livestock contact raises the risk of disease transmission to both humans and animals. Reducing this disease burden, especially in low-income countries like Tanzania where livestock are key to income and food security, is essential. Vaccinating livestock with locally adapted strains can significantly reduce leptospirosis transmission.

Keywords: Leptospirosis, Zoonosis, Serovars, Microscopic Agglutination Test (MAT), Livestock, Kilwa District, Tanzania

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Background

Leptospirosis is a zoonotic bacterial disease of public health significance that spreads worldwide but is endemic in tropical and sub-tropical countries [1-3]. Leptospirosis was first discovered in Russia as a cattle disease in 1935 [4,5]. The disease is caused by thin and coiled gram-negative bacteria belonging to the genus Leptospira [6,7]. Some of the bacteria in this genus are harmless bacteria known as saprophytes (non-pathogenic) and others are pathogenic and comprise a large part of the genus Leptospira of which more than 250 serovars are pathogenic in nature [8-10]. Certain serovars are geographically confined and isolated and occur only in certain species of mammals for example serovars Hardjo, Pomona, and Grippotyphosa are common in cattle [11,12]. The human morbidity and mortality rate of the disease is 1.03 million and 58,900 per year respectively [8]. The disease is reported to cause livestock economic losses as it is associated with decreased milk production, death, stillbirth, abortion, infertility, and mastitis [13-16]. Both livestock and wild animals act, as reservoirs of Leptospira bacteria and are capable of transmitting them to human beings. Among mammals, rodents are noticeable as the principal reservoir due to their ability to occur in different habitats [17-22]. Humans acquire infection through direct contact with infected animals or indirectly through an

environment contaminated by reservoir agents through their urine [23,24]. Human infection is accompanied by several symptoms like blood vomiting, fever, jaundice, muscle pains chills, and headache and such symptoms appear to be similar to other diseases like dengue, malaria, typhoid fever, Rift Valley fever, and brucellosis consequently such situations make leptospirosis difficult to diagnose in different medical facilities and communities [1,3,25], In Tanzania, leptospirosis has been a challenge reported in different areas [3,26-29]. In the Lindi region following the outbreak, twenty confirmed cases and three people were reported to die of leptospirosis [30]. Therefore, due to this public health significance of this neglected public health issue, the objective of this study was to determine the prevalence of leptospirosis and their respective serovars in livestock so that we may establish the epidemiological surveillance of the disease which is the prerequisite step toward disease prevention and control strategies but also to investigate the role of the livestock in the transmission of this neglected public health disaster; Cross-sectional study was done in Kilwa district due to its potential outbreak associated with a different potential risk factor that may favor leptospirosis outbreak as disease recognized as occupational hazard disease, risk groups are farmers, sewer worker, livestock keeper, abattoir workers veterinarians and fishermen [6,31]. Availability of conducive climates such as temperature and humidity favor the survival of the bacteria but also flood which has been considered also as the main factor for bacteria dispersion and increased human exposure to infection [32,33]. This study aimed to assess the prevalence of leptospirosis among livestock in Kilwa, located in southern Tanzania.

Methods

Study area

Kilwa District, established in 1974 in Tanzania's Lindi Region, spans latitudes 8°20 to 9°56 and longitudes 38°36 to 39°50. The climate features high temperatures (22-30°C) and humidity, peaking at 98-100% during the long rains (Masika) from mid-March to May and the short rains (Vuli) from October to December. Annual rainfall ranges from 800 to 1400 mm, with Kilwa Masoko receiving the most. The region's landscape includes coastal forests and Miombo woodlands inland. Kilwa's drainage is supported by three major rivers: Matandu, Mavuji, and Mbwemkuru, along with 10 seasonal streams. The 2022 census recorded a population of 297,676, with economic activities centered on subsistence agriculture, which employs 81% of the workforce, along with livestock keeping, fishing, tourism, and limited industry [34]. Kilwa's warm, humid climate and prevalent economic activities, such as agriculture, fishing, and tourism, foster conditions conducive to Leptospira bacteria, making the district ideal for studying leptospirosis transmission risk factors (Fig.1).

Study design, sampling techniques

From January to March 2023, a cross-sectional investigation was undertaken to establish the prevalence of leptospirosis in livestock in Kilwa district, southern Tanzania. This study involved the collection of blood samples from cattle, goats, and sheep, sourced from various specifically chosen villages, including Mavuji, Kiwawa, Hoteli tatu, Kiranjeranje, and Mbwemkuru. The selection of these study villages was done purposively, considering the presence of livestock, and villages devoid of livestock were entirely omitted from the research.

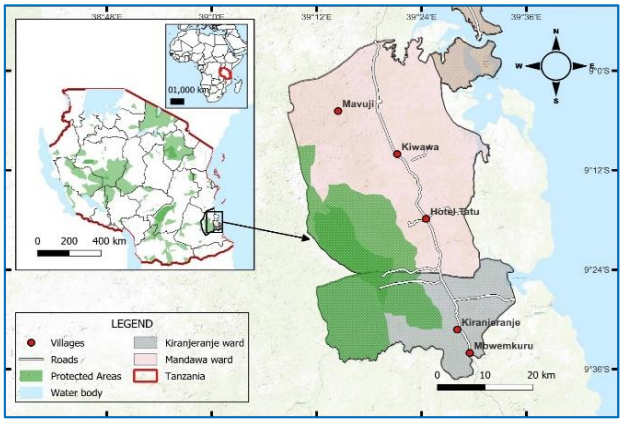

Figure 1: A map of Kilwa district with Villages involved in the study highlighted. The map was created using QGIS software version 3.26.1 and shape files from DIVA-GIS (retrieved on 5 July 2024).

Sample size determination

The sample size of 100 for cattle, 120 for goats, and 20 for sheep was determined by the following formula: n=Z2 p (1-p)/ d2. Whereby n= sample size, P=previous prevalence, d= desired precision 5%, Z= statistics corresponding to the level of confidence=1.96. The previous prevalence for goats was 8.47% [29], for sheep was 1.2% [21], and for cattle was 5.8% [3].

Cattle, Goat, and Sheep blood sampling

All livestock keepers were informed about the study across five villages in Kilwa district, and those livestock keepers who only agreed under consent were included in this study to have their cattle, sheep, and goat sampled. Across the all-villages responses were positive but for the sake of the study, three to five livestock keepers were selected in each village to make samples representative. Considering the number of animals they have, a maximum of five cattle, six goats, and one sheep were taken their blood from the consented livestock keeper to make a total of one hundred cattle, one hundred and twenty goats, and twenty sheep. Blood sample collection was done in the early morning before grazing [3]. In average of 4ml to 8ml of Blood sample was collected without contamination from the jugular vein using vacutainer needles and the collected blood samples were allowed to clot in the plain vacutainer tube followed by serum separation after twenty-four hours. Serum samples were stored at -20°C for serological microscopic agglutination test [2,3,35].

Microscopic Agglutination Test (MAT)

This study employed the use of a microscopic agglutination test (MAT), recognized as the gold standard method for detecting leptospiral antibodies [14,36-39]. To conduct this test, five prevalent leptospiral serogroups circulating in Tanzania were selected: Icterohaemorrhagiae (Leptospira interrogans serovar Sokoine), Australis (Leptospira interrogans serovar Lora), Grippotyphosa (Leptospira Kirschneri serovar grippotyphosa), Hebdomadis (Leptospira santarosai serovar Hebdomadis), and L. interrogans serogroup Pomona (serovar Pomona) [29]. The Ellinghausen McCullough medium, modified by Johnson and Harris (EMJH), was used to cultivate leptospires.

After 5 days of incubation at 30°C, cultures with a density of approximately 300 × 10^8 leptospires per milliliter were obtained. These cultures served as live antigens for the Microscopic Agglutination test. In the testing process, 10 µl of sera were mixed with phosphate-buffered saline (PBS) to create a 100 µl diluted serum in a 'U' microtiter plate, resulting in an initial dilution range of 1:20–1:160. Subsequently, 50 µl of fully grown antigens were added to all wells of the microtiter plate and thoroughly mixed. The microtiter plates were then incubated at 30°C for two hours. Darkfield microscopy was employed to observe the serum-antigen mixture for the presence of agglutination [3,29]. For positive samples that tested positive with antigens at ≥1:20, titration was performed once more, with dilutions of 1:20, 1:40, 1:80, 1:160, 1:320, 1:640, 1:1,280, 1:2,560, 1:5, 120, 1:10, 240, and 1:20, 480. This process determined the endpoint titer, which helped discern whether the infection was current or passive [3,29].

Data analysis

Data were entered organized and cleaned using Microsoft Excel 2019 before actual analysis commenced. The prevalence of leptospirosis in livestock (cattle, Goat, sheep) was computed by taking the number of samples that tested positive for leptospirosis and dividing by the total number of samples examined. For data visualization, plots were generated using the ggplot2 package within the R statistical software version 4.2.2 [40]. Logistic regression (LR) was performed to determine the association between the prevalence of disease and different characteristics like sites/locations, sex, and serovars using the Epi-Info version 7.2.5.0 (CDC Atlanta, USA). The Findings were considered statistically significant at $p \leq 0.05$.

Results

Livestock leptospirosis

A total of 26 (26%) leptospiral antibodies from cattle were detected out of 100 samples (Table 1). Serovar Sokoine was predominantly tested for about 11 (42.31%) of the positive sample followed by Pomona, 6 (23.08%), Grippotyphosa 4 (15.38%), Lora, 3 (11.54%) and Hebdomads 2 (7.69%) (Table 2). Most cattle samples reacted positively at relatively low titer (between 1:40 to 1:160), 120 goats were tested against five leptospiral serovars such as Sokoine serovar, Grippotyphosa, Lora, Hebdomadis, and Pomona serovar, the overall prevalence of leptospirosis in goats was 33(27.5%) (Table 1).

Serovar Sokoine was more prevalent for about 46.15% of the tested serovars followed by Pomona, (24.24%) Grippotyphosa (15.15%), Hebdomadis (12.12%), and Lora (12.12%) respectively. Most of the positive samples were tested at a titer of 1:40 and 1:80 which is below the suggested cut-off point of 1:160. Few positive samples of goats tested at high titers which also may have significant information on the current infection of leptospirosis. Contrary to the expectation, about 20 collected samples of sheep demonstrated a high prevalence of leptospirosis for about 30.0% whereby Sokoine serovars were more prevalent, followed by Pomona and Gripptyphosa. The two serovars, Hebdomadis and Lora tested nothing against sheep (Table 2.0). As shown in Figure 2, the proportional Leptospira antibody titer of 1:80 was high across different hosts and the antibody titer of 1:640 which was the highest titer occurred only in goat and none in sheep and cattle. Antibody titers of 1:20 and 1:640 were not obtained in cattle, equally antibody titers of 1:20, 1:40, 1:320, and 1:640 were not found in sheep. Meanwhile, all recorded Leptospira antibody titers were found in goats (Figure 2). Figure 3 shows that Sokoine serovar was more infective and prevalent in all host species followed by Pomona and Hebdomadis which were the least reactive over all tested serovars. Cattle and Goats reacted against all tested common serovars while serovars Grippotyphosa, Lora, and Hebdomadis did not react with Sera samples from sheep. In the Hotel Tatu site cattle reacted with all tested serovar except serovar Lora, goats reacted with two serovars except Lora, Hebdo, and Grippotyphosa, sheep from Hoteli Tatu reacted with one serovar excluding Lora, Hebdo, Sokoine, and Pomona. In the Mbwemkuru site cattle tested positive with only two serovars except for Lora, Pomona, and Grippotyphosa; goats tested positive with all tested serovars and sheep tested none against all tested serovars. In Kiranjeranje cattle and goats reacted with all tested serovars excluding Hebdo and Lora. Sheep reacted positively with two serovars except Lora, Grippotyphosa, and Lora. In the Kiwawa site sample collected from cattle reacted positively with three serovars except for Grippotyphosa and Hebdomadis goats tested positive with all tested serovars, and sheep tested with only two serovars except Grippotyphosa, Hebdo, and Lora. And the last site which is Mavuji, cattle samples collected from this area reacted with all tested serovars except Hebdo, Goat tested with all serovars except Grippotyphosa, and sheep tested with only Sokoine (Figure 4), (Table 1).

Table 1: Leptospiral antibody titer composition and percentage in various host species

Host							Total
Titre	1:20	1:40	1:80	1:160	1:320	1:640	
Cattle	0	5 (19.23%)	16 (61.54%)	4 (15.38%)	1 (3.85%)	0	26
Goat	6 (18.18%)	6 (18.18%)	14 (42.42%)	3 (9.09%)	2 (6.06%)	2 (6.06%)	33
Sheep	0	0	4 (66.67%)	2 (33.33%)	0	0	6
TOTAL	6	11	34	9	3	2	65

Table 2: Leptospira serovar that included in microscopic agglutination to test against host species

Host		Serovars				
	No of hosts	Grippotyphosa	Hebdo	Lora	Pomona	Sokoine
Cattle	100	4	2	3	6	11
Goat	120	5	4	4	8	12
Sheep	20	1	0	0	2	3
Total	240	10	6	7	16	26

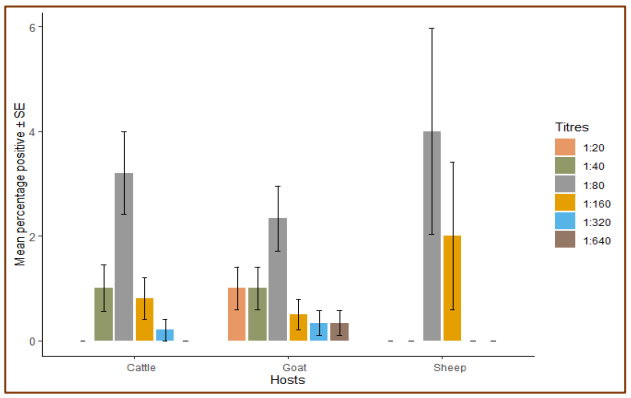

Figure 2: Proportion of antibody titers in different host species. A high titer of 1:640 was obtained only in goats.

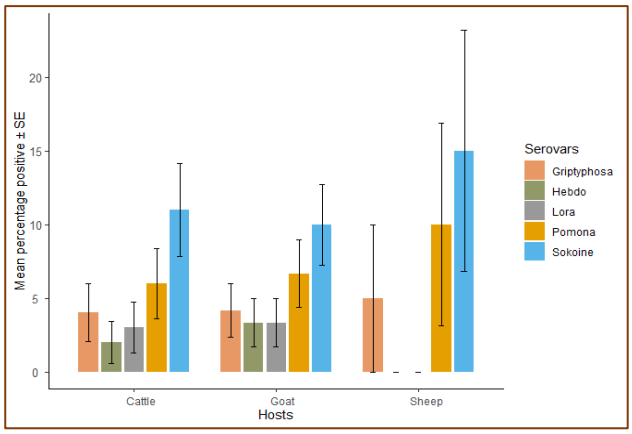

Figure 3. The proportion of Leptospira serovars that occurred in different hosts.

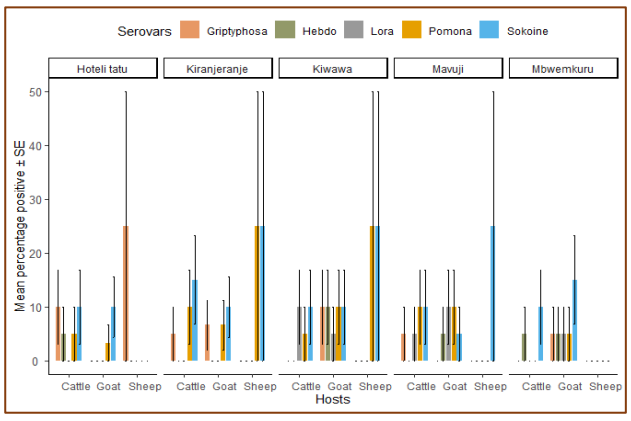

Figure 4. Proportion of leptospiral serovars in different sites where samples were collected.

Logistic regression analysis

Logistic regression analysis was performed to determine the association between different characteristics and disease (Table 3). A significant (P=0.0086) association was obtained between disease prevalence and different characteristics such as location, sex, host, and serovars. Also, the association between serovars such as Sokoine and Grippotyphosa and the disease was found to be significant with P=0.0073. There was no significant association between the prevalence of the disease with sex (p=0.8505). Also, there was no significant association between the disease and the host. For example, between Goat and cattle had P=0.7658, and between sheep and cattle had p=0.7452 (Table 3).

Discussion

The study objective was to explore the prevalence of leptospirosis in livestock (Cattle, Goats, and Sheep) in the Kilwa district of southern Tanzania. The overall prevalence of leptospirosis in Cattle, Coat, and Sheep were 26.0%, 27.5%, and 30.0% respectively. These results suggest a high prevalence of Leptospira infection in livestock. The prevalence of leptospirosis in livestock (Cattle, Sheep, and Goats) in the Kilwa district is high probably due to the recently reported outbreak that occurred in the same region also this is the first study to be done in the Kilwa district to determine the prevalence of leptospirosis in this livestock [30]. These reported prevalences were not consistent with the prevalence reported in a semi-arid area of Bahi district central Tanzania where the prevalence of leptospirosis in goats and sheep was 62.0%. This high prevalence is due to high interaction between livestock at water source points that are scarce around central Tanzania [3]. The recorded prevalence of leptospirosis in cattle in east Usambara Mountains, Tanzania (21.3%) is below the prevalence reported in this current study. The difference may be due to geographical and climatic factors that favor the existence of leptospiral bacteria in the Kilwa district and this is supported due to the presence of outbreak that occurred in 2022 [30,41]. The study conducted in the Katavi-Rukwa ecosystem recorded a 30.37% prevalence of leptospirosis in cattle and an 8.47% prevalence of leptospirosis in goats, the observed difference is largely contributed by management factors and climatic factors. Tanzania is regarded as one of many favorable regions for the growth of Leptospirosis outbreaks because it is a tropical rain climate [21,42]. Cattle are thought to be the main source of Leptospira bacteria as a zoonotic disease is a concern and are thus crucial for human transmission but sheep and goats have also been reported to be infected [43]. Leptospirosis is considered an occupation hazard disease therefore farmers and livestock keepers are believed to be at high risk of contracting the disease [21]. The health of livestock is negatively impacted by leptospiral infection, which can result in production losses due to reproductive failure, such as abortions or infertility, or decreased milk yield [44]. Despite, the impact of the disease being observed, the financial effects of infection have not yet been systematically quantified, in a low-income country like Tanzania where livestock is crucial for household income, food security, and the country's economy, nevertheless, the disease reported to cause financial loses to different livestock keeper [44]. Because of the proximity between these animals and human beings, this high prevalence of leptospirosis suggests a potential threat to humans and other animals kept together such as cattle, sheep, and goats like dogs, cats, and donkeys [24,28,34]. Most of the Leptospira antibody titers observed in this study were below the cut-off point of 1:160 adopted from the European countries [45]. Therefore, these findings point to the urgent need to review the threshold for the microscopic agglutination test used to diagnose leptospirosis in tropical African countries including Tanzania due to environmental differences and climatic factors [27]. The lower titer of seropositive animals suggested that livestock had been exposed to Leptospira pathogens for a longer period such as a year; It is expected that animals or livestock that are prolonged exposure to leptospiral infection should demonstrate low leptospiral antibody titers compared to those that recently infected [3].

Table 3: Logistic regression table shows an association between disease and different characteristics

Variable	Term	OR	95%	C.I.	Coefficient	S.E.	P-Value
Location	Mbwemkuru/Hoteli tatu	1.1318	0.468	2.739	0.1238	0.451	0.7837
	Kiranjeranje/Hoteli tatu	1.3924	0.623	3.11	0.331	0.41	0.4194
	Kiwawa/Hoteli tatu	1.8766	0.845	4.17	0.6294	0.407	0.1223
	Mavuji/Hoteli tatu	1.4917	0.649	3.431	0.3999	0.425	0.3467
Sex	Male/Female	1.0513	0.625	1.77	0.0501	0.266	0.8505
Host	Goat/Cattle	1.085	0.635	1.855	0.0815	0.274	0.7658
	Sheep/Cattle	1.1659	0.462	2.942	0.1535	0.472	0.7452
Serovars	Hebdo/Gripptyphosa	0.5895	0.211	1.65	-0.5285	0.525	0.3141
	Lora/Gripptyphosa	0.6906	0.258	1.847	-0.3702	0.502	0.4608
	Pomona/Gripptyphosa	1.645	0.73	3.706	0.4977	0.414	0.2297
	Sokoine/Gripptyphosa	2.8054	1.32	5.962	1.0316	0.385	0.0073*
	Constant	*	*	*	-3.5283	0.488	0

Note * stand for significance at $p \leq 0.05$, OR, odd ratio, C.I, Confidence interval and S.E. Standard error (P=0.0086) association was obtained between disease prevalence and different characteristics such as location, sex, host, and serovars.

Few high Leptospira antibody titers were detected in goats which may suggest a new infection of leptospirosis. Serovar Sokoine was more dominant across the host in this study. This is consistence with a study conducted around Bahi district central Tanzania [3], which also demonstrated Serovar Sokoine to be most prevalent. Serovars Sokoine was first identified in cattle in Morogoro [26] and has been reported in different animal hosts such as rodents, bats, cats, and dogs in eastern and central Africa [14,27,28,46,47]. Therefore, these findings suggest serovars Sokoine is the most infective serovar and more prevalent than the others common circulating serovars in Tanzania such Pomona, Grippotyphosa, Lora, and Hebdomadis. Some serovars tested negative against a particular host, for example, Grippotyphosa and Hebdomadis tested negative against sheep. This might probably suggest host specificity as described by the different researchers that some serovars are geographical endemic and affecting only a particular host [11,12,29]. For the successful management of this severely undertreated zoonotic disease, additional research is required to ascertain the diversity and distribution of Leptospira serovars in various geographic areas. In areas where interaction between animals and human beings is high especially livestock keeper's vaccination of livestock animals using local-strains based vaccines can have a significant reduction of transmission of leptospirosis to other livestock and human [3]. Figure 4 shows the proportion of leptospiral serovars in the different sites where samples were collected knowing which serovars are common in a particular area is of paramount importance because it helps to be focused when controlling leptospirosis infection, beginning with Hoteli Tatu leptospiral serovar Lora was not common in all animals sample collected, sheep tested positive with only one serovar out of five tested one for Grippotyphosa, Lora, Hebdomadis and Pomona reacted none with the sample collected from sheep host. In the Mbwemkuru site, none of the tested serovars reacted with sheep, goats reacted with all tested serovars, and Sokoine and Hebdomadis were tested in cattle. In the Kiranjeranje site, Lora and Hebdomadis were not common Serovars in this site in all animals sampled. In the Kiwawa site, Grippotyphosa and Hebdomadis were not common in cattle and sheep while goats reacted positively with all tested serovars, and in the Mavuji site, sheep tested with only Sokoine serovar while other hosts tested with at least four serovars except Hebdomadis in cattle and Gripptyphosa in goats. In the Kiwawa site cattle tested with Sokoine, Pomona, and Lora, goats tested will all tested serovars, and sheep tested only with Sokoine and Pomona. In the Kiranjeranje site sheep tested with two serovars such as Sokoine and Pomona, and goats tested with Pomona, Sokoine, and Grippotyphosa also cattle reacted with three serovars such as Grippotyphosa, Pomona, and Sokoine. Therefore, for the effective control of this neglected public health issue, knowledge of the common circulating serovars is indispensable [3]. The logistic regression analysis performed showed a significant association between the disease with different characteristics such as location, sex, host and serovars with P=0.0086. The association between the disease and location/site was not significant as presented in Table 3. These might be due to the same environmental factors across the sampled areas, for example, leptospirosis transmission is highly associated with a flood [32,33] and places where sample was collected there is periodic flood especially during the rainy season due to presence of Mavuji river which contribute to the drainage pattern of these areas [34]. Most livestock keeper in Kilwa district keep their livestock in large herds, mixed management, and grazing of multiple livestock species which is also noted as risk factors for leptospirosis infection [48-50]. There was no significant association between sex and disease this is because both sexes are susceptible to infection as reported previously by [51]. The association between the disease and host (Cattle, Sheep, and Goats) was also not significant because despite cattle being more vulnerable both ruminants are susceptible to leptospiral infection [43, 44]. Serovar Sokoine was more prevalent over all tested serovars in this study and it has shown statistical significance with Grippotyphosa with p=0.0073. According to a recent study done in semi-arid Tanzania, it is shown that serovar Sokoine was also more prevalent than all tested serovars [3]. Therefore, this may suggest that this serovar is more infective and affects different hosts hence control measures must be taken to reduce the burden of this neglected public health problem. The observed high prevalence of leptospirosis in this study may be associated with rainfall. Natural disasters like flooding after heavy rainfall have been reported to be one of and greatest risk factors for the transmission of waterborne diseases including leptospirosis in tropical and subtropical countries [52]. The distribution of serovars may be explained by the reason that some serovars are known to occur in a certain geographical area and reside only in a particular animal species [11,12]. Sheep demonstrated a high prevalence of leptospirosis in this study compared to cattle and

goats, this might be influenced by a relatively small sample collected in the Kilwa district of southern, Tanzania [3].

Conclusion

The result obtained from this study shows the existence of a high prevalence of leptospirosis in the Kilwa district of southern Tanzania. Therefore, this suggests possible transmission of leptospirosis from livestock to human beings also the occurrence of the high prevalence of Sokoine serovars suggests that this serovar is the most infective Serovars across the region. It is imperative to prioritize public awareness efforts among livestock keepers and the communities residing near these animals. These livestock are recognized as the primary hosts for leptospiral bacteria and are capable of transmitting the infection to humans. Educational initiatives should extend to medical schools and colleges to enhance knowledge about leptospirosis. Additionally, the animals themselves may experience health issues due to the high prevalence of infections. The effects of Leptospira infection on livestock in Tanzania are not well understood, but given how widespread the infection is, there is a significant risk of production losses for example, abortions, infertility, and reduced milk yield [44]. This has consequences in a low-income country like Tanzania where livestock is crucial for household income, food security, and the overall economy. Given the close interaction between humans and animals in these areas, the vaccination of animals with locally suitable vaccines should be promoted as a control measure to mitigate the disease burden in both humans and livestock [3]. Encouraging further similar research to identify prevalent serovars in specific regions will also contribute to more effective control of this public health challenge in the country.

Abbreviation

MAT: Microscopic Agglutination Test; EMJH; Ellinghausen McCullough Medium-Johnson and Harris; LR: Logistic Regression; PBS: Phosphate Buffered Saline; URT: United Republic of Tanzania; NBS: National Bureau of Statistics; ACE: African Centre of Excellence; QGIS: Geographic Information System; BTD: Biosensor Technology Development; IRPM: Innovative Rodent Pest Management; PBS: Phosphate Buffered Saline; CDC: Centre for Disease Control and Prevention.

Declaration

Acknowledgment

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Availability of data and materials

Data will be available by emailing matthewkikoti@gmail.com

Authors' contributions

Mathayo Cralency Kikoti (MCK) is the principal investigator (PI) who contributed to the conceptualization, data curation, formal analysis, and writing of the original draft. Abdul Selemani Katakweba (ASK) and Athumani M. Lupindu (AML) are the supervisors who contributed to the methodology, supervision, review, editing, and re-writing of the manuscript. All authors have read the final version of the manuscript.

Ethics approval and consent to participate

This research was conducted following the Declaration of Helsinki. Ethical clearance for this study was approved by the Institutional Review Board of the Sokoine University of Agriculture with reference number (SUA/DPRTC/R/186/39) issued on 14/08/2023. Furthermore, permission was also granted from the Kilwa district administrative authorities to allow the research activity in all respective study sites (wards and villages) before conducting the study with (Ref No. EA.76/249/03/35) issued on 03/02/2023. Before collecting data, participants were informed about the study objectives and allowed to provide verbal consent.

Consent for publication

Not applicable

Competing interest

The authors declare that they have no competing interests.

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